Initial post-cardiac arrest care in children

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INTRODUCTION

This topic discusses post-cardiac arrest care in children. The epidemiology, recognition, and treatment of cardiac arrest are discussed separately. (See "Pediatric basic life support (BLS) for health care providers", section on 'Epidemiology and survival' and "Pediatric advanced life support (PALS)".)

DEFINITIONS

Important definitions for this topic include:

- **Return of spontaneous circulation (ROSC)** – ROSC describes a patient with a perfusing heart rhythm and a palpable central pulse.
- **Return of circulation** – Return of circulation applies to ROSC or extracorporeal circulation established with extracorporeal membrane oxygenation (ECMO).
- **Active temperature control (also called targeted temperature management)** – Active temperature control targets normal core body temperature (36°C to 37.5°C) or hypothermia (32°C to 34°C) using cooling devices or ECMO.
- **Post-cardiac arrest syndrome (PCAS)** – PCAS and associated clinical manifestations are described in the figure (figure 1). The key components consist of [1]:
  - Post-cardiac arrest brain injury
  - Post-cardiac arrest myocardial dysfunction
  - Systemic ischemia/reperfusion response

- Precipitating pathophysiology

PRIORITIES IN CARE

Priorities in post-cardiac arrest care include (table 1) [1-3]:

- Prevent secondary brain injury caused by hypoxemia or shock with decreased cerebral perfusion
- Identify and manage cardiovascular dysfunction (eg, recurrent arrhythmias, high or low systemic vascular resistance, and impaired cardiac contractility)
- Treat reversible causes of cardiac arrest
- Identify and manage systemic ischemia/reperfusion injury manifested by hyperglycemia, coagulopathy, systemic inflammatory response with capillary leak, acute ischemic kidney and liver injury

APPROACH TO STABILIZATION

The approach to post-cardiac arrest stabilization consists of ongoing monitoring of oxygenation, ventilation, and hemodynamic status with continued management of the airway, breathing, and circulation. Active temperature control and rapid treatment of seizures, increased intracranial pressure, and hyperglycemia are also critically important (table 2).

Monitoring — As soon as return of spontaneous circulation (ROSC) occurs, the resuscitation team should ensure continuous monitoring of:

- Cardio-respiratory status
- Blood pressure (BP)
- Pulse oximetry
- End-tidal capnography (intubated patients)
- Core body temperature

After ROSC, the blood pressure is frequently labile. Close BP monitoring is achieved with continuously cycled non-invasive BP monitoring or insertion of an intra-arterial catheter. Efforts to obtain intra-arterial access should **not** interfere with post-cardiac arrest stabilization. In many hospitals, arterial access is obtained after transfer to the pediatric intensive care unit. Procedures for obtaining intra-arterial access in children are discussed separately. (See "Arterial puncture and cannulation in children", section on 'Arterial cannulation'.)

Airway (C-spine motion restriction) — After ROSC, airway assessment and management should occur simultaneously with support of breathing (oxygenation and ventilation) and circulation. C-spine motion restriction should be maintained or, if not present, initiated for patients with a history or suspicion of trauma until appropriate imaging can be performed. (See "Evaluation and acute management of cervical spine injuries in children and adolescents", section on 'Cervical spine imaging'.)

Airway management depends upon interventions performed during cardiac arrest [1,2]:

Unintubated — For unintubated children with ROSC, the clinician should provide supplemental oxygen and assist ventilations with a bag and mask as needed, and must determine if the airway is maintainable or needs to be secured. Most children with altered mental status, respiratory distress, or shock after ROSC require endotracheal intubation. Prior to rapid sequence intubation (RSI) and if it does not delay timely airway management, the clinician should perform a focused neurologic examination to determine level of responsiveness (AVPU), pupillary response, and presence of key reflexes prior to neuromuscular blockade. (See 'Disability/Dextrose' below.)

These children are at increased risk of hypotension during RSI. Furthermore, any sedative or analgesic medication can result in hypotension during the post-arrest period. For this reason, intermittent doses of short-acting sedatives are good choices. Medications traditionally used for RSI in patients with hemodynamic instability such as etomidate, ketamine, midazolam, or fentanyl are potential candidates. (See "Rapid sequence intubation (RSI) in children for emergency medicine: Medications for sedation and paralysis".)

Our approach is as follows:

- If airway reflexes are absent, suggesting deep coma, we perform RSI with rocuronium as a paralytic in a dose of 1.2 mg/kg to promote rapid onset of intubating conditions; we do not provide a sedative.
- If airway reflexes are present, we perform RSI with low-dose sedatives, as above, and rocuronium as a paralytic in a dose of 1.2 mg/kg to promote the rapid onset of intubating conditions.

RSI and the technique for emergency endotracheal intubation in children are described in detail separately. (See "Rapid sequence intubation (RSI) in children for emergency medicine: Approach" and "Technique of emergency endotracheal intubation in children".)

Children who are awake and without signs of shock after ROSC should receive supplemental oxygen as needed (table 3) to maintain pulse oximetry 94 to 99 percent. Patients who have acute hypoxemic respiratory failure but are awake and can maintain their airway may be candidates for high-flow nasal cannula oxygen therapy or non-invasive ventilation. (See

"High-flow nasal cannula oxygen therapy in children" and "Noninvasive ventilation for acute and impending respiratory failure in children".)

Intubated — All intubated children require continued assessment to ensure proper endotracheal tube positioning, including auscultation and capnography ($EtCO_2$). Insertion of a gastric tube helps to relieve gastric distension and may prevent vomiting. If not already obtained, the child should have a chest radiograph to ensure correct endotracheal tube position. (See "Technique of emergency endotracheal intubation in children", section on 'Post-intubation care'.)

The causes of sudden decompensation in a child who has been successfully intubated with an artificial airway is described by the mnemonic "DOPE" [4]:

●**D**: Dislodged or displaced endotracheal tube (right mainstem or esophageal location)

●**O**: Obstructed endotracheal tube (eg, mucous plug, kinked endotracheal tube)

●**P**: Pneumothorax

●**E**: Equipment failure (eg, ventilator malfunction, oxygen disconnected or off)

Breathing

Oxygenation (pulse oximetry target) — After ROSC, the clinician should avoid hypoxemia using initial measurement of arterial oxygen to correlate with continuous pulse oximetry. For children with ROSC, we suggest supplemental oxygen to maintain pulse oximetry between 94 and 99 percent or, if the child has congenital heart disease, the baseline value appropriate for the child's condition [2,3,5,6]. The clinician should avoid oxygen toxicity by gradually lowering inspired supplemental oxygen, as tolerated, to keep oxygen saturation <100 percent while avoiding hypoxemia.

An association between post-arrest arterial oxygenation and mortality in resuscitated children has been inconsistent but supports the harmful effects of insufficient or excess oxygenation [3,5-10]:

- In one large, retrospective, multicenter observational pediatric study of 1875 infants and children who survived to pediatric intensive care unit (PICU) admission, multivariate analysis found that both hypoxemia (PaO_2 <60 mmHg) and hyperoxemia (PaO_2 ≥300 mmHg) were associated with an increased estimated risk of death [5]. Overall mortality prior to PICU discharge was 39 percent in this study. However, this study did not adjust for cardiac arrest characteristics and almost one-third of patients did not have arterial measure of PaO_2 within one hour of ROSC, indicating a high risk for bias [3].

- In a separate retrospective cohort study of 1500 post-cardiac arrest patients admitted to a pediatric ICU, the probability of death using a validated mortality score was not related to the initial p_aO_2 obtained within one hour of admission despite one-quarter of patients having hypoxia (P_aO_2 <50 mmHg) or hyperoxia (p_aO_2 >300 mmHg) [6]. However, overall mortality in this cohort was high (63 percent). In addition, all of these patients had monitoring and targeting of arterial oxygenation to avoid persistent hypoxemia or hyperoxia.

Adverse effects of hyperoxia are discussed in greater detail separately. (See "Adverse effects of supplemental oxygen".)

Ventilation (PaCO2 target) — After ROSC, the clinician should target normocapnia (eg, $PaCO_2$ 35 to 45 mmHg) using initial arterial blood gas measurements and correlated with continuous quantitative end-tidal capnography. Severe hypocapnia ($PaCO_2$ <30 mmHg) or hypercapnia ($PaCO_2$ >50 mmHg) should be avoided [3,11-13]. For patients with chronic lung disease with hypercapnia at baseline, target the $PaCO_2$ near their baseline but ensure that the pH is ≥7.3. Exceptions to the target $PaCO_2$ include permissive hypercapnia in patients with chronic lung disease or emergency hyperventilation with hypocapnia in patients with increased intracranial pressure and impending herniation [3]. (See "Severe traumatic brain injury (TBI) in children: Initial evaluation and management", section on 'Ventilation'.)

In one prospective, multicenter observational study of 223 infants and children who sustained an in-hospital arrest, $PaCO_2$ 30 to 50 mmHg was associated with lower mortality (33 percent) compared with $PaCO_2$ <30 mmHg (50 percent) or >50 mmHg (59 percent) [7].

Mechanical ventilation — For children receiving mechanical ventilation after ROSC, consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. Lung protective strategies including low-inspiratory volume and use of appropriate levels of positive end-expiratory pressure are typically warranted (table 4) [1]. (See "Initiating mechanical ventilation in children", section on 'Inadequate oxygenation'.)

For these patients, the physician must assess oxygenation and ventilation by measurement of an arterial blood gas or by pulse oximetry and venous blood gas shortly after initiation of mechanical ventilation and adjust settings based upon repeat arterial blood gases or correlated pulse oximetry, and/or capnography. When using non-invasive monitoring, the clinician should be aware of the errors associated with pulse oximetry (table 5) and the limited accuracy of capnography in ROSC patients due to changing cardiac output and alveolar dead space. If there is concern for an inaccurate reading, the clinician should obtain an arterial blood gas. (See "Pulse oximetry", section on 'Troubleshooting sources of error' and "Carbon dioxide monitoring (capnography)", section on 'Limitations'.)

The approach to stabilized patients who abruptly decompensate during mechanical ventilation is provided in the algorithm (algorithm 1) and discussed separately. (See "Initiating mechanical ventilation in children", section on 'Approach to decompensation'.)

Circulation

Vascular access — To optimize management, a second point of vascular access should be obtained after ROSC. In the emergency department, either a peripheral intravenous (IV) or intraosseous catheter (IO) is an acceptable second form of access. However, patients with persistent altered mental status or fluid-refractory shock may eventually need central venous access to permit measurement of central venous pressure and oxygen saturation and to provide central access for vasopressor administration.

Maintain blood pressure and treat shock — After ROSC in children, the general aims are to maintain a normal blood pressure that ensures adequate cerebral perfusion and to avoid shock [11,12,14]:

- **Maintain blood pressure** – After cardiac arrest, autoregulation of cerebral perfusion is impaired. In children, most experts try to achieve a near-normal blood pressure (table 6 and table 7 and table 8) that is well above the 5th percentile threshold for shock, although precise thresholds have not been established. Preliminary evidence suggests improved clinical outcomes with this approach. For example, in a secondary analysis of almost 700 prospectively collected blood pressure measurements obtained within 6 hours of an in-hospital pediatric cardiac arrest, a higher survival to discharge with a favorable neurologic outcome was associated with a systolic blood pressure threshold >10th percentile (adjusted relative risk [RR] 1.2, 95% CI 1.1 to 1.3) and a diastolic blood pressure >50th percentile threshold (adjusted RR 1.2 (95% CI 1.1 to 1.4) [14]. Limitations of this study included lack of standardized post-arrest care, use of systolic and diastolic blood pressure rather than mean arterial pressure as the key measures, and inability to correct for the presence of post-cardiac arrest myocardial dysfunction.

  Evidence in adults suggests that higher-than-normal blood pressures are needed to maintain cerebral perfusion and improve clinical outcomes after cardiac, as discussed separately. (See "Initial assessment and management of the adult post-cardiac arrest patient", section on 'Determining blood pressure goals'.)

- **Treat shock** – The physician should rapidly treat shock in post-arrest pediatric patients, especially hypotensive shock, as indicated by a systolic blood pressure <5th percentile for age [11,12] (see "Pediatric advanced life support (PALS)", section on 'Shock'):

•Term neonates (0 to 28 days): <60 mmHg

- Infants (1 to 12 months): <70 mmHg
- Children (1 to 10 years): <70 mmHg + (child's age in years x 2)
- Children >10 years: <90 mmHg

Initial treatment of post-arrest shock consists of a bolus of isotonic fluid (lactated Ringer's or normal saline) (algorithm 2). The typical volume and rate is 10 to 20 mL/kg over 10 to 20 minutes with the lower volume used for patients with suspected or confirmed myocardial dysfunction [2]. After the fluid bolus, provide further treatment based upon clinical response such as improvement in skin perfusion, quality of pulses, blood pressure, mental status, and, when rapidly available, serum lactate. Also assess for signs of fluid overload and right-sided congestion (eg, pulmonary edema, hepatomegaly, or jugular venous distention) (algorithm 3). (See "Shock in children in resource-abundant settings: Initial management", section on 'Volume and rate'.)

Children with fluid-refractory post-arrest shock also require vasopressor support. In patients with ongoing shock despite fluid administration, start a vasoactive infusion, typically epinephrine. For patients without central venous access, epinephrine may be started via the IV or IO route at a dose of 0.03 to 0.05 mcg/kg per minute and titrated as needed up to 1 mcg/kg per minute. Other agents may be used in addition to or instead of epinephrine depending upon the patient's hemodynamic status and response to epinephrine. (See "Shock in children in resource-abundant settings: Initial management", section on 'Vasoactive agents'.)

Vasoactive agent options according to blood pressure and suggested by Pediatric Advanced Life support include [2] (algorithm 2):

- **Hypotensive shock** – For patients with hypotensive shock, the physician may administer a continuous infusion of epinephrine or norepinephrine. The choice between epinephrine and norepinephrine is guided by preference of the physician, patient physiology, and local system factors. Typically, epinephrine is used in patients with signs of myocardial dysfunction, and norepinephrine is used in patients with signs of low systemic vascular resistance or vasodilation. This suggestion is based upon indirect evidence of benefit of epinephrine or norepinephrine in children and adults with fluid-refractory septic shock. (See "Children with early and life-threatening sepsis in resource-abundant settings: Rapid recognition and initial resuscitation (first hour)", section on 'Hypotensive patients' and "Evaluation and management of suspected sepsis and septic shock in adults", section on 'Vasopressors'.)

- **Normotensive shock** – For patients with signs of shock (poor perfusion, delayed capillary refill, thready peripheral pulses, and/or persistent lactic acidosis) without hypotension, epinephrine is the most commonly used agent. Milrinone is an

alternative option that is sometimes used in patients with known or suspected cardiac dysfunction and high systemic vascular resistance (SVR). It can be used alone or in combination with epinephrine. However, milrinone has a substantial risk of causing hypotension and requires careful titration. For this reason, milrinone should only be used by experienced clinicians in a setting where the child can be adequately monitored (ie, an intensive care unit).

Patients with recurrent or persistent shock require central venous access, preferably with a central line catheter equipped with multiple ports to permit administration of resuscitation fluids and vasopressors, as well as measurement of central venous pressure (CVP). (See "Emergency and elective venous access in children".)

After cardiac arrest, circulatory instability may recur as the result of ongoing fluid loss, including due to capillary leak, decreased cardiac function, and/or changes in systemic vascular resistance. In several retrospective, observational studies, hypotension after ROSC has been associated with decreased survival to hospital discharge [15-19] and, for infants and children with an inpatient arrest, decreased survival with favorable neurologic outcome [15]. High-quality evidence is lacking regarding the benefit of vasoactive agents and the preferred vasoactive agent or combination of agents for the treatment of fluid-refractory shock after cardiac arrest [1].

Treat arrythmias — Recurrent arrest and arrhythmias that occur after ROSC and compromise circulation should receive treatment according to Pediatric Advanced Life Support with correction of any identified reversible causes:

- Recurrent pulseless arrest (algorithm 4 and algorithm 5)
- Tachyarrhythmias with a pulse (algorithm 6) – For patients with recurrent ventricular arrhythmias who are hemodynamically compromised, synchronized cardioversion is the initial treatment. If drugs are necessary, our approach is to use lidocaine to avoid medications such as amiodarone or procainamide, which are arrhythmogenic. Such patients may have a congenital conduction defect such as Brugada or Long QT syndrome as the cause of the initial arrest. Early consultation with a pediatric cardiologist is recommended.
- Bradyarrhythmias with a pulse (algorithm 7) – Primary bradyarrhythmias are rare in children. Bradycardia commonly accompanies therapeutic hypothermia but does not require treatment if perfusion is adequate [1]. Recurrent bradycardia may suggest a toxic ingestion (eg, beta blocker or calcium channel blocker) or intracranial pathology (eg, ruptured arteriovenous malformation with intracranial hypertension).

Ongoing arrhythmias after ROSC require pediatric cardiology consultation to identify cardiac pathology and to select the optimal antiarrhythmic therapy [1].

Extracorporeal membrane oxygenation (ECMO) — For patients with recurrent arrest or persistent post-arrest shock, ECMO may be an option if there is an underlying condition with potential for recovery. Examples include ingestions of cardiotoxic medications or thrombosis of an aorta-pulmonary shunt following surgical palliation procedures. Rapid consultation with a pediatric critical care specialist is recommended as soon as ECMO is being considered. In general, ECMO is not indicated following unwitnessed or prolonged out-of-hospital cardiac arrest due to associated hypoxic-ischemic organ injury unless there are mitigating circumstances such as moderate to severe environmental hypothermia. (See "Hypothermia in children: Management".)

The use of ECMO during cardiopulmonary resuscitation (ECPR) is discussed separately. (See "Pediatric advanced life support (PALS)", section on 'Extracorporeal membrane oxygenation (ECMO) with CPR (ECPR)'.)

Disability/Dextrose — Soon after ROSC, essential interventions related to disability include:

- Check bedside blood glucose and treat hypoglycemia (table 9); initiate blood glucose monitoring (see 'Glucose homeostasis' below)
- Assess neurologic status before sedation and neuromuscular blockade or, if performed, initiation of hypothermia including:
  - Glasgow coma scale
  - Mental status using AVPU: alert, responds to voice, responds to pain, or unresponsive
  - Pupil responses
  - Gag, corneal, and, for patients with **no** concern for C-spine trauma, oculocephalic (doll's eyes) reflex (figure 2)
  - Muscle tone and presence of myoclonus
  - Gross sensory or motor deficits
  - Upper and lower extremity reflexes
  - Babinski sign
- If signs of impending brain herniation (table 10), treat per the algorithm (algorithm 8) and obtain emergency consultation with a neurosurgeon with pediatric expertise
- Treat seizures (algorithm 9)
- Initiate active temperature control (see 'Active temperature control' below)
- For patients with adequate blood pressure and perfusion:
  - Elevated head of the bed 15 to 30 degrees and keep head midline
  - Maintain oxygenation and normocarbia (see 'Breathing' above)

Exposure — Fully undress the patient, perform a complete examination, and then initiate continuous core body temperature monitoring with active temperature control. Since fever is

associated with worse outcomes following cardiac arrest, aggressively treat temperature >37.5°C with cooling measures and acetaminophen. (See 'Active temperature control' below.)

Accurate monitoring of core body temperature requires the use of a low-reading thermometer and is best obtained with a flexible temperature probe. Sites of measurement include the bladder, rectum, esophagus, nasopharynx, and central vein. Rectal temperatures, though widely used, are prone to artifact and may lag significantly behind changes in true core temperature. (See "Hypothermia in children: Clinical manifestations and diagnosis", section on 'Diagnosis'.)

Ancillary studies — Children should undergo the following studies as soon as possible after ROSC:

- Arterial or venous blood gas
- Rapid blood glucose
- Complete blood count with differential and, whenever available, point-of-care hematocrit
- Electrolytes
- Ionized or serum calcium
- Serum lactate
- Blood urea nitrogen and creatinine
- Serum alanine aminotransferase (ALT), (AST) aspartate aminotransferase, and total/direct bilirubin
- Prothrombin/international normalized ratio (PT/INR)
- Partial thromboplastin time (PTT)
- Type and screen
- Urine rapid dipstick and urinalysis
- Urine beta hCG (in post-menarchal females)
- Electrocardiogram (ECG)
- Chest radiograph
- If a trained and experienced provider is present, point-of-care ultrasonography to assess for pericardial tamponade, pneumothorax, and poor myocardial function

Febrile patients and those with suspected sepsis should also undergo:

- Cultures of blood, urine, and, if hemodynamically stable with a secured or maintainable airway, cerebrospinal fluid and culture from a tracheal aspirate if intubated
- Cultures from other sites of infection (eg, skin lesions or abscess)
- Blood polymerase chain reaction or respiratory molecular panel for viral and bacterial pathogens

Other studies may also be indicated based upon the suspected cause of arrest such as:

- Head CT – Unknown cause of arrest, suspected brain lesion or intracranial hemorrhage with increased intracranial pressure (ICP), or suspected child abuse (table 11 and table 12)
- Type and cross – Hemorrhage or severe anemia
- Blood ammonia – Patients with elevated liver enzymes, PT/INR, or total/direct bilirubin suggesting liver failure; concern for inborn error of metabolism
- Urine testing for drugs of abuse and other toxicology testing – Suspected poisoning, other testing is based on history of exposure, medications or other substances (including illicit drugs) available in the home, or found near the patient (see "Testing for drugs of abuse (DOAs)" and "Approach to the child with occult toxic exposure", section on 'Toxicology screens')
- Troponin I or T and brain natriuretic peptide (BNP; or N-terminal BNP) – Primary cardiac etiology (h/o congenital heart disease, heart failure, or primary arrhythmia)
- D-dimer – Patients at risk for thrombosis (eg, sickle cell disease or pro-thrombotic conditions such as nephrotic syndrome, protein C deficiency, Protein S deficiency)

TRANSFER TO DEFINITIVE CARE

After return of spontaneous circulation, children should receive post-cardiac arrest care under the direction of a pediatric critical care specialist in a pediatric intensive care unit. If the child is not being treated in a center with pediatric critical care expertise, the child should be stabilized and rapidly transferred for definitive care at a regional pediatric center with a full complement of pediatric specialty care and advanced technologic capabilities including dialysis and, whenever available, Extracorporeal membrane oxygenation (ECMO). Critically ill or injured children typically benefit from transport by a team with pediatric expertise and advanced pediatric treatment capability as well, although in some isolated cases more rapid transport by an immediately available non-pediatric team may be acceptable. (See "Prehospital pediatrics and emergency medical services (EMS)", section on 'Interfacility transport'.)

Prior to transfer, the physician responsible for the child's care at the transferring hospital should speak directly to the physician who will be taking charge of the patient at the receiving hospital. All documentation of care (eg, medical chart, medication administration record, laboratory results, copies of ancillary studies [radiographs, ECGs]) should be sent with the patient. (See "Prehospital pediatrics and emergency medical services (EMS)", section on 'Interfacility transport'.)

TREATMENT OF REVERSIBLE CAUSES

Reversible causes of cardiac arrest and their initial treatment are provided in the table (table 1) [20]:

For children with an inpatient cardiac arrest, the cause and relevant comorbidities are frequently known. For these patients, specific treatment is continued with escalation of therapies as indicated.

When the cause is unclear (eg, previously healthy child without a known precipitating illness or event), a comprehensive evaluation should include close examination for signs of child abuse (table 11), especially in infants in young children, and testing for drugs of abuse and other signs of occult toxic exposure. (See "Physical child abuse: Recognition" and "Approach to the child with occult toxic exposure", section on 'Ancillary studies'.)

In addition, pediatric survivors of sudden cardiac arrest should undergo a comprehensive evaluation under the direction of a pediatric cardiologist as described separately. (See "Sudden cardiac arrest (SCA) and sudden cardiac death (SCD) in children", section on 'Survivors of SCA'.)

ONGOING MANAGEMENT

Ongoing post-cardiac arrest care in children should be directed by a pediatric critical care specialist in a pediatric intensive care unit.

Oxygenation and ventilation — Ensuring that oxygenation and ventilation goals are met is a critical aspect of post-cardiac arrest care:

- **Oxygenation** – For children with return of spontaneous circulation (ROSC), give supplemental oxygen to maintain pulse oximetry between 94 and 99 percent or the value appropriate for the child's condition if the child has cyanotic congenital heart disease [2,3,5,6]. Adjust supplemental oxygen to avoid hyperoxia (oxygen saturation 100 percent). (See 'Oxygenation (pulse oximetry target)' above.)

- **Ventilation** – After ROSC, maintain normocarbia ($PaCO_2$ 35 to 45 mmHg) using initial arterial or venous blood gas measurements and correlated with continuous quantitative end-tidal capnography. Avoid severe hypocapnia ($PaCO_2$ <30 mmHg) or hypercapnia ($PaCO_2$ >50 mmHg). (See 'Ventilation (PaCO2 target)' above.)

Cardiovascular dysfunction — Children who are comatose after ROSC often have derangements in vascular tone. In addition, impaired cardiac contractility commonly occurs within hours after ROSC in children and significantly raises the risk of mortality. Peak

impairment is typically 8 hours after arrest with improvement at 24 hours and resolution by 72 hours [1].

Management of cardiovascular function after ROSC requires careful monitoring of measures of perfusion including:

- Arterial blood pressure
- Capillary refill time
- Quality of pulses
- Mental status
- Urine output
- Serial arterial or venous blood gases and blood lactate
- In patients with evidence of cardiovascular dysfunction, central venous pressure and oxygen saturation ($ScvO_2$)

Treatment of cardiovascular dysfunction includes:

- **Correct metabolic abnormalities** – Correction of metabolic derangements such as hypocalcemia, hypoglycemia and severe metabolic acidosis. (See 'Glucose homeostasis' below and 'Electrolyte abnormalities' below.)

- **Fluid resuscitation** – Judicious use of fluid resuscitation with crystalloid solution (lactated Ringer's or normal saline) to ensure adequate venous pressure.

- **Vasoactive agents** – Vasoactive infusions to provide support for cardiac contractility. Epinephrine infusion is often needed soon after ROSC to manage ongoing shock and cardiac dysfunction. For patients with severe cardiac dysfunction, milrinone infusion may also be needed to support cardiac contractility while reducing afterload. (See "Shock in children in resource-abundant settings: Initial management", section on 'Vasoactive agents'.)

Hypoxic-ischemic brain injury — After a cardiac arrest, it is essential that the clinician optimize cerebral oxygenation and perfusion and avoid increased metabolic demand caused by fever and seizures. In addition, general measures to address increased intracranial pressure (ICP) should be employed.

Active temperature control — Active temperature control (ATC; also called targeted temperature management) after cardiac arrest refers to the practice of continuously monitoring core body temperature and actively intervening (typically with cooling blankets and antipyretics [eg, acetaminophen]) to maintain core temperature in a narrow pre-defined range.

ATC is a broad term that includes targeted normothermia (maintaining core temperature 36 to 37.5°C [96.8 to 99.5°F]), mild hypothermia (core temperature 34 to 36°C [93.2 to 96.8°F]), and therapeutic hypothermia (core temperature 32 to 34°C [89.6 to 93.2°F]). The optimal temperature is uncertain, as discussed below.

The rationale for ATC following cardiac arrest is based upon observations that fever is common in the initial days after cardiac arrest and that fevers are associated with worse outcomes [21]. Thus, avoiding fever is an important part of post-resuscitation care. The rationale for therapeutic hypothermia is to reduce cerebral metabolic demand, which may reduce the risk of reperfusion injury during the early post-resuscitation period.

- **Indications** – We suggest ATC in all pediatric patients who do not have purposeful movements or responses on neurologic examination following cardiac arrest.

- **Target temperature** – We suggest maintaining core body temperature ≤37.5°C (99.5°F). Based upon the available evidence and international resuscitation guidelines for comatose infants and children after cardiac arrest, it is reasonable to use one of two temperature targets [11,12,22,23]:

  - Normothermia (temperature 36 to 37.5°C [96.8 to 99.5°F]) for a duration of three to five days or per institutional guidelines.

    Or

  - Therapeutic hypothermia (targeted temperature range 32 to 34°C [89.6 to 93.2°F]) for two days followed by three days of normothermia. Patients who receive therapeutic hypothermia are at increased risk of shivering, coagulopathy with bleeding, hyperglycemia, arrhythmias, myocardial dysfunction, and cold diuresis that can cause hypovolemia and electrolyte imbalance [1,24-26].

  The authors maintain normothermia with strict avoidance of fever for most patients during post-cardiac arrest care because of fewer adverse effects and similar benefit when compared to hypothermia. When targeting normothermia, many experts maintain children at 35°C to provide a buffer that avoids fever because temperature elevation can occur rapidly in these patients. However, this approach has not been studied or compared to either normothermia or therapeutic hypothermia.

- **Timing and duration** – ATC should be started as soon as is feasible (within minutes to hours after achieving ROSC). It is typically continued for three to five days. When targeting normothermia, the same temperature target is used for the entire duration. When using therapeutic hypothermia, the lower temperature is maintained for 48 hours, followed by a period of slow rewarming and then one to three days of targeted normothermia.

- **Cooling devices** – ATC is administered using cooling devices that have automated feedback mechanisms to maintain the temperature in the target range. Various cooling devices are commercially available. The most common approach is a surface method such as a water-circulating gel-coated pad or water and/or air-circulating blanket. Additional details are provided separately. (See "Intensive care unit management of the intubated post-cardiac arrest adult patient", section on 'Devices'.)

●**Monitoring** – Accurate monitoring of core body temperature requires the use of a low-reading thermometer and is best obtained with a flexible temperature probe. Sites of measurement include the bladder, rectum, esophagus, nasopharynx, and central vein. Rectal temperature probes are commonly used for this purpose; however, clinicians should be aware that the rectal temperature may lag behind the true core temperature.

During active temperature control, frequent monitoring of the following laboratory studies is also warranted:

- White blood cell count
- Blood glucose
- Electrolytes and calcium
- PT/INR and aPTT

The frequency of monitoring of these studies is determined by whether the target is therapeutic hypothermia (more frequent) or normothermia (less frequent) as well as the presence of derangements soon after ROSC.

Many centers also perform daily blood cultures in these patients because they are prevented from developing a fever as a sign of infection.

- **Adverse effects** – Shivering is common among patients receiving ATC, particularly when targeting lower temperatures. Sedation is generally required, and some patients may require neuromuscular blockade for management of shivering. (See 'Sedation, analgesia, and neuromuscular blockade' below.)

Other adverse effects that can occur in patients receiving therapeutic hypothermia include [1,24-26]:

- Coagulopathy and bleeding – The risk increases with decreasing temperature; major bleeding is uncommon at the temperatures used for therapeutic hypothermia
- Hyperglycemia
- Cardiovascular effects (bradycardia, arrhythmias, ventricular dysfunction, hypotension)
- Cold diuresis
- Electrolyte derangements (eg, hypokalemia, hyperkalemia, and hypocalcemia)

- **Supporting evidence** – The evidence supporting ATC after cardiac arrest in pediatric patients comes from two multicenter clinical trials and several observational studies [24,27-29]. Additional indirect evidence comes from studies in neonates and adult patients, which are discussed separately. (See "Intensive care unit management of the intubated post-cardiac arrest adult patient", section on 'Efficacy'.)

  - **Trials comparing therapeutic hypothermia versus targeted normothermia** – The available clinical trial data suggest that clinical outcomes are similar for patients managed with therapeutic hypothermia (32 to 34°C [89.6 to 93.2°F]) or targeted normothermia (36 to 37.5°C [96.8 to 99.5°F]) [24,27,28]. This question was addressed in two randomized controlled trials, one involving 260 children who were resuscitated from an out-of-hospital cardiac arrest (THAPCA-OH [Therapeutic Hypothermia after Pediatric Cardiac Arrest Out of Hospital trial]) and the other involving 329 children resuscitated from in-hospital cardiac arrest (THAPCA-IH) [27,28]. In an individual patient-level meta-analysis of both trials, patients who were assigned to therapeutic hypothermia had similar one-year survival compared with those assigned to targeted normothermia (44 versus 38 percent; RR 1.15, 95% CI 0.95-1.38) [24]. Rates of moderate or greater neurologic disability at one year were also similar in both groups (17 versus 11 percent).

  - **Studies comparing ATC versus no ATC** – The THAPCA trials do not address the question of whether ATC improves outcomes relative to standard post-resuscitation care without ATC because all patients enrolled in these trials received ATC (albeit targeting different temperatures). The evidence addressing this question is limited to retrospective observational studies evaluating outcomes in patients who received ATC (mostly in the form of mild therapeutic hypothermia) compared with patients who were managed without ATC [29]. These studies have reached variable conclusions, with some finding no association between ATC and survival or neurologic outcome [26,30-33], whereas others reported that ATC was associated with improved survival and/or favorable neurologic outcome [34,35].

  Important uncertainties remain, including the optimal temperature range and duration for ATC and the optimal methods for cooling and rewarming. An ongoing clinical trial is addressing some of these questions [36].

Increased intracranial pressure (ICP) — Patients with significant anoxic brain injury are presumed to have cerebral edema and increased intracranial pressure during the first 48 hours after cardiac arrest. For this reason, in patients with **stable** blood pressure and **without** signs of shock, general measures to mitigate increased ICP are appropriate:

- Elevation of the head of the bed 15 to 30 degrees with head maintained in midline
- Active temperature control as described above (see 'Active temperature control' above)

- In intubated patients, sedation, analgesia, and neuromuscular blockade (see 'Sedation, analgesia, and neuromuscular blockade' below)

However, unless the patient has severe traumatic brain injury, placement of an intracranial pressure monitor is **not** indicated. Furthermore, osmotic therapy for intracranial hypertension with hypertonic saline or mannitol is typically reserved for patients with clinical signs of acute brain herniation.

Seizures — Infants and children who remain comatose after cardiac arrest should have electroencephalogram (EEG) evaluation and continuous EEG monitoring for the presence of seizures. EEG evidence of seizure activity requires prompt antiseizure therapy to reduce the risk of worsening neurologic injury. However, prophylactic administration of antiseizure medications has not been shown to improve outcomes and is not recommended [1,2]. The management of convulsive status epilepticus in children is provided in the algorithm (algorithm 9) and along with nonconvulsive status is discussed separately. (See "Management of convulsive status epilepticus in children" and "Nonconvulsive status epilepticus: Treatment and prognosis".)

Based upon small observational studies, seizures are common following resuscitation from pediatric cardiac arrest occurring in approximately 33 to 50 percent of patients [37-39]. Non-convulsive status epilepticus has also been described and may affect a significant proportion of patients. As an example, non-convulsive status epilepticus was found after cardiac arrest in 6 of 19 children in one series [37].

Sedation, analgesia, and neuromuscular blockade — During post-cardiac arrest care, children frequently require sedation and analgesia to control pain and to prevent or manage shivering. Dosing, type of administration (intermittent or continuous), and specific agent depends upon a variety of factors that include the patient's age, underlying comorbidities, degree of neurologic injury, hemodynamic status, and time since arrest. Agents used for sedation and analgesia can cause hypotension and complicate neurologic assessment. Thus, the minimally effective dose should be used.

Our typical approach consists of sedation with a continuous infusion of dexmedetomidine combined with fentanyl or morphine for analgesia. For patients with seizures, we use a continuous infusion of midazolam instead of dexmedetomidine. We also use midazolam in single doses to supplement dexmedetomidine sedation as needed.

Some patients may also require neuromuscular blockade (eg, intermittent dosing of vecuronium or rocuronium) to achieve oxygen saturation or p_aCO_2 targets and to avoid asynchrony between the patient's breathing and mechanical ventilation. Patients receiving active temperature control may also require neuromuscular blockade to counteract shivering.

Sedation and neuromuscular blockade conceal neurologic examination and impair the ability to detect clinical seizures, determine adequacy of analgesia, and assess prognosis [1]. Thus, children receiving neuromuscular blockade should also have continuous EEG monitoring, if not already established, to identify seizures. In addition, neuromuscular blockade should be permitted to wear off on a scheduled basis to permit regular evaluation of neurologic status and discomfort.

Glucose homeostasis — The clinician should monitor blood glucose levels and promptly treat hypoglycemia. (See "Approach to hypoglycemia in infants and children", section on 'Immediate management'.)

In addition, sustained hyperglycemia (blood glucose >180 mg/dL [10 mmol/L]) is associated with higher mortality in critically ill children and should be avoided [40,41]. Evidence indicates that blood glucose should be maintained below this threshold, but the role of "tight control" that uses insulin to achieve a specified blood glucose range is of uncertain value in children after cardiac arrest [42]. If performed, tight glucose control requires close monitoring of blood glucose and avoidance of hypoglycemia. Intensive insulin therapy in adults to maintain a blood glucose range of 80 to 110 mg/dL (4.4 to 6.1 mmol/L) increases the risk of hypoglycemia without benefit. (See "Glycemic control in critically ill adult and pediatric patients", section on 'Our approach'.)

Electrolyte abnormalities — Hypokalemia, hyperkalemia, and hypocalcemia are common electrolyte abnormalities encountered in post-cardiac arrest care and can cause cardiac arrhythmias with recurrent cardiac arrest. For this reason, serum electrolytes and ionized calcium should be evaluated frequently (eg, at minimum every four to six hours and more frequently in patients who have abnormal values). The treatment of specific electrolyte abnormalities is discussed in detail separately:

- Hyperkalemia (algorithm 10) (see "Management of hyperkalemia in children")
- Hypokalemia (see "Hypokalemia in children", section on 'Potassium supplementation')
- Hypocalcemia (see "Primary drugs in pediatric resuscitation", section on 'Calcium')

Patients with hypokalemia should also have serum magnesium measured for detection and treatment of hypomagnesemia, as hypokalemia may not correct until magnesium is repleted. (See "Primary drugs in pediatric resuscitation", section on 'Magnesium sulfate'.)

Acute kidney injury — Approximately 30 to 40 percent children who survive cardiac arrest develop acute kidney injury (AKI) during post-cardiac arrest care [43]. Rarely, patients with severe AKI may require renal replacement therapy within the first 48 hours after ROSC [43]. For this reason, ongoing assessment of urine output and serial measurement of blood urea nitrogen and serum creatinine (eg, every 12 hours) are necessary to assess kidney function. In addition, frequent measurement of serum electrolytes, calcium, and phosphate (eg, every

4 to 6 hours) is required to identify and treat related electrolyte abnormalities such as hyperkalemia (algorithm 10), metabolic acidosis, and hyperphosphatemia with hypocalcemia. (See "Prevention and management of acute kidney injury in children", section on 'Management of acute kidney injury'.)

Maintaining adequate blood pressure while avoiding fluid overload are important priorities to decrease the likelihood of AKI in these patients. Avoid nephrotoxic medications in the immediate post-cardiac arrest period. For children with significant AKI, renal adjustment of medication dosing is best accomplished in consultation with trained pharmacy teams and nephrologists with pediatric expertise, as described separately. (See "Prevention and management of acute kidney injury in children".)

The primary indications for renal replacement therapy during post-cardiac arrest care include fluid overload unresponsive to pharmacologic therapy such as diuretics, hyperkalemia (serum or plasma potassium >6.5 mEq/L), and uremia (BUN >80 to 100 mg/dL). (See "Pediatric acute kidney injury: Indications, timing, and choice of modality for kidney replacement therapy".)

PROGNOSIS

Neuroprognostication for children during post-cardiac arrest care should be performed by pediatric neurologists or physicians with similar expertise. Many factors impact the prognosis for neurologic recovery after cardiac arrest in children. The ability to predict outcomes within the first 24 to 48 hours of arrest is generally poor, especially when the physical examination is altered by sedation and/or the use of therapeutic hypothermia. In particular, lack of motor function and pupillary response should **not** be used as reasons to withdraw care soon after return of spontaneous circulation (ROSC) in children [1].

Serial electroencephalograms, evoked potentials, and magnetic resonance imaging (MRI) are all studies that can be used to assess cerebral function but have limitations as well, especially soon after cardiac arrest. Thus, they should **not** be used in isolation to make clinical decisions regarding withdrawal of care [2,3]. In particular, MRI performed for prognostic purposes is typically performed between three and seven days post-arrest.

COMMUNICATION WITH FAMILY

During post-cardiac arrest care, parents/primary caregivers require accurate and empathetic communication of their child's condition, current level of support and treatments, and next steps in care. Soon after return of spontaneous circulation, the clinician should emphasize that outcomes are difficult to predict and that multiple clinical findings must be considered

by a physician with the appropriate expertise. The clinician should avoid premature predictions of clinical outcomes. Given the dynamic nature of post-arrest physiology, it is generally our practice to provide a broad overview during initial communication without focusing on speculative details. It is often helpful for families to anticipate at least several days of critical care; for comatose patients, the prognosis may remain unknown for at least three to five days.

SUMMARY AND RECOMMENDATIONS

- **Stabilization** – During post-cardiac arrest care in children, important interventions to prevent recurrent arrest soon after return of circulation (ROSC) include (table 2):

  - **Oxygenation** – Provide supplemental oxygen, as needed, to maintain pulse oximetry 94 to 99 percent or, if the child has cyanotic congenital heart disease, the baseline value appropriate for the child's condition; avoid hyperoxia (pulse oximetry 100 percent). Both hypoxemia and hyperoxemia are harmful after a cardiac arrest. (See 'Oxygenation (pulse oximetry target)' above.)

  - **Airway** – Assess airway and maintain C-spine motion restriction in patients with trauma. (See 'Airway (C-spine motion restriction)' above.)

    Most children with altered mental status, respiratory distress, or shock after ROSC require endotracheal intubation. For unintubated children, perform endotracheal intubation as indicated. Modify sedation for rapid sequence intubation, as needed, to avoid hypotension. (See 'Unintubated' above and "Rapid sequence intubation (RSI) in children for emergency medicine: Approach".)

    For intubated children, ensure correct endotracheal tube positioning clinically and with chest radiography; place a gastric tube to prevent gastric distension and vomiting. (See 'Intubated' above.)

  - **Breathing** – For intubated children, correlate continuous quantitative end-tidal capnography with an initial arterial blood gas measurement to monitor $PaCO_2$. Target mechanical ventilation to maintain normocapnia (eg, $PaCO_2$ 35 to 45 mm Hg) or, in patients with chronic lung disease with hypercapnia, near their baseline $PaCO_2$. (See 'Ventilation (PaCO2 target)' above.)

  - **Circulation** – After ROSC, provide support to achieve a near-normal blood pressure (table 6 and table 7 and table 8) that is well above the 5th percentile threshold for shock and address any contributing factors to hemodynamic instability, as shown in the table (table 1).

Treat shock with a rapid infusion of isotonic fluid (lactated Ringer's or normal saline) (algorithm 2). The typical volume and rate is 10 to 20 mL/kg over 10 to 20 minutes with the lower volume used for patients with suspected or confirmed myocardial dysfunction. In patients with ongoing shock despite fluid administration, start a vasoactive infusion, typically epinephrine. (See 'Maintain blood pressure and treat shock' above and "Shock in children in resource-abundant settings: Initial management".)

Treat recurrent arrest (algorithm 4 and algorithm 5) and arrhythmias (algorithm 6 and algorithm 7) per Pediatric Advanced Life Support guidelines. (See 'Treat arrythmias' above.)

Obtain ancillary studies as described above. (See 'Ancillary studies' above.)

- **Disability** – Minimize the risk of secondary brain injury:
  - Dextrose – Measure rapid blood glucose and treat hypoglycemia (table 9), as needed.
  - Elevate head of bed – For hemodynamically stable patients, elevate the head of the bed 15 to 30 degrees and keep the head midline. (See 'Increased intracranial pressure (ICP)' above.)
  - Active temperature control, as discussed below.
  - Electroencephalogram (EEG) monitoring – Initiate continuous EEG monitoring; promptly treat convulsive (algorithm 9) and non-convulsive seizures. (See "Management of convulsive status epilepticus in children" and "Nonconvulsive status epilepticus: Treatment and prognosis".)
- **Active temperature control (targeted temperature management)** – For children who do not have purposeful movements or responses on neurologic examination after cardiac arrest, we suggest active temperature control to maintain core body temperature ≤37.5°C (99.5°F) (**Grade 2C**). It is reasonable to use one of two temperature targets (see 'Active temperature control' above):
  - Normothermia (temperature 36 to 37.5°C [96.8 to 99.5°F]) for a duration of three to five days or per institutional guidelines. When targeting normothermia, many experts maintain children at 35°C to provide a buffer that avoids fever because temperature elevation can occur rapidly in these patients. However, evidence is lacking for this approach.

    Or

- Therapeutic hypothermia (targeted temperature range 32 to 34°C [89.6 to 93.2°F]) for two days followed by three days of normothermia.

- **Definitive care** – After ROSC, stabilize the child, consult with a pediatric critical care specialist, and rapidly transfer to a pediatric intensive care unit for ongoing management. (See 'Transfer to definitive care' above.)

- **Post-cardiac arrest care (PCAC) priorities** – Priorities in PCAC in children and ongoing management are provided in the table (table 1). In addition, to continuing interventions established during stabilization as above, important actions include (see 'Ongoing management' above):

  - **Treat reversible causes** – Continue to evaluate and treat reversible and underlying causes of the cardiac arrest.

  - **Sedation, analgesia, and neuromuscular blockade** – Provide sedation and analgesia using the minimally effective dose to avoid hypotension. For most patients, we suggest a continuous infusion of dexmedetomidine plus fentanyl or morphine rather than other sedations regimens (**Grade 2C**). An exception is the patient with seizures, for whom we use a continuous infusion of midazolam instead of dexmedetomidine. (See 'Sedation, analgesia, and neuromuscular blockade' above.)

    We suggest neuromuscular blockade (eg, intermittent dosing of vecuronium or rocuronium) for patients with any of the following (**Grade 2C**):

    - Inability to achieve oxygen saturation or P_aCO_2 targets despite optimizing ventilator settings and sedation
    - Asynchrony with the ventilator
    - Shivering in the setting of active temperature control (ATC) that is refractory to sedation

  - **Maintain glucose homeostasis** – Continue to monitor blood glucose. Promptly treat hypoglycemia. Avoid sustained hyperglycemia (blood glucose >180 mg/dL [10 mmol/L]) as described separately. (See "Glycemic control in critically ill adult and pediatric patients", section on 'Our approach'.)

  - **Anticipate and manage cardiovascular dysfunction** – Impaired cardiac contractility and derangements in vascular tone commonly occur during the first 24 hours of PCAC. Management consists of fluid resuscitation with isotonic fluids (eg, lactated Ringer's or normal saline) to maintain central venous pressure, titration of vasoactive infusions (eg, epinephrine, milrinone, or both), and correction of hypocalcemia, hypoglycemia, and severe metabolic acidosis, as indicated.

- **Family communication and prognosis** – Soon after ROSC, emphasize to the parents/primary caregivers that outcomes are difficult to predict and avoid speculating about the chance of survival or recovery. Consult pediatric neurologists or physicians with similar expertise to provide neuroprognostication. (See 'Prognosis' above.)

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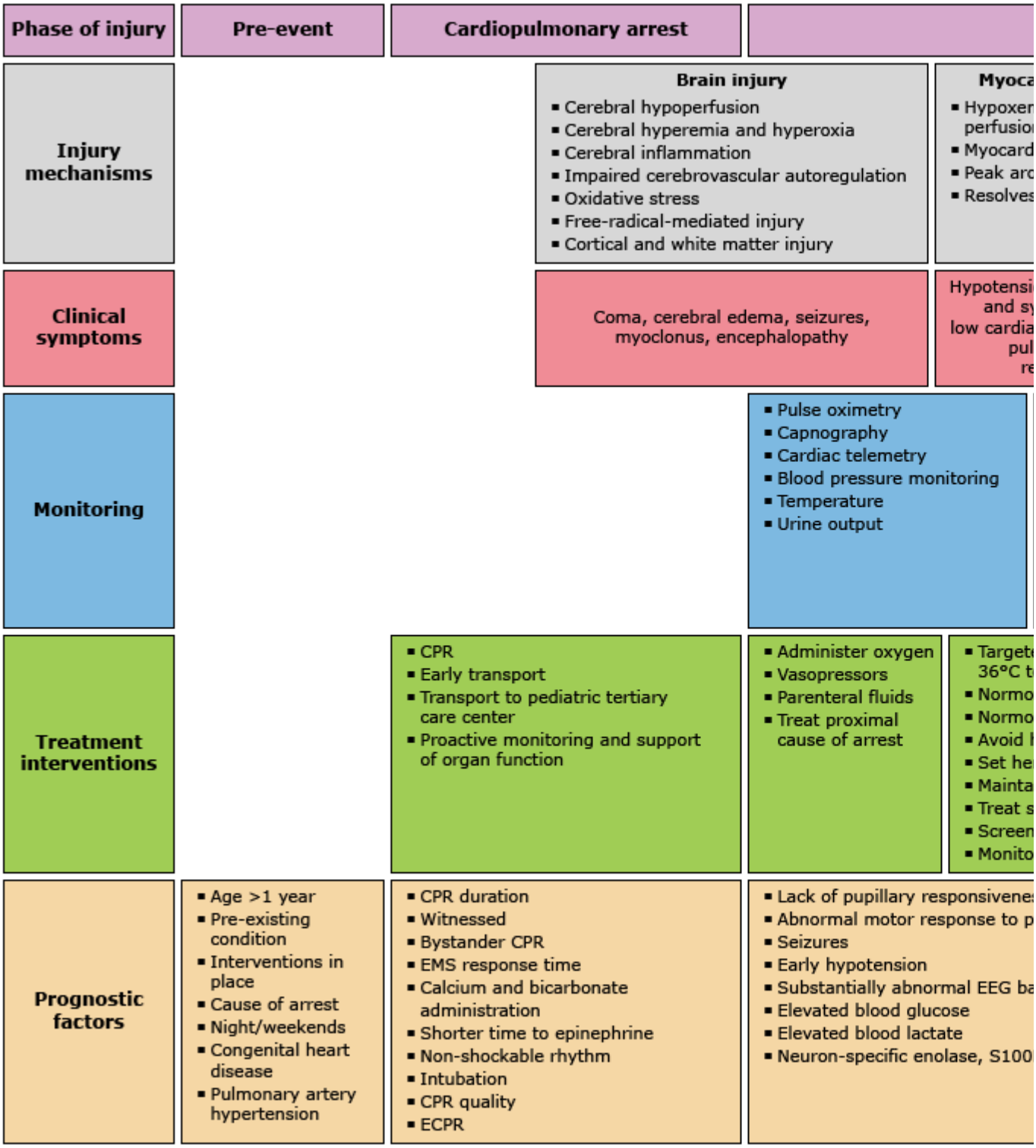
Topic 140197 Version 7.0

GRAPHICS

Phases of cardiac arrest in children with associated mechanisms, clinical symptoms, monitoring, treatment interventions, and prognostics factors



AKI: acute kidney injury; CBC: complete blood count; cEEG: continuous electroencephalogram; CNS: central nervous system; CO_2: carbon dioxide; CPR: cardiopulmonary resuscitation; ECMO: extracorporeal membrane oxygenation; ECPR: extracorporeal cardiopulmonary resuscitation; EEG: electroencephalogram; EMS: emergency medical service; LV: left ventricular; $PaCO_2$: partial pressure

of carbon dioxide; RV: right ventricular; SBP: systolic blood pressure; SIRS: systemic inflammatory response syndrome.

Graphic 142113 Version 2.0

Post-cardiac arrest care in children: Priorities and management

Care priorities	Clinical manifestations	Interventions
Prevent secondary brain injury	▪ Coma ▪ Cerebral edema ▪ Seizures ▪ Myoclonus ▪ Sympathetic hyperarousal ▪ Long-term neurologic and cognitive deficits	▪ Maintain: • Normal oxygenation (pulse oximetry 94 to 99%); avoid hyperoxia (pulse oximetry 100% or P_aO_2 >200 mmHg) • Normal p_aCO_2 (35 to 45 mmHg, avoid hypo- or hypercapnia) • Blood pressure (see below) ▪ Active temperature control (either normothermia or therapeutic hypothermia) ▪ Perform continuous EEG monitoring to detect and treat seizures ▪ In patients who have normal BP and perfusion, elevate head of bed
Identify and manage cardiovascular dysfunction	▪ Heart failure ▪ Myocardial dysfunction that peaks 8 hours after arrest and resolves in 48 to 72 hours ▪ Arrhythmias/recurrent arrest	**As above and:** ▪ Maintain systolic blood pressure >5th percentile for age: • Infusion of balanced crystalloid fluids, as needed • Continuous infusion vasopressor infusion (fluid-refractory shock), as needed* ▪ Treat arrhythmias/recurrent arrest per PALS
Treat reversible causes	**Hs and Ts:**	**Treatment:**
	▪ Respiratory failure (hypoxia)	▪ Oxygenation and ventilation as above
	▪ Hypovolemia	▪ Fluid resuscitation as above
	▪ Hydrogen ion (acidosis)	▪ Ventilation for respiratory acidosis; treat underlying cause of metabolic acidosis, sodium bicarbonate if severe (pH <7.1)
	▪ Hypo- or hyperkalemia	▪ Hypokalemia: Cautious administration of parenteral

		potassium ▪ Hyperkalemia: Parenteral calcium, insulin/glucose, continuous albuterol, and sodium bicarbonate[¶]
	▪ Severe hypothermia	▪ Rewarming
	▪ Toxins/drug overdose	▪ Supportive care ▪ For selected patients: Antidotes and/or extracorporeal toxin removal[Δ]
	▪ Tension pneumothorax	▪ Thoracentesis and thoracostomy tube/pigtail
	▪ Pericardial tamponade	▪ Pericardiocentesis
	▪ Pulmonary embolus	▪ Anticoagulation
	▪ Myocardial infarction (Rare in children)	▪ Thrombolytic therapy and/or percutaneous coronary intervention
Identify and manage systemic ischemia/reperfusion injury		**As above and:**
	▪ Hyperglycemia	▪ Target glucose 150 to 180 mg/dL[◇]
	▪ Coagulopathy	▪ Monitor for and treat DIC[§]
	▪ Acute kidney injury	▪ Manage fluid and electrolyte balance, metabolic acidosis, and, rarely, initiate renal replacement therapy
	▪ Capillary leak with intravascular hypovolemia ▪ Impaired tissue oxygen utilization	▪ Adjust oxygenation, ventilation, fluid therapy, and vasoactive infusion based upon close monitoring of volume status and tissue oxygenation[¥]
	▪ Multi-system organ dysfunction	▪ Provide supportive care; adjust medications, as needed, for kidney and/or hepatic dysfunction

BP: blood pressure; EEG: electroencephalogram; PALS: Pediatric Advanced Life Support.

* Vasopressor options according to blood pressure include:
- Hypotensive shock: Continuous infusion of epinephrine or norepinephrine
- Normotensive shock: Continuous infusion of epinephrine or, for physicians experienced with its use in children, milrinone

Refer to UpToDate content on Pediatric Advanced Life Support: Management of shock after return of spontaneous circulation.

¶ Refer to UpToDate content on treatment of hyperkalemia in children.

Δ Refer to UpToDate content on occult poisoning in children.

◇ In infants and children, may require continuous infusion of insulin. Refer to UpToDate content on glycemic control in critically ill pediatric patients.

§ Refer to UpToDate content on the management of DIC in children.

¥ Provide sedation and analgesia to control pain and to prevent or manage shivering; use the minimally effective dose to avoid hypotension. Some patients may also require neuromuscular blockade to achieve oxygen saturation or p_aCO_2 targets to prevent shivering, and/or to avoid asynchrony between the patient's breathing and mechanical ventilation. For suggested regiments, refer to UpToDate content on post-cardiac arrest care in children.

Adapted from: Topjian AA, de Caen A, Wainwright MS, et al. Pediatric Post-Cardiac Arrest Care: A Scientific Statement From the American Heart Association. Circulation 2019; 140:e194.

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Components of post-cardiac arrest care in children

Oxygenation and ventilation	
Measure oxygenation and target normoxemia 94 to 99% (or child's normal/appropriate oxygen saturation).	☐
Avoid hypoxemia.	☐
Measure $PaCO_2$ and target a clinically appropriate value.	☐
Avoid hypocapnia.	☐
Hemodynamic monitoring	
Set specific hemodynamic goals during PCAC and review daily.	☐
Use cardiac telemetry.	☐
Monitor arterial blood pressure.	☐
Monitor serum lactate, urine output, and central venous oxygen saturation to help guide therapies.	☐
Use parenteral fluid bolus with or without inotropes or vasopressors to maintain a systolic blood pressure greater than the fifth percentile for age and sex.	☐
TTM	
Measure and monitor continuous core temperature.	☐
Prevent and promptly treat fever.	☐
Apply TTM (32°C to 34°C) for 48 hours and then maintain TTM (36°C to 37.5°C) for 3 days after rewarming, or apply TTM (36°C to 37.5°C) for 5 days if patient is unresponsive after ROSC.	☐
Prevent shivering.	☐
Monitor blood pressure and treat hypotension during rewarming.	☐
Prevent fever after rewarming.	☐
Neuromonitoring	
Treat clinical seizures.	☐
Ensure no routine use of pharmacological prophylaxis for seizures.	☐
Consider early brain imaging to diagnose treatable causes of cardiac arrest.	☐
Glucose control	
Measure blood glucose.	☐
Avoid hypoglycemia.	☐
Sedation	
Treat with sedatives and anxiolytics.	☐
Prognosis	

Always consider multiple modalities (clinical and other) over any single predictive factor.	☐
EEG in conjunction with other factors may be useful within the first 7 days of PCAS.	☐
Neuroimaging such as MRI during the first 7 days may be valuable.	☐
Remember that assessments may be modified by TTM or induced hypothermia.	☐

EEG: electroencephalogram; MRI: magnetic resonance imaging; PCAC: post-cardiac arrest care; PCAS: post-cardiac arrest syndrome; ROSC: return of spontaneous circulation; TTM: targeted temperature management.

Graphic 140374 Version 2.0

Oxygen delivery systems

System	Percent oxygen delivered*	Indications	Comments
Blow by	Less than 30 percent	Use for spontaneously breathing children who require low doses of oxygen and do not tolerate a mask	Best delivered at a flow rate of at least 10 L/minute through a reservoir (ie, a simple mask or Styrofoam or paper drinking cup with oxygen tubing poked through the bottom) with the reservoir held near the patient's face by a parent or other caregiver
Low flow nasal cannula (1 to 4 L/min)	25 to 40 percent	Use to deliver low-dose oxygen to spontaneously breathing patients	Percent oxygen delivered affected by respiratory rate, tidal volume, and extent of mouth breathing. In infants, limit flow rate to 2 L/min or less to avoid inadvertent administration of positive airway pressure
Simple mask	35 to 50 percent	Use to deliver low-dose oxygen to spontaneously breathing patients	Percent oxygen delivered affected by mask fit and respiratory rate
Small diffuser (OxyMask)	25 to >80 percent	Use to provide low- or high-dose oxygen to spontaneously breathing patients	Range of oxygen delivery at different flow rates (approximately 25 percent at 1.5 L/min to >80 percent at ≥15 L/min) Open-mask design may be better tolerated by children. May provide equivalent oxygen delivery at lower flow rates than other mask devices.
Partial rebreather mask	50 to 60 percent	Use to conserve oxygen	
Nonrebreather mask	65 to 95 percent	Use to deliver high-dose oxygen to spontaneously breathing patients	Tight mask fit required to deliver higher concentrations of oxygen
Hood	30 to 90 percent	Infants less than one year of age	Noisy for patient
Tent	25 to 50 percent	Use for children who require 30 percent oxygen or less	Mist may obscure view of patient. Noisy for patient. Low-flow nasal cannula or masks preferred.
Self-inflating ventilation bag	95 to 100 percent, with reservoir	Use to provide assisted ventilation and oxygen	Do not use to provide blow by. Must use with a reservoir to provide higher oxygen concentrations.

Flow-inflating ventilation bag	100 percent	Use to provide assisted ventilation and oxygen	May use to provide blow by. Requires experience to use reliably.

*Actual percent oxygen delivered may vary widely depending on the type of delivery device, device manufacturer, oxygen flow rate provided to the device, and, for oxygen masks, mask fit. All patients receiving supplemental oxygen warrant monitoring with pulse oximetry.

Graphic 60610 Version 9.0

Initial settings for volume-controlled mechanical ventilation in children*

	Infant (<1 year of age)	Toddler/child (1 to 12 years)	Adolescent (>12 years)
Tidal volume (mL)	5 to 8 mL/kg (healthy lungs)	5 to 8 mL/kg (healthy lungs)	5 to 8 mL/kg (healthy lungs)
	3 to 6 mL/kg (lung protective strategy)	3 to 6 mL/kg (lung protective strategy)	3 to 6 mL/kg (lung protective strategy)
Rate (breaths/minute)	20 to 30	15 to 25	12 to 20
PEEP (cm H_2O)	3 to 8	3 to 8	3 to 8
Pressure support (cm H_2O)¶	Minimum 6 to 10	Minimum 6 to 10	Minimum 6 to 10
Peak inspiratory flow (L/minute)	Adjusted to fit desired inspiratory time	Adjusted to fit desired inspiratory time	Adjusted to fit desired inspiratory time
Inspiratory time (seconds) Targeted, based upon changes to inspiratory flow	0.4 to 0.6	0.7 to 0.9	0.9 to 1.2
FiO_2 (%)Δ	Start with 1.0, rapidly wean to ≤0.6	Start with 1.0, rapidly wean to ≤0.6	Start with 1.0, rapidly wean to ≤0.6
Flow trigger (L/minute)	0.25 to 0.5	0.8 to 2	0.8 to 2
Pressure support cycle	10 to 25% of peak flow rate	10 to 25% of peak flow rate	10 to 25% of peak flow rate

PEEP: positive end-expiratory pressure; FiO_2: fraction of inspired oxygen.

* Consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. Regardless of ventilator settings employed, the physician must assess ventilator settings shortly after initiation and frequently thereafter and adjust them as needed to meet oxygenation and ventilation goals as the natural course of the underlying pathophysiology evolves.

¶ Adjust according to endotracheal tube size: 3 to 3.5 mm: 10 cm H_2O; 4 to 4.5 mm: 8 cm H_2O; ≥5 mm: 6 cm H_2O.

Δ Wean to 0.6 or below to maintain arterial oxygen tension (PaO_2) 60 to 80, oxygen saturation (SpO_2) 92 to 97% when required PEEP is <10 cm H_2O; if required PEEP is ≥10 cm H_2O, then targeted oxygen saturation may be reduced to 88 to 92% for those patients with pediatric acute respiratory distress syndrome (PARDS).

Graphic 113548 Version 3.0

Causes and troubleshooting erroneous pulse oximetry readings

Problem and potential errors	Solution
Inadequate waveform	
Malposition of probe	Reposition probe, alternate site
Motion artifact	Reposition probe, alternate site
Hypoperfusion	Reposition probe, alternate site, warming
Hypothermia	Use ear or forehead probe, warming
Skin pigment	Measure ABG
Falsely normal or elevated oximetry reading	
Carboxyhemoglobin (eg, carbon monoxide poisoning)	Co-oximetry
High levels of glycohemoglobin A1c	Measure ABG
metHb, sulfHb*	Multiwavelength co-oximetry (metHb), biochemical analysis (sulfHb)
Ambient light	Remove ambient light source
Skin pigment	Measure ABG
Falsely low oximetry reading	
Inadequate waveform	Reposition probe, alternate site
metHb*	Multiwavelength co-oximetry
sulfHb*	Biochemical analysis
HbS and inherited forms of abnormal Hb	Measure HbS and abnormal Hb levels
Severe anemia	Measure ABG
Venous pulsations or congestion	Loosen probe, reposition patient or probe, measure ABG
Ambient light	Remove ambient light source
Nail polish	Remove polish or change site
Vital dyes	Usually transient, measure ABG

ABG: arterial blood gas; metHb: methemoglobin; sulfHb: sulfhemoglobin; HbS: sickle hemoglobin; Hb: hemoglobin; SpO_2: peripheral arterial oxygen saturation; SaO_2: true arterial oxygen saturation.

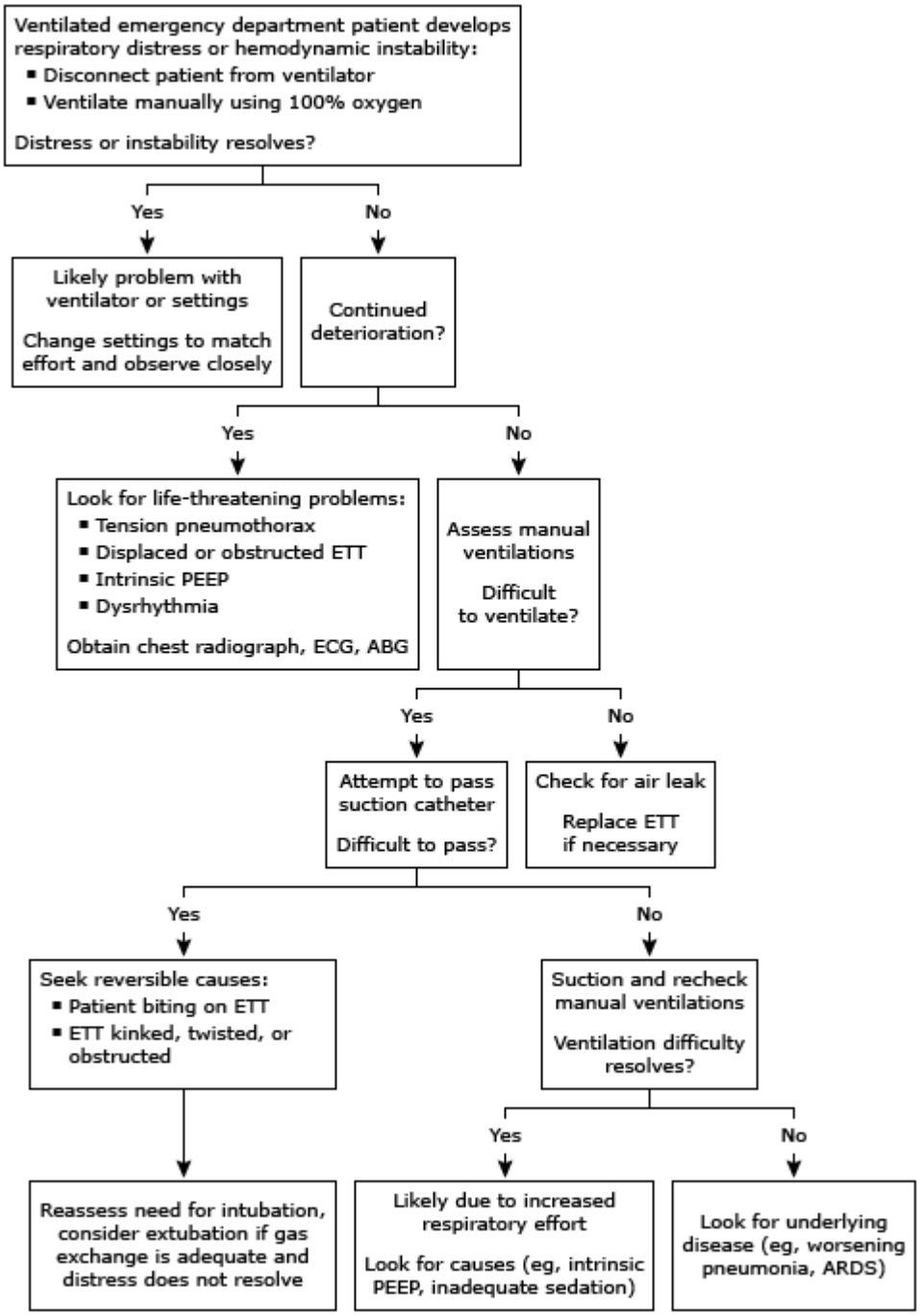
* In these conditions, SpO_2 is low; when levels of metHb or sulfHb are mildly elevated, SpO_2 underestimates the SaO_2, but when levels are high, the SpO_2 automatically trends towards 85% such that pulse oximetry can overestimate SaO_2.

Adapted from: Chan ED, Chan MM, Chan MM. Pulse oximetry: understanding its basic principles facilitates appreciation of its

limitations. Respir Med 2013; 107:789.

Graphic 107546 Version 4.0

Emergency department approach to the ventilated patient in respiratory distress



ETT: endotracheal tube; PEEP: peak end-expiratory pressure; ECG: electrocardiogram; ABG: arterial blood gas; ARDS: acute respiratory distress syndrome.

Graphic 77096 Version 5.0

Normal blood pressure for infants at one year of age

Gender	BP (percentile)	Systolic BP (mmHg)							Diastolic			
		Percentile of height							Percentil			
		5th	10th	25th	50th	75th	90th	95th	5th	10th	25th	50
Boys	50th	80	81	83	85	87	88	89	34	35	36	3
	90th	94	95	97	99	100	102	103	49	50	51	5
	95th	98	99	101	103	104	106	106	54	54	55	5
	99th	105	106	108	110	112	113	114	61	62	63	6
Girls	50th	83	84	85	86	88	89	90	38	39	39	4
	90th	97	97	98	100	101	102	103	52	53	53	5
	95th	100	101	102	104	105	106	107	56	57	57	5
	99th	108	108	109	111	112	113	114	64	64	65	6

The 90th percentile is 1.28 standard deviation, 95th percentile is 1.645 standard deviation, and the 99th percentile is 2.326 over the mean.

BP: blood pressure.

Data from: Fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. National Heart, Lung, and Blood Institute. National Institutes of Health, May 2004.

Graphic 103281 Version 1.0

Blood pressure levels for males by age and height percentile

BP (percentile)	Systolic BP (mmHg)							Diastolic BP			
	Height percentile or measured height							Height percentile or			
	5%	10%	25%	50%	75%	90%	95%	5%	10%	25%	50%
1 year											
Height (in)	30.4	30.8	31.6	32.4	33.3	34.1	34.6	30.4	30.8	31.6	32.4
Height (cm)	77.2	78.3	80.2	82.4	84.6	86.7	87.9	77.2	78.3	80.2	82.4
50th	85	85	86	86	87	88	88	40	40	40	41
90th	98	99	99	100	100	101	101	52	52	53	53
95th	102	102	103	103	104	105	105	54	54	55	55
95th + 12 mmHg	114	114	115	115	116	117	117	66	66	67	67
2 years											
Height (in)	33.9	34.4	35.3	36.3	37.3	38.2	38.8	33.9	34.4	35.3	36.3
Height (cm)	86.1	87.4	89.6	92.1	94.7	97.1	98.5	86.1	87.4	89.6	92.
50th	87	87	88	89	89	90	91	43	43	44	44
90th	100	100	101	102	103	103	104	55	55	56	56
95th	104	105	105	106	107	107	108	57	58	58	59
95th + 12 mmHg	116	117	117	118	119	119	120	69	70	70	71
3 years											
Height (in)	36.4	37.0	37.9	39.0	40.1	41.1	41.7	36.4	37.0	37.9	39.(
Height (cm)	92.5	93.9	96.3	99.0	101.8	104.3	105.8	92.5	93.9	96.3	99.(
50th	88	89	89	90	91	92	92	45	46	46	47
90th	101	102	102	103	104	105	105	58	58	59	59
95th	106	106	107	107	108	109	109	60	61	61	62
95th + 12 mmHg	118	118	119	119	120	121	121	72	73	73	74
4 years											
Height (in)	38.8	39.4	40.5	41.7	42.9	43.9	44.5	38.8	39.4	40.5	41.7

Height (cm)	98.5	100.2	102.9	105.9	108.9	111.5	113.2	98.5	100.2	102.9	105
50th	90	90	91	92	93	94	94	48	49	49	50
90th	102	103	104	105	105	106	107	60	61	62	62
95th	107	107	108	108	109	110	110	63	64	65	66
95th + 12 mmHg	119	119	120	120	121	122	122	75	76	77	78
5 years											
Height (in)	41.1	41.8	43.0	44.3	45.5	46.7	47.4	41.1	41.8	43.0	44.
Height (cm)	104.4	106.2	109.1	112.4	115.7	118.6	120.3	104.4	106.2	109.1	112
50th	91	92	93	94	95	96	96	51	51	52	53
90th	103	104	105	106	107	108	108	63	64	65	65
95th	107	108	109	109	110	111	112	66	67	68	69
95th + 12 mmHg	119	120	121	121	122	123	124	78	79	80	81
6 years											
Height (in)	43.4	44.2	45.4	46.8	48.2	49.4	50.2	43.4	44.2	45.4	46.
Height (cm)	110.3	112.2	115.3	118.9	122.4	125.6	127.5	110.3	112.2	115.3	118
50th	93	93	94	95	96	97	98	54	54	55	56
90th	105	105	106	107	109	110	110	66	66	67	68
95th	108	109	110	111	112	113	114	69	70	70	71
95th + 12 mmHg	120	121	122	123	124	125	126	81	82	82	83
7 years											
Height (in)	45.7	46.5	47.8	49.3	50.8	52.1	52.9	45.7	46.5	47.8	49.
Height (cm)	116.1	118.0	121.4	125.1	128.9	132.4	134.5	116.1	118.0	121.4	125
50th	94	94	95	97	98	98	99	56	56	57	58
90th	106	107	108	109	110	111	111	68	68	69	70
95th	110	110	111	112	114	115	116	71	71	72	73
95th + 12 mmHg	122	122	123	124	126	127	128	83	83	84	85
8 years											
Height (in)	47.8	48.6	50.0	51.6	53.2	54.6	55.5	47.8	48.6	50.0	51.

Height (cm)	121.4	123.5	127.0	131.0	135.1	138.8	141.0	121.4	123.5	127.0	131
50th	95	96	97	98	99	99	100	57	57	58	59
90th	107	108	109	110	111	112	112	69	70	70	71
95th	111	112	112	114	115	116	117	72	73	73	74
95th + 12 mmHg	123	124	124	126	127	128	129	84	85	85	86
9 years											
Height (in)	49.6	50.5	52.0	53.7	55.4	56.9	57.9	49.6	50.5	52.0	53.
Height (cm)	126.0	128.3	132.1	136.3	140.7	144.7	147.1	126.0	128.3	132.1	136
50th	96	97	98	99	100	101	101	57	58	59	60
90th	107	108	109	110	112	113	114	70	71	72	73
95th	112	112	113	115	116	118	119	74	74	75	76
95th + 12 mmHg	124	124	125	127	128	130	131	86	86	87	88
10 years											
Height (in)	51.3	52.2	53.8	55.6	57.4	59.1	60.1	51.3	52.2	53.8	55.
Height (cm)	130.2	132.7	136.7	141.3	145.9	150.1	152.7	130.2	132.7	136.7	141
50th	97	98	99	100	101	102	103	59	60	61	62
90th	108	109	111	112	113	115	116	72	73	74	74
95th	112	113	114	116	118	120	121	76	76	77	77
95th + 12 mmHg	124	125	126	128	130	132	133	88	88	89	89
11 years											
Height (in)	53.0	54.0	55.7	57.6	59.6	61.3	62.4	53.0	54.0	55.7	57.
Height (cm)	134.7	137.3	141.5	146.4	151.3	155.8	158.6	134.7	137.3	141.5	146
50th	99	99	101	102	103	104	106	61	61	62	63
90th	110	111	112	114	116	117	118	74	74	75	75
95th	114	114	116	118	120	123	124	77	78	78	78
95th + 12 mmHg	126	126	128	130	132	135	136	89	90	90	90
12 years											
Height (in)	55.2	56.3	58.1	60.1	62.2	64.0	65.2	55.2	56.3	58.1	60.

Height (cm)	140.3	143.0	147.5	152.7	157.9	162.6	165.5	140.3	143.0	147.5	152
50th	101	101	102	104	106	108	109	61	62	62	62
90th	113	114	115	117	119	121	122	75	75	75	75
95th	116	117	118	121	124	126	128	78	78	78	78
95th + 12 mmHg	128	129	130	133	136	138	140	90	90	90	90
13 years											
Height (in)	57.9	59.1	61.0	63.1	65.2	67.1	68.3	57.9	59.1	61.0	63.
Height (cm)	147.0	150.0	154.9	160.3	165.7	170.5	173.4	147.0	150.0	154.9	160
50th	103	104	105	108	110	111	112	61	60	61	62
90th	115	116	118	121	124	126	126	74	74	74	75
95th	119	120	122	125	128	130	131	78	78	78	78
95th + 12 mmHg	131	132	134	137	140	142	143	90	90	90	90
14 years											
Height (in)	60.6	61.8	63.8	65.9	68.0	69.8	70.9	60.6	61.8	63.8	65.
Height (cm)	153.8	156.9	162.0	167.5	172.7	177.4	180.1	153.8	156.9	162.0	167
50th	105	106	109	111	112	113	113	60	60	62	64
90th	119	120	123	126	127	128	129	74	74	75	77
95th	123	125	127	130	132	133	134	77	78	79	81
95th + 12 mmHg	135	137	139	142	144	145	146	89	90	91	93
15 years											
Height (in)	62.6	63.8	65.7	67.8	69.8	71.5	72.5	62.6	63.8	65.7	67.
Height (cm)	159.0	162.0	166.9	172.2	177.2	181.6	184.2	159.0	162.0	166.9	172
50th	108	110	112	113	114	114	114	61	62	64	65
90th	123	124	126	128	129	130	130	75	76	78	79
95th	127	129	131	132	134	135	135	78	79	81	83
95th + 12 mmHg	139	141	143	144	146	147	147	90	91	93	95
16 years											
Height (in)	63.8	64.9	66.8	68.8	70.7	72.4	73.4	63.8	64.9	66.8	68.

Height (cm)	162.1	165.0	169.6	174.6	179.5	183.8	186.4	162.1	165.0	169.6	174
50th	111	112	114	115	115	116	116	63	64	66	67
90th	126	127	128	129	131	131	132	77	78	79	80
95th	130	131	133	134	135	136	137	80	81	83	84
95th + 12 mmHg	142	143	145	146	147	148	149	92	93	95	96
17 years											
Height (in)	64.5	65.5	67.3	69.2	71.1	72.8	73.8	64.5	65.5	67.3	69.
Height (cm)	163.8	166.5	170.9	175.8	180.7	184.9	187.5	163.8	166.5	170.9	175
50th	114	115	116	117	117	118	118	65	66	67	68
90th	128	129	130	131	132	133	134	78	79	80	81
95th	132	133	134	135	137	138	138	81	82	84	85
95th + 12 mmHg	144	145	146	147	149	150	150	93	94	96	97

The 50th, 90th, and 95th percentiles were derived by using quantile regression on the basis of normal-weight children (BMI <85th percentile). BP stages are defined as elevated BP ≥90th percentile but <95th percentile; stage 1 HTN: ≥95th percentile or 130/80 to 139/89 mmHg; and stage 2 HTN: ≥95th percentile + 12 mmHg or >140/90 mmHg.

BMI: body mass index; BP: blood pressure; HTN: hypertension.

Graphic 63856 Version 20.0

Blood pressure levels for females by age and height percentile

BP (percentile)	Systolic BP (mmHg)							Diastolic BP			
	Height percentile or measured height							Height percentile or			
	5%	10%	25%	50%	75%	90%	95%	5%	10%	25%	50%
1 year											
Height (in)	29.7	30.2	30.9	31.8	32.7	33.4	33.9	29.7	30.2	30.9	31.8
Height (cm)	75.4	76.6	78.6	80.8	83.0	84.9	86.1	75.4	76.6	78.6	80.8
50th	84	85	86	86	87	88	88	41	42	42	43
90th	98	99	99	100	101	102	102	54	55	56	56
95th	101	102	102	103	104	105	105	59	59	60	60
95th + 12 mmHg	113	114	114	115	116	117	117	71	71	72	72
2 years											
Height (in)	33.4	34.0	34.9	35.9	36.9	37.8	38.4	33.4	34.0	34.9	35.9
Height (cm)	84.9	86.3	88.6	91.1	93.7	96.0	97.4	84.9	86.3	88.6	91.1
50th	87	87	88	89	90	91	91	45	46	47	48
90th	101	101	102	103	104	105	106	58	58	59	60
95th	104	105	106	106	107	108	109	62	63	63	64
95th + 12 mmHg	116	117	118	118	119	120	121	74	75	75	76
3 years											
Height (in)	35.8	36.4	37.3	38.4	39.6	40.6	41.2	35.8	36.4	37.3	38.4
Height (cm)	91.0	92.4	94.9	97.6	100.5	103.1	104.6	91.0	92.4	94.9	97.6
50th	88	89	89	90	91	92	93	48	48	49	50
90th	102	103	104	104	105	106	107	60	61	61	62
95th	106	106	107	108	109	110	110	64	65	65	66
95th + 12 mmHg	118	118	119	120	121	122	122	76	77	77	78
4 years											
Height (in)	38.3	38.9	39.9	41.1	42.4	43.5	44.2	38.3	38.9	39.9	41.1

Height (cm)	97.2	98.8	101.4	104.5	107.6	110.5	112.2	97.2	98.8	101.4	104
50th	89	90	91	92	93	94	94	50	51	51	53
90th	103	104	105	106	107	108	108	62	63	64	65
95th	107	108	109	109	110	111	112	66	67	68	69
95th + 12 mmHg	119	120	121	121	122	123	124	78	79	80	81
5 years											
Height (in)	40.8	41.5	42.6	43.9	45.2	46.5	47.3	40.8	41.5	42.6	43.
Height (cm)	103.6	105.3	108.2	111.5	114.9	118.1	120.0	103.6	105.3	108.2	111
50th	90	91	92	93	94	95	96	52	52	53	55
90th	104	105	106	107	108	109	110	64	65	66	67
95th	108	109	109	110	111	112	113	68	69	70	71
95th + 12 mmHg	120	121	121	122	123	124	125	80	81	82	83
6 years											
Height (in)	43.3	44.0	45.2	46.6	48.1	49.4	50.3	43.3	44.0	45.2	46.
Height (cm)	110.0	111.8	114.9	118.4	122.1	125.6	127.7	110.0	111.8	114.9	118
50th	92	92	93	94	96	97	97	54	54	55	56
90th	105	106	107	108	109	110	111	67	67	68	69
95th	109	109	110	111	112	113	114	70	71	72	72
95th + 12 mmHg	121	121	122	123	124	125	126	82	83	84	84
7 years											
Height (in)	45.6	46.4	47.7	49.2	50.7	52.1	53.0	45.6	46.4	47.7	49.
Height (cm)	115.9	117.8	121.1	124.9	128.8	132.5	134.7	115.9	117.8	121.1	124
50th	92	93	94	95	97	98	99	55	55	56	57
90th	106	106	107	109	110	111	112	68	68	69	70
95th	109	110	111	112	113	114	115	72	72	73	73
95th + 12 mmHg	121	122	123	124	125	126	127	84	84	85	85
8 years											
Height (in)	47.6	48.4	49.8	51.4	53.0	54.5	55.5	47.6	48.4	49.8	51.

Height (cm)	121.0	123.0	126.5	130.6	134.7	138.5	140.9	121.0	123.0	126.5	130
50th	93	94	95	97	98	99	100	56	56	57	59
90th	107	107	108	110	111	112	113	69	70	71	72
95th	110	111	112	113	115	116	117	72	73	74	74
95th + 12 mmHg	122	123	124	125	127	128	129	84	85	86	86
9 years											
Height (in)	49.3	50.2	51.7	53.4	55.1	56.7	57.7	49.3	50.2	51.7	53.4
Height (cm)	125.3	127.6	131.3	135.6	140.1	144.1	146.6	125.3	127.6	131.3	135
50th	95	95	97	98	99	100	101	57	58	59	60
90th	108	108	109	111	112	113	114	71	71	72	73
95th	112	112	113	114	116	117	118	74	74	75	75
95th + 12 mmHg	124	124	125	126	128	129	130	86	86	87	87
10 years											
Height (in)	51.1	52.0	53.7	55.5	57.4	59.1	60.2	51.1	52.0	53.7	55.5
Height (cm)	129.7	132.2	136.3	141.0	145.8	150.2	152.8	129.7	132.2	136.3	141
50th	96	97	98	99	101	102	103	58	59	59	60
90th	109	110	111	112	113	115	116	72	73	73	73
95th	113	114	114	116	117	119	120	75	75	76	76
95th + 12 mmHg	125	126	126	128	129	131	132	87	87	88	88
11 years											
Height (in)	53.4	54.5	56.2	58.2	60.2	61.9	63.0	53.4	54.5	56.2	58.2
Height (cm)	135.6	138.3	142.8	147.8	152.8	157.3	160.0	135.6	138.3	142.8	147
50th	98	99	101	102	104	105	106	60	60	60	61
90th	111	112	113	114	116	118	120	74	74	74	74
95th	115	116	117	118	120	123	124	76	77	77	77
95th + 12 mmHg	127	128	129	130	132	135	136	88	89	89	89
12 years											
Height (in)	56.2	57.3	59.0	60.9	62.8	64.5	65.5	56.2	57.3	59.0	60.9

Height (cm)	142.8	145.5	149.9	154.8	159.6	163.8	166.4	142.8	145.5	149.9	154
50th	102	102	104	105	107	108	108	61	61	61	62
90th	114	115	116	118	120	122	122	75	75	75	75
95th	118	119	120	122	124	125	126	78	78	78	78
95th + 12 mmHg	130	131	132	134	136	137	138	90	90	90	90
13 years											
Height (in)	58.3	59.3	60.9	62.7	64.5	66.1	67.0	58.3	59.3	60.9	62.
Height (cm)	148.1	150.6	154.7	159.2	163.7	167.8	170.2	148.1	150.6	154.7	159
50th	104	105	106	107	108	108	109	62	62	63	64
90th	116	117	119	121	122	123	123	75	75	75	76
95th	121	122	123	124	126	126	127	79	79	79	79
95th + 12 mmHg	133	134	135	136	138	138	139	91	91	91	91
14 years											
Height (in)	59.3	60.2	61.8	63.5	65.2	66.8	67.7	59.3	60.2	61.8	63.
Height (cm)	150.6	153.0	156.9	161.3	165.7	169.7	172.1	150.6	153.0	156.9	161
50th	105	106	107	108	109	109	109	63	63	64	65
90th	118	118	120	122	123	123	123	76	76	76	76
95th	123	123	124	125	126	127	127	80	80	80	80
95th + 12 mmHg	135	135	136	137	138	139	139	92	92	92	92
15 years											
Height (in)	59.7	60.6	62.2	63.9	65.6	67.2	68.1	59.7	60.6	62.2	63.
Height (cm)	151.7	154.0	157.9	162.3	166.7	170.6	173.0	151.7	154.0	157.9	162
50th	105	106	107	108	109	109	109	64	64	64	65
90th	118	119	121	122	123	123	124	76	76	76	77
95th	124	124	125	126	127	127	128	80	80	80	81
95th + 12 mmHg	136	136	137	138	139	139	140	92	92	92	93
16 years											
Height (in)	59.9	60.8	62.4	64.1	65.8	67.3	68.3	59.9	60.8	62.4	64.

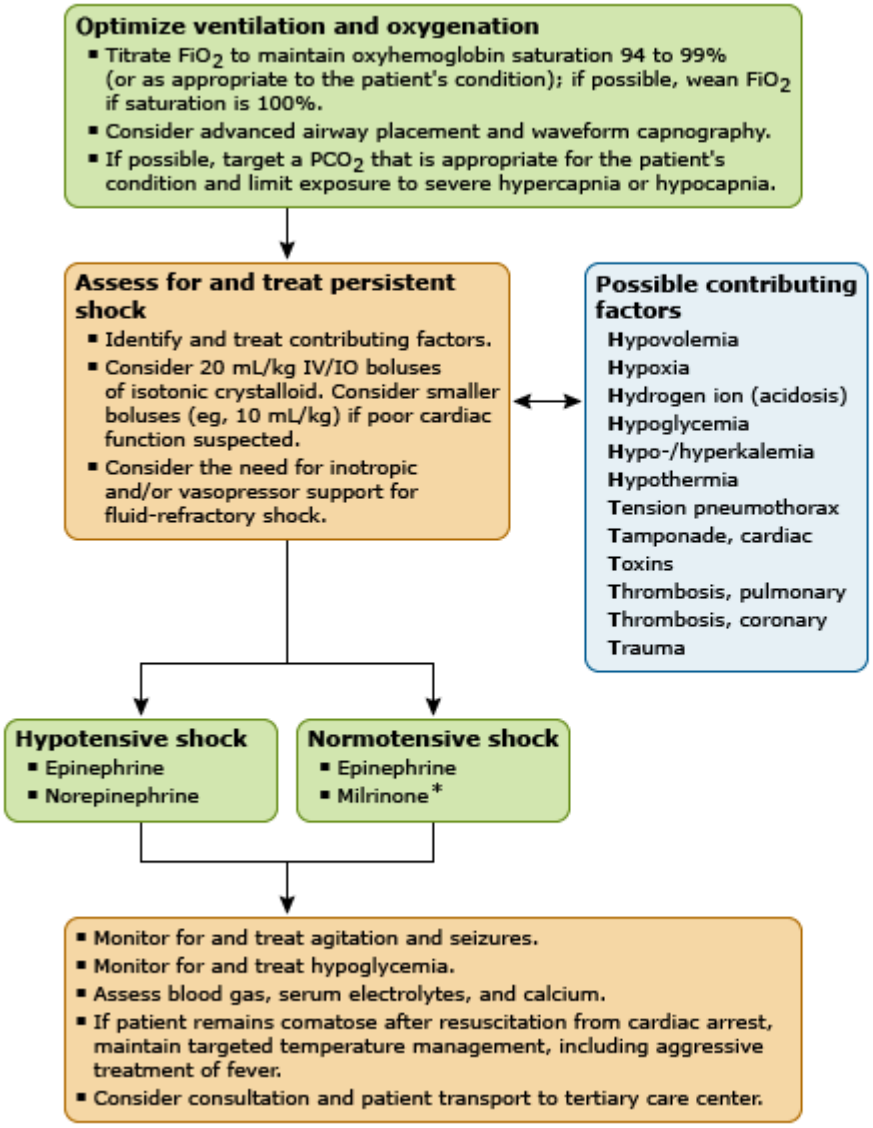
Height (cm)	152.1	154.5	158.4	162.8	167.1	171.1	173.4	152.1	154.5	158.4	162
50th	106	107	108	109	109	110	110	64	64	65	66
90th	119	120	122	123	124	124	124	76	76	76	77
95th	124	125	125	127	127	128	128	80	80	80	81
95th + 12 mmHg	136	137	137	139	139	140	140	92	92	92	93
17 years											
Height (in)	60.0	60.9	62.5	64.2	65.9	67.4	68.4	60.0	60.9	62.5	64.
Height (cm)	154.4	154.7	158.7	163.0	167.4	171.3	173.7	154.4	154.7	158.7	163
50th	107	108	109	110	110	110	111	64	64	65	66
90th	120	121	123	124	124	125	125	76	76	77	77
95th	125	125	126	127	128	128	128	80	80	80	81
95th + 12 mmHg	137	137	138	139	140	140	140	92	92	92	93

The 50th, 90th, and 95th percentiles were derived by using quantile regression on the basis of normal-weight children (BMI <85th percentile). BP stages are defined as elevated BP ≥90th percentile but <95th percentile; stage 1 HTN: ≥95th percentile or 130/80 to 139/89 mmHg; and stage 2 HTN: ≥95th percentile + 12 mmHg or >140/90 mmHg.

BMI: body mass index; BP: blood pressure; HTN: hypertension.

Graphic 52646 Version 19.0

Management of shock after return of spontaneous circulation in children



Estimation of maintenance fluid requirements

- **Infants <10 kg:** 4 mL/kg per hour.

  Example: For an 8 kg infant, estimated maintenance fluid rate
  = 4 mL/kg per hour × 8 kg
  = 32 mL per hour

- **Children 10 to 20 kg:** 4 mL/kg per hour for the first 10 kg + 2 mL/kg per hour for each kg above 10 kg.

  Example: For a 15 kg child, estimated maintenance fluid rate
  = (4 mL/kg per hour × 10 kg)
  + (2 mL/kg per hour × 5 kg)
  = 40 mL/hour + 10 mL/hour
  = 50 mL/hour

- **Children >20 kg:** 4 mL/kg per hour for the first 10 kg + 2 mL/kg per hour for 11 to 20 kg + 1 mL/kg per hour for each kg above 20 kg.

  Example: For a 28 kg child, estimated maintenance fluid rate
  = (4 mL/kg per hour × 10 kg)
  + (2 mL/kg per hour × 10 kg)
  + (1 mL/kg per hour × 8 kg)
  = 40 mL per hour + 20 mL per hour
  + 8 mL per hour
  = 68 mL per hour

After initial stabilization, adjust the rate and composition of intravenous fluids based on the patient's clinical condition and state of hydration. In general, provide a continuous infusion of a dextrose-containing solution for infants. Avoid hypotonic solutions in critically ill children; for most patients use isotonic fluid such as normal saline (0.9% NaCl) or lactated Ringer's solution with or without dextrose, based on the child's clinical status.

FiO_2: fraction of inspired oxygen; ICU: intensive care unit; IO: intraosseous; IV: intravenous; PCO_2: partial pressure of carbon dioxide.

* Milrinone can cause hypotension. The use of milrinone is generally reserved for a pediatric intensivist or clinician with similar experience and expertise.

Graphic 140375 Version 2.0

Initial shock management in children in settings with access to ICU care


Clinical signs of shock present (2 or more):
Diminished peripheral pulses
Cool, pale, or mottled skin
Altered mental status
Tachycardia or bradycardia
Provide supplemental oxygen, as needed, to avoid hypoxemia
Identify and treat life-threatening conditions:
Arrhythmia
Obstructive shock caused by tension pneumothorax, hemothorax, or cardiac tamponade
Anaphylaxis
Initiate continuous monitoring of HR, BP, and pulse oximetry
Treat respiratory failure with HFNC, NIV, or mechanical ventilation as needed*
Within 5 minutes, obtain venous access:
Preferred: two peripheral IVs of largest caliber that can be reliably inserted
If peripheral access not achieved: place IO cannula or central venous line
Obtain bedside glucose and laboratory studies (refer to inset)¶
If no signs of fluid overload, give IV or IO fluid resuscitation with balanced crystalloid solution (eg, Ringer's lactate) or normal saline as follows:Δ
Hypotensive shock: 20 mL/kg over 5 to 10 minutes
Compensated shock: 10 to 20 mL/kg over 5 to 20 minutes
Identify need for and give time-sensitive treatment based upon underlying condition:
Blood transfusion for hemorrhage
Empiric antimicrobial therapy for septic shock
Dextrose infusion for hypoglycemia
Prostaglandin E1 for ductal-dependent congenital heart disease
Systemic corticosteroids for adrenal insufficiency
Treatment of electrolyte abnormalities (eg, hyperkalemia, hypokalemia, or hypocalcemia)
Evaluate clinical targets; are all of the following present?
BP >5th percentile
Strong central and distal pulses
Warm skin with capillary refill <2 seconds
Alert mental status
Urine output 1 mL/kg or greater after circulating volume is restored
Yes
No
Continue monitoring
Treat underlying condition
Admit to appropriate inpatient setting
Signs of fluid overload (one or more of the following):
Pulmonary rales
Worsening respiratory distress with new or worsening oxygen requirement
Gallop rhythm
Jugular venous distension
Hepatomegaly
Cardiomegaly or pulmonary edema on bedside US or chest radiograph
Yes
No
Probable cardiogenic shock:
Evaluate cardiac function (bedside US, ECHO◇, and pediatric cardiology consultation)
If indicated, give smaller fluid boluses over a longer period of time (eg, 5 to 10 mL/kg over 15 to 30 minutes)§
Start vasoactive therapy¥
For persistent signs of shock, repeat 10 to 20 mL/kg f
up to 60 mL/kg within the first hour
Evaluate clinical targets after each bolus
Signs of shock persist
Re-evaluate presumed cause of shock
For suspected hemorrhagic shock, evaluate for source of bleeding and give blood products
For suspected hypovolemic shock, re-estimate fluid losses and continue fluid replacement
For patients with suspected distributive shock, start vasoactive agents¥
Obtain consultation with a pediatric critical care specialist and arrange transfer to a pediatric ICU
Inset: Initial laboratory stud
All patients:
Rapid blood glucose
Complete blood count with d
Serum electrolytes
Venous or arterial blood gas
Blood lactate
Blood urea nitrogen and seru
Urine dipstick
Septic shock suspected:
Serum total bilirubin
Alanine aminotransferase
Ionized blood calcium
PT and INR
PTT
Fibrinogen and D-dimer
Blood culture
Other cultures as indicated b
Diagnostic serologic testing a
Inflammatory biomarkers (e
Urinalysis
Urine culture
Hemorrhagic shock suspected:
Type and cross-match
PT and INR
PTT
Additional studies based upo
(refer to UpToDate content o
Other studies:
ECG (arrhythmia or signs of
Bedside US (suspected obstr
Pediatric cardiology specialis
Chest radiograph for patients
60 mL/kg of isotonic fluid ad
Two-view abdominal radiogra
suggest possible perforation

ICU: intensive care unit; HR: heart rate; BP: blood pressure; HFNC: high-flow oxygen by nasal cannula; NIV: noninvasive ventilation; IV: intravenous; IO: intraosseous; US: ultrasound; ECHO: echocardiography; PT: prothrombin time; INR: international normalized ratio; PTT partial thromboplastin time; ECG: electrocardiography; e-FAST: extended focused assessment with sonography for trauma.

* A trial of HFNC or NIV, such as continuous positive airway pressure ventilation or bi-level positive airway pressure ventilation, may avoid the need for endotracheal intubation in selected patients. Patients with hemodynamic instability should receive appropriate interventions to treat shock prior to or during intubation. Refer to UpToDate content on HFNC, NIV, and rapid sequence intubation in children.

¶ Ancillary studies are determined by patient presentation and suspected type or types of shock present. Other laboratory and ancillary studies may also be indicated based upon the suspected underlying condition that is causing shock.

Δ Fluid volume should be calculated based upon ideal body weight (eg, 50^{th} percentile for age).

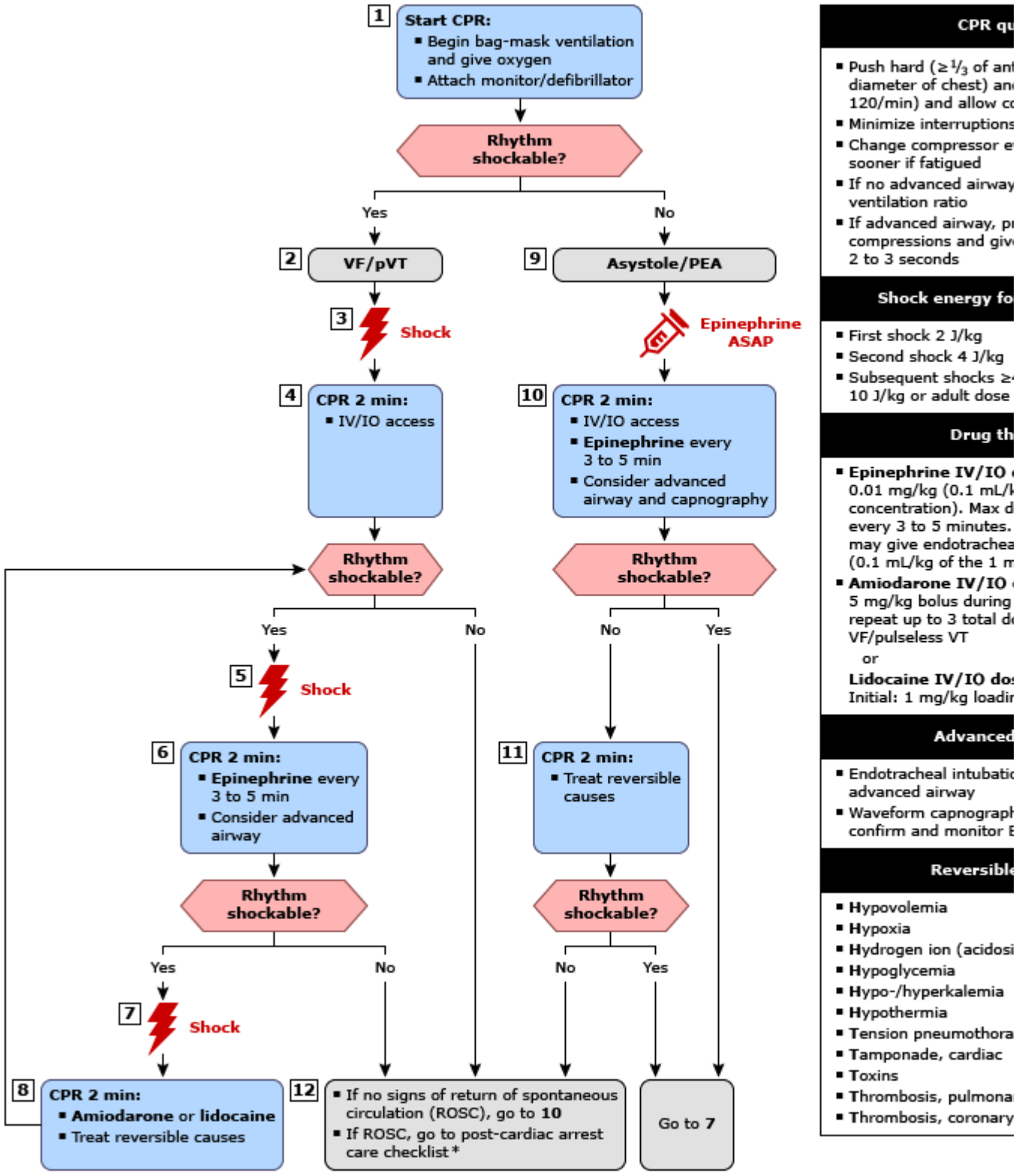
◇ When performed by trained and experienced physicians, bedside ECHO can provide rapid evidence of myocardial dysfunction, including dysfunction due to obstructive shock.

§ Patients with signs of fluid overload who continue to receive fluid boluses warrant close monitoring for respiratory and cardiac failure. The clinician should have a low threshold for endotracheal intubation and mechanical ventilation to treat pulmonary edema in these patients.

¥ Suggested vasoactive therapy depends upon type of shock and clinical findings; refer to UpToDate topics and graphics on management of shock in children.

Graphic 129655 Version 1.0

Pediatric cardiac arrest algorithm 2020 update



CPR: cardiopulmonary resuscitation; VF: ventricular fibrillation; pVT: pulseless ventricular tachycardia; PEA: pulseless electrical activity; IV: intravenous; IO: intraosseous; ROSC: return of spontaneous circulation; ET: endotracheal.

* If ROSC, go to post-cardiac arrest care checklist. The post-cardiac arrest care checklist can be found here.

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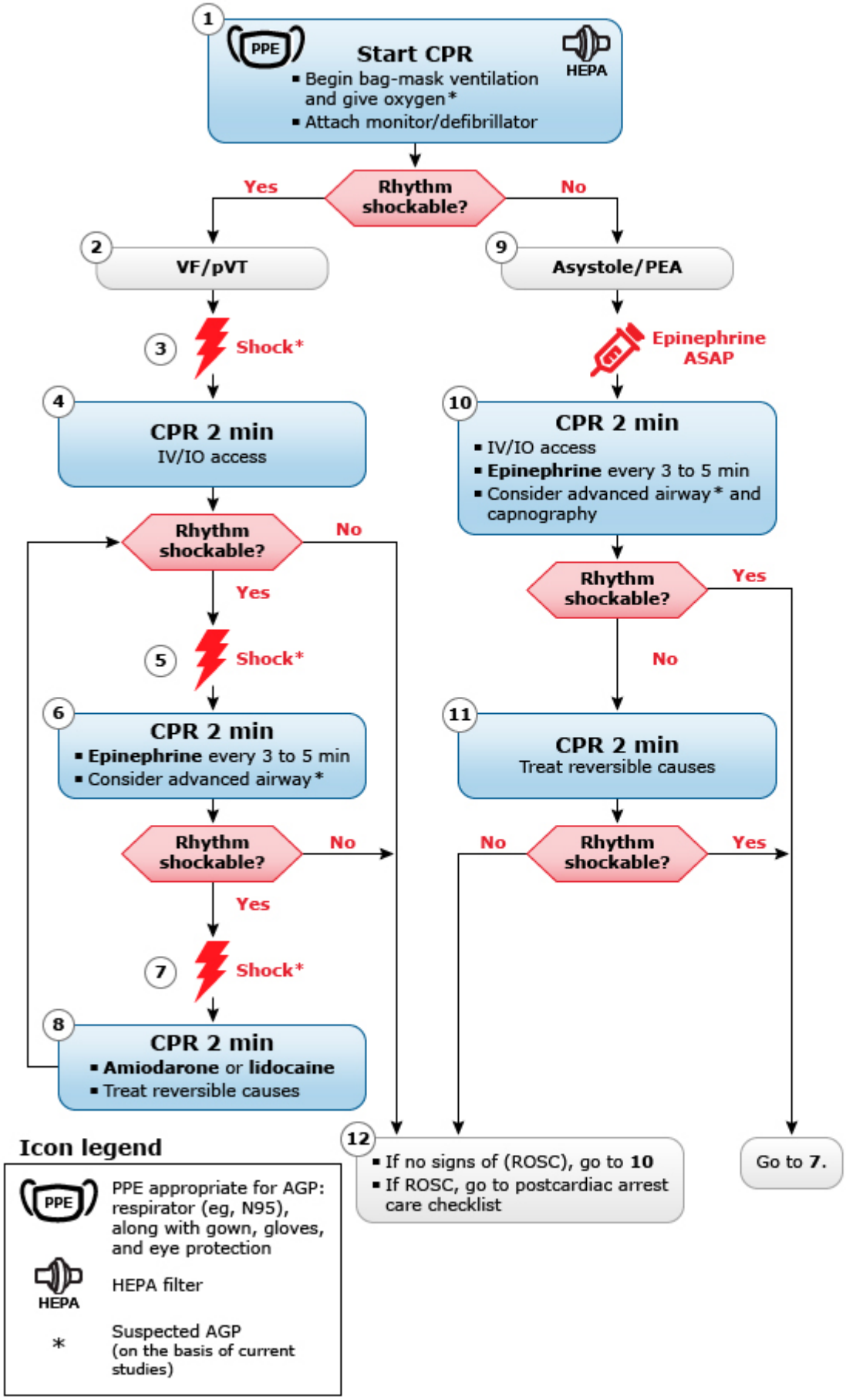
Graphic 129942 Version 10.0

Pediatric cardiac arrest algorithm for suspected or confirmed COVID-19 patients



CPR quality

- Push hard (≥⅓ of ant diameter of chest) an (100-120/min) and all chest recoil
- Minimize interruptions compressions
- Change compressor e 2 minutes, or sooner i
- If no advanced airway 15:2 compression-ver
- If advanced airway, p continuous compressi give a breath every 2-

Shock energy for de

- First shock 2 J/kg
- Second shock 4 J/kg
- Subsequent shocks ≥ maximum 10 J/kg or

Drug therapy

- **Epinephrine IV/IO** 0.01 mg/kg (0.1 mL/k 0.1 mg/mL concentrat Max dose 1 mg. Repeat every 3 to 5 m If no IV/IO access, ma endotracheal dose: 0. (0.1 mL/kg of the 1 m concentration).
- **Amiodarone IV/IO** 5 mg/kg bolus during May repeat up to 3 tot refractory VF/pulseles

  or

  Lidocaine IV/IO dos Initial: 1 mg/kg loadin

Advanced airway

- **Rapidly apply PPE b**
- Provide endotracheal i or supraglottic advanc
- Perform waveform cap or capnometry to conf monitor ET tube place
- **For all ventilation, u filter.**

Reversible causes

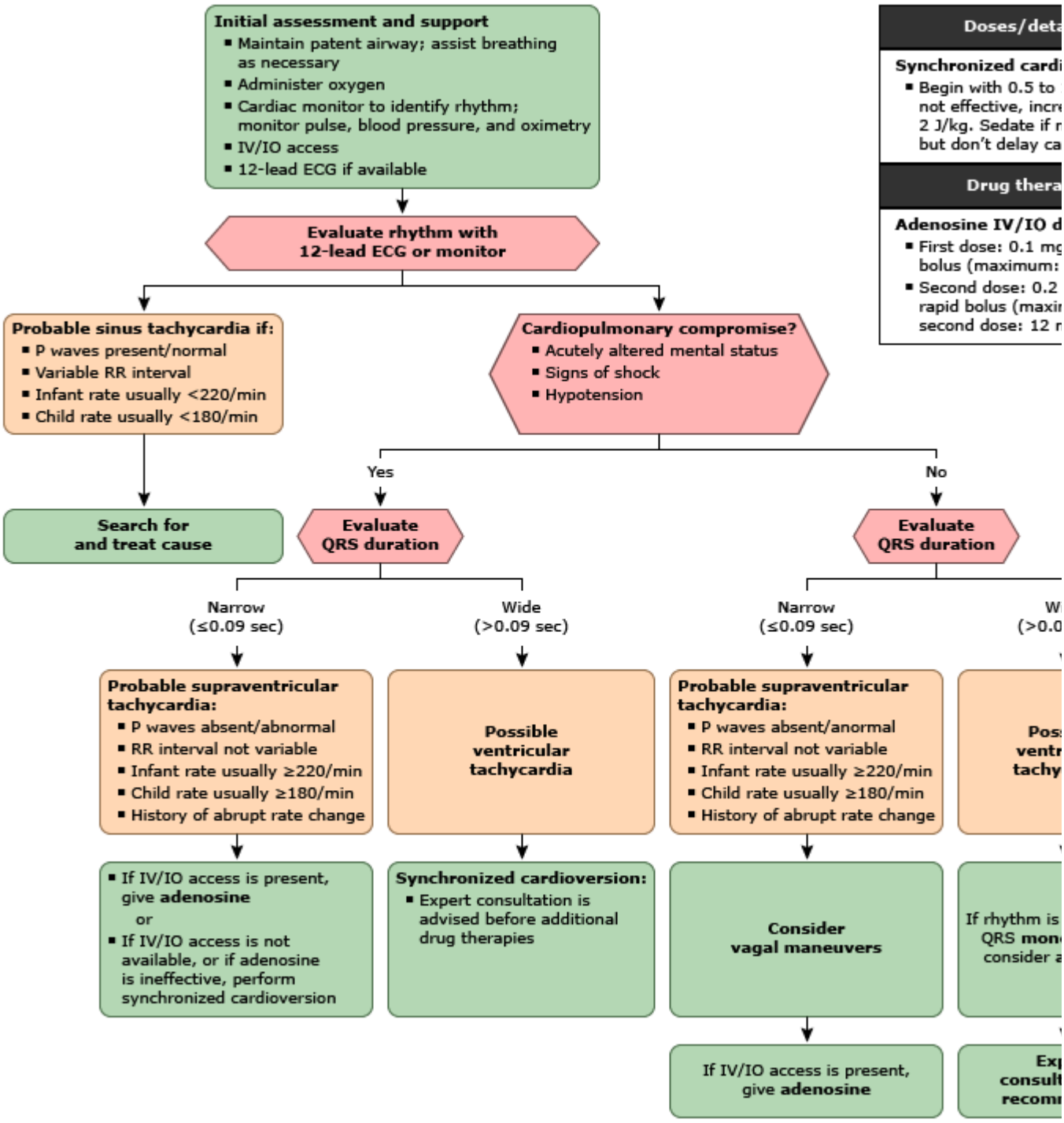
- **Hypovolemia**
- **Hypoxia**
- **Hydrogen ion (acidosi**
- **Hypoglycemia**
- **Hypo-/hyperkalemia**
- **Hypothermia**
- **Tension pneumothora**
- **Tamponade, cardiac**
- **Toxins**
- **Thrombosis, pulmona**
- **Thrombosis, coronary**

Pediatric cardiac arrest algorithm for patients with suspected or confirmed COVID-19.

PPE: personal protective equipment; CPR: cardiopulmonary resuscitation; HEPA: high efficiency particulate air; VF: ventricular fibrillation; pVT: pulseless ventricular tachycardia; PEA: pulseless electrical activity; IV: intravenous; IO: intraosseous; ROSC: return of spontaneous circulation; AGP: aerosol-generating procedure; ET: endotracheal.

Graphic 127842 Version 11.0

Pediatric tachycardia with a pulse 2020 update



IV: intravenous; IO: intraosseous; ECG: electrocardiogram; J/kg: joules per kilogram.

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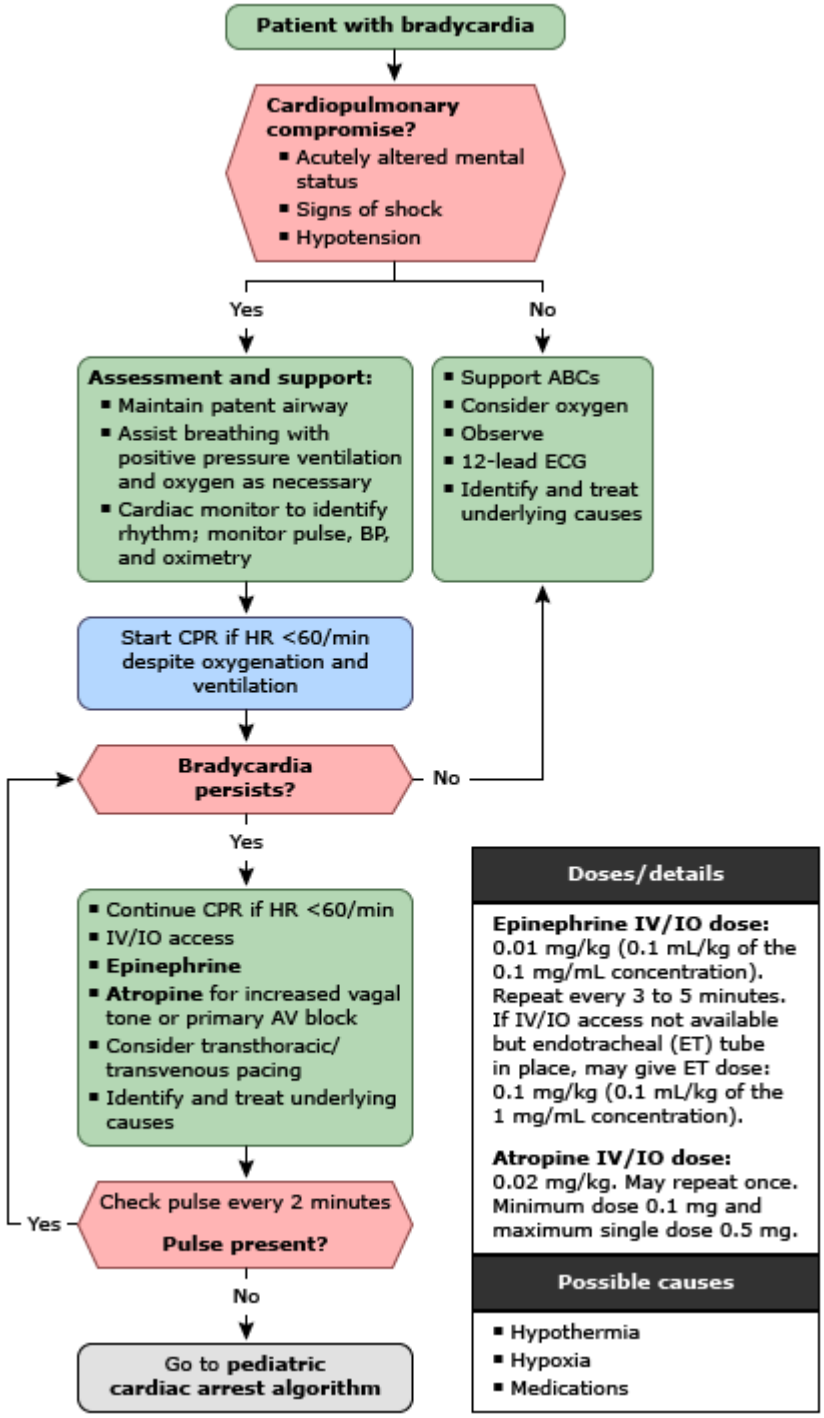
Graphic 129940 Version 10.0

Pediatric bradycardia with a pulse 2020 update



BP: blood pressure; ABCs: airway, breathing, circulation; ECG: electrocardiogram; CPR: cardiopulmonary resuscitation; HR: heart rate; IV: intravenous; IO: intraosseous; AV: atrioventricular; ET: endotracheal.

Graphic 129941 Version 9.0

Hypoglycemia in adolescents and children (other than neonates): Rapid overview of emergency management

Clinical features

Any patient with acute lethargy or coma should have an immediate measurement of blood glucose to determine if hypoglycemia is a possible cause.

Other findings of hypoglycemia are nonspecific* and vary by age:

Infants	Older children and adolescents	
▪ Irritability ▪ Lethargy ▪ Jitteriness ▪ Feeding problems ▪ Hypothermia ▪ Hypotonia ▪ Tachypnea ▪ Cyanosis ▪ Apnea ▪ Seizures	▪ Neurogenic (autonomic) response: • Sweating • Tachycardia • Palpitations • Tremor • Nervousness • Hunger • Paresthesias • Pallor	▪ Neuroglycopenic response: • Irritability • Confusion • Uncharacteristic behavio • Weakness • Lethargy • Loss of consciousness • Seizures • Coma • Occasionally, transient focal neurologic deficits

Diagnosis

- Obtain rapid bedside point-of-care glucose concentration (and beta-hydroxybutyrate, if available as a point-of-care measurement).
- Confirm the presence of hypoglycemia with a plasma glucose measurement (drawn close in time to the point-of-care sample).
- Treat, as outlined below, if the bedside value is low (<70 mg/dL [3.89 mmol/L]) in symptomatic patients.
- For all infants and young children who are not being treated for diabetes mellitus or do not have a known cause for hypoglycemia, obtain a blood sample for additional diagnostic studies prior to glucose administration, if possible, and collect the first voided urine after the hypoglycemic event¶.

Treatment

- **Do not delay** treatment if symptomatic hypoglycemia is suspected. However, every reasonable effort should be made to obtain a rapid plasma glucose measurement (fingerstick or point-of-care device) **prior** to administering glucose.
- **Give glucose based on the patient's level of consciousness and ability to swallow safely (ie, alert enough to do so and with intact gag reflex), as follows:**
  - **Conscious and able to drink and swallow safely:**

    Administer 0.3 g/kg (10 to 20 g) of a rapidly absorbed carbohydrate. May repeat in 10 to 15 minutes.

    Options include any 1 of the following:
    - Glucose tablets (5 g per tablet)

- Glucose gel (15 g per tube)
- Sweetened fruit juice – 12 g carbohydrate per 4 oz (120 mL)
- Regular soda (not diet) – 18 g carbohydrate per 6 oz (180 mL)
- Honey – 17 g carbohydrate per 1 tablespoon (15 mL)
- Table sugar (granulated sugar) – 12.5 g sugar per 1 tablespoon

- **Altered mental status, unable to swallow, or does not respond to oral glucose administration within 15 minutes:**

  Give an initial IV bolus of glucose of 0.25 to 0.5 g/kg of dextrose (maximum single dose 25 g)[Δ]. The volume and concentration of glucose bolus is infused slowly at 2 to 3 mL per minute and based on age:

  - Infants and children up to 12 years – 2.5 to 5 mL/kg of D10W or 1 to 2 mL/kg of D25W. D10W is typically used in infants and children <5 years of age. (10% dextrose is 100 mg/mL; 25% dextrose is 250 mg/mL.)
  - Adolescents ≥12 years – 1 to 2 mL/kg of D25W.

- **Unable to receive oral glucose and unable to obtain IV access:**

  Give glucagon 0.5 mg (for <25 kg body weight) or 1 mg (for ≥25 kg body weight) IM or SC (maximum dose 1 mg)[◇]:

  - Perform blood glucose monitoring every 10 to 15 minutes as the effects of glucagon may be transient.
  - Establish vascular access as soon as possible; if unable to achieve access and hypoglycemia persists or is recurrent, ensure the airway is protected and, if not, secure it with rapid sequence intubation. Then, place a nasogastric tube and administer 0.2 to 0.25 g/kg dextrose using volume and concentration guidance for IV administration above.

- After initial hypoglycemia is reversed, provide additional glucose and treatment based on suspected etiology:
  - For patients with type 1 diabetes mellitus – Give a normal diet; initiate IV dextrose-containing fluids if intake is inadequate.
  - For patients with an underlying hypoglycemic disorder or with an unknown cause of hypoglycemia – Administer an IV infusion of dextrose 10%:
    - For infants, start with initial GIR of 5 to 6 mg/kg/minute.
    - For older children, start with GIR of 2 to 3 mg/kg/minute.
    - Calculation to convert target GIR to infusion rate:
      - Rate of dextrose infusion (mL/hr) = GIR (mg/kg/minute) × 6 × weight (kg) ÷ dextrose percentage of fluid (eg, 5 for D5W or 10 for D10W)
    - Titrate infusion to maintain plasma glucose in a safe and appropriate range (70 to 120 mg/dL [3.89 to 8.33 mmol/L]).
  - Patients who have ingested a long-acting hypoglycemia agent such as a sulfonylurea may require prolonged treatment until the effect wears off. Selected patients may also warrant treatment with octreotide. (Refer to UpToDate topic on sulfonylurea poisoning.)
- Measure a rapid plasma glucose 15 to 30 minutes after the initial IV glucose bolus, and then monitor every 30 to 60 minutes until stable (minimum of hours) to ensure that plasma glucose concentration is maintained in the normal range (>70 to 100 mg/dL [>3.89 to 5.55 mmol/L]).
- Obtain pediatric endocrinology consultation for patients with persistent hypoglycemia and for hypoglycemia of unknown cause.

- Obtain medical toxicology consultation for patients with ingestion of oral hypoglycemic agents b calling a regional poison control center§.
- Admit the following patients:
  - Cannot maintain normoglycemia with oral intake
  - Hypoglycemia of unknown cause
  - Ingestion of long-acting hypoglycemic agents
  - Recurrent hypoglycemia during the period of observation

D5W: 5% dextrose in water; D10W: 10% dextrose in water; D25W: 25% dextrose in water; D50W: 50% dextrose in water; GIR: glucose infusion rate; IM: intramuscular; IV: intravenous; SQ: subcutaneous.

* These findings may also occur in infants with sepsis, congenital heart disease, respiratory distress syndrome, intraventricular hemorrhage, and other metabolic disorders and in children and adolescents with a variety of underlying conditions.

¶ Specific laboratory studies to obtain in children include blood samples for glucose, insulin, C-peptide, beta-hydroxybutyrate, lactate (free flowing blood must be obtained without a tourniquet), plasma acylcarnitines, free fatty acids, growth hormone, and cortisol.

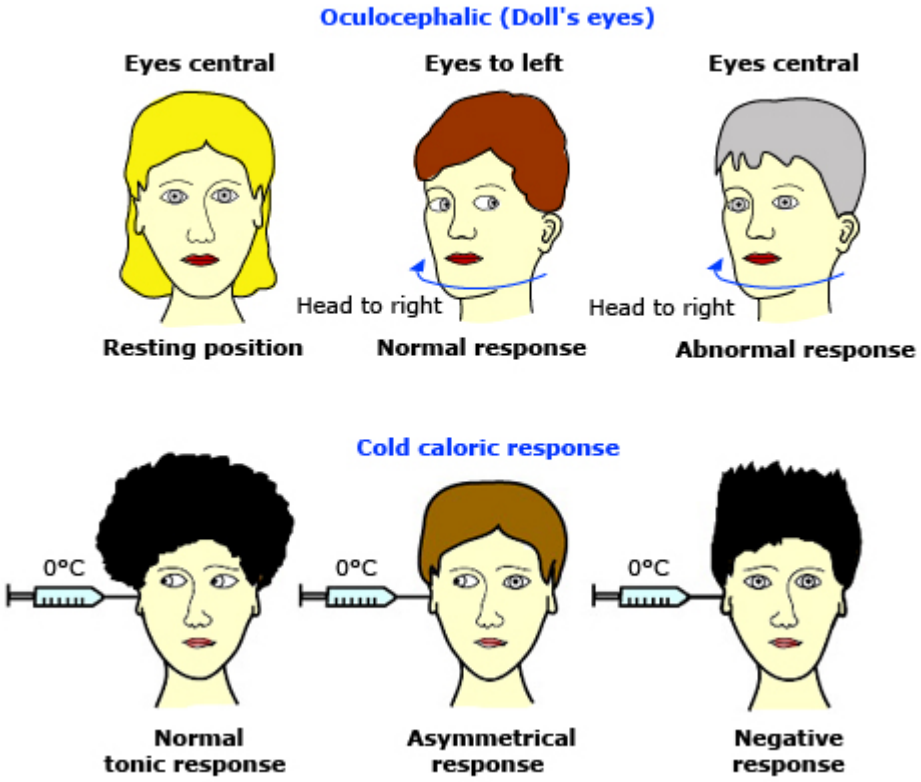
Δ Higher doses of glucose (eg, 0.5 to 1 g/kg [5 to 10 mL/kg of D10W **or** 2 to 4 mL/kg of D25W]) is recommended by the Pediatric Advanced Life Support course and may be needed to correct hypoglycemia caused by excess insulin administration or sulfonylurea ingestion. (For more detail, refer to UpToDate topic on sulfonylurea agent poisoning.)

◇ Glucagon will reverse hypoglycemia caused by excess endogenous or exogenous insulin and will not be effective in patients with inadequate glycogen stores (prolonged fasting) or ketotic hypoglycemia or those who are unable to mobilize glycogen (glycogen storage diseases). Of note, children may exhaust their glycogen stores in as little as 12 hours. Other conditions in which glycogen cannot be effectively mobilized include ethanol intoxication in children, adrenal insufficiency, and certain inborn errors of metabolism (eg, a disorder of glycogen synthesis and glycogen storage diseases).

§ To access a regional poison control center in the United States, call 1-800-222-1222. Contact information for poison centers around the world is available online.

Graphic 83485 Version 9.0

Oculocephalic and caloric response



- **Oculocephalic (doll's eyes) response:** This test should not be performed if a cervical spine injury is suspected. Observe the motion of the eyes while passively moving the head. In a comatose patient, conjugate movement of the eyes in the direction opposite to the head movement is expected. An absent or asymmetric response in an unconscious patient implies brainstem dysfunction.
- **Caloric response:** After visually checking that the tympanic membrane is intact, ice cold water is used to irrigate the ear canal and should produce a slow conjugate deviation toward the irrigated side. An absent or asymmetric response indicates brainstem dysfunction. Intact eye deviation with nystagmus suggests that the patient may not be in coma.

Adapted from: Bateman DE. Neurologic assessment of coma. J Neurol Neurosurg Psychiatry 2001; 71 Suppl 1:13.

Graphic 61416 Version 7.0

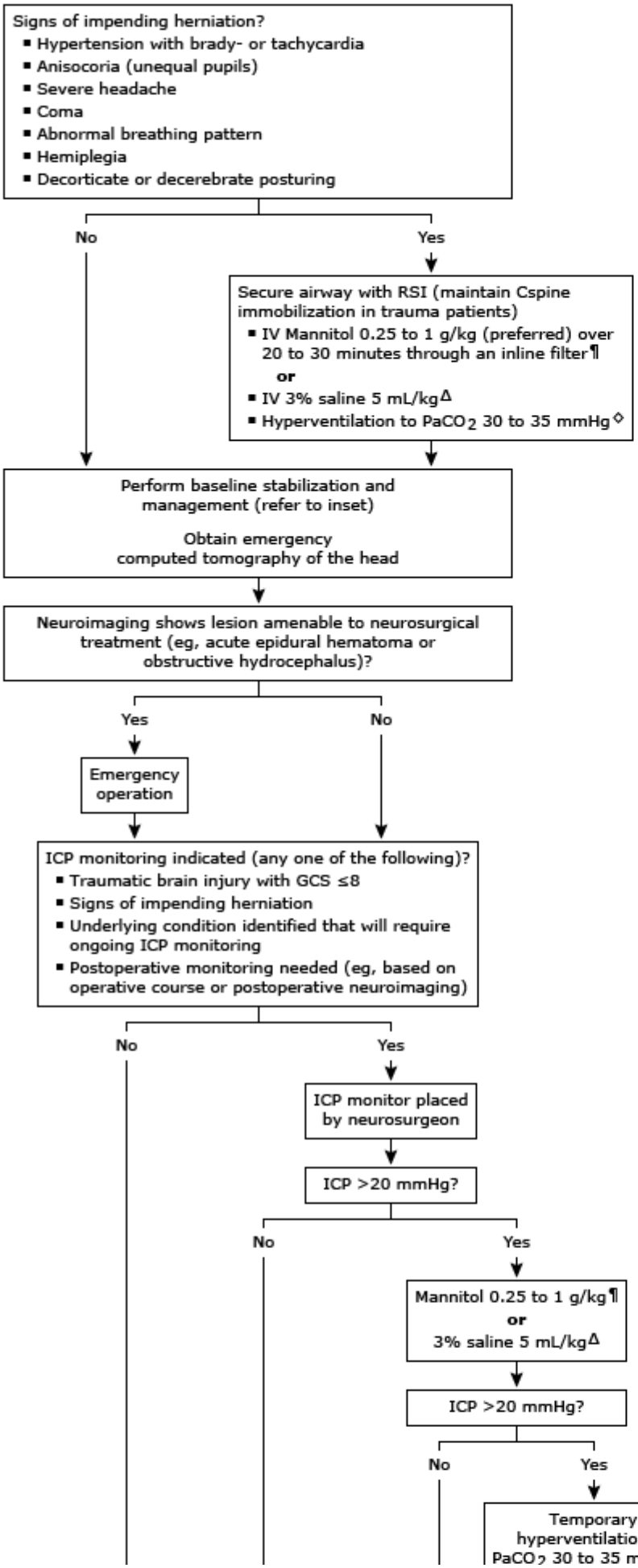
Clinical progression of transtentorial herniation

Headache
Altered level of consciousness
Dilation of ipsilateral pupil
Cranial nerve III palsy
Ptosis
Loss of medial gaze
Decerebrate posturing
Hemiparesis
Dilation of opposite pupil
Alteration of respiration
Bradycardia
Hypertension
Respiratory arrest

Graphic 70683 Version 2.0

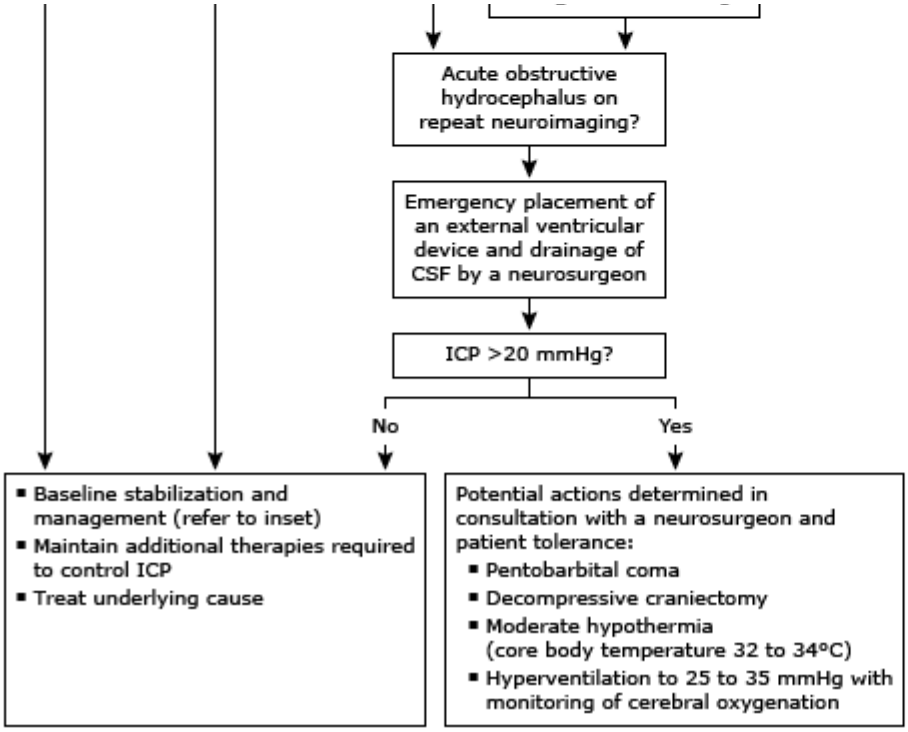
Treatment of acute brain herniation or symptomatic intracranial hypertension (ICP >20 mmHg [27 cm H_20]) in children*

Early involvement of a neurosurgeon should occur for all children with signs of herniation or symptomatic intracranial hypertension, whenever possible



Baseline stabilization and management

1. If not already performed for herniation, secu Cspine immobilization in trauma patients (re in children) in the following patients:
   - Refractory hypoxia
   - Hypoventilation
   - GCS ≤8 or <12 and rapidly declining
   - Loss of airway protective reflexes
2. Maintain normal oxygenation and blood pres For intubated patients, maintain $PaCO_2$ at 3 signs of herniation.
3. Elevate the head of the bed 15 to 30 degree
4. Maintain normal body temperature using an as needed
5. Administer dexamethasone 0.5 mg/kg (max 6 hours to patients with conditions causing v tumors, intracranial hematomas, cerebral ab nervous system infections (eg, meningitis or
6. Administer prophylactic anticonvulsants (eg, phenobarbital) to patients with severe traun skull fractures, or parenchymal abnormalitie
7. During mechanical ventilation, avoid high pe and end expiratory pressure (PEEP) as long are maintained
8. Provide sedation and analgesia with continu morphine
9. Maintain paralysis with a continuous infusion
10. Administer lidocaine 1 mg/kg, 3 to 5 minute endotracheal tube§



CSF: cerebrospinal fluid; GCS: Glasgow coma scale; ICP: intracranial pressure; IV: intravenous; $PaCO_2$: partial partial pressure of carbon dioxide; RSI: rapid sequence intubation.

* This algorithm is intended for children in whom increased ICP is diagnosed based upon neuroimaging or intracranial monitoring, or in whom it is strongly suspected based upon signs of brain herniation. Refer to UpToDate topics on elevated ICP in children.

¶ A large diuresis is expected with mannitol and may require normal saline boluses to prevent hypotension. Thus, placement of a urinary Foley catheter is suggested. Monitoring of serum osmolal gap is necessary to avoid complications. Refer to UpToDate topics on the management of elevated ICP in children.

Δ When administering 3% saline, the expected serum sodium rise is 1 mEq/L for every 1 mL/kg bolus, and 1 mEq/L/hour for every 1 mL/kg/hour of continuous infusion. Monitoring of serum sodium is necessary to avoid complications. Patients with a serum sodium level >160 mEq/L are unlikely to benefit from hypertonic saline administration. Refer to UpToDate topics on management of elevated ICP in children.

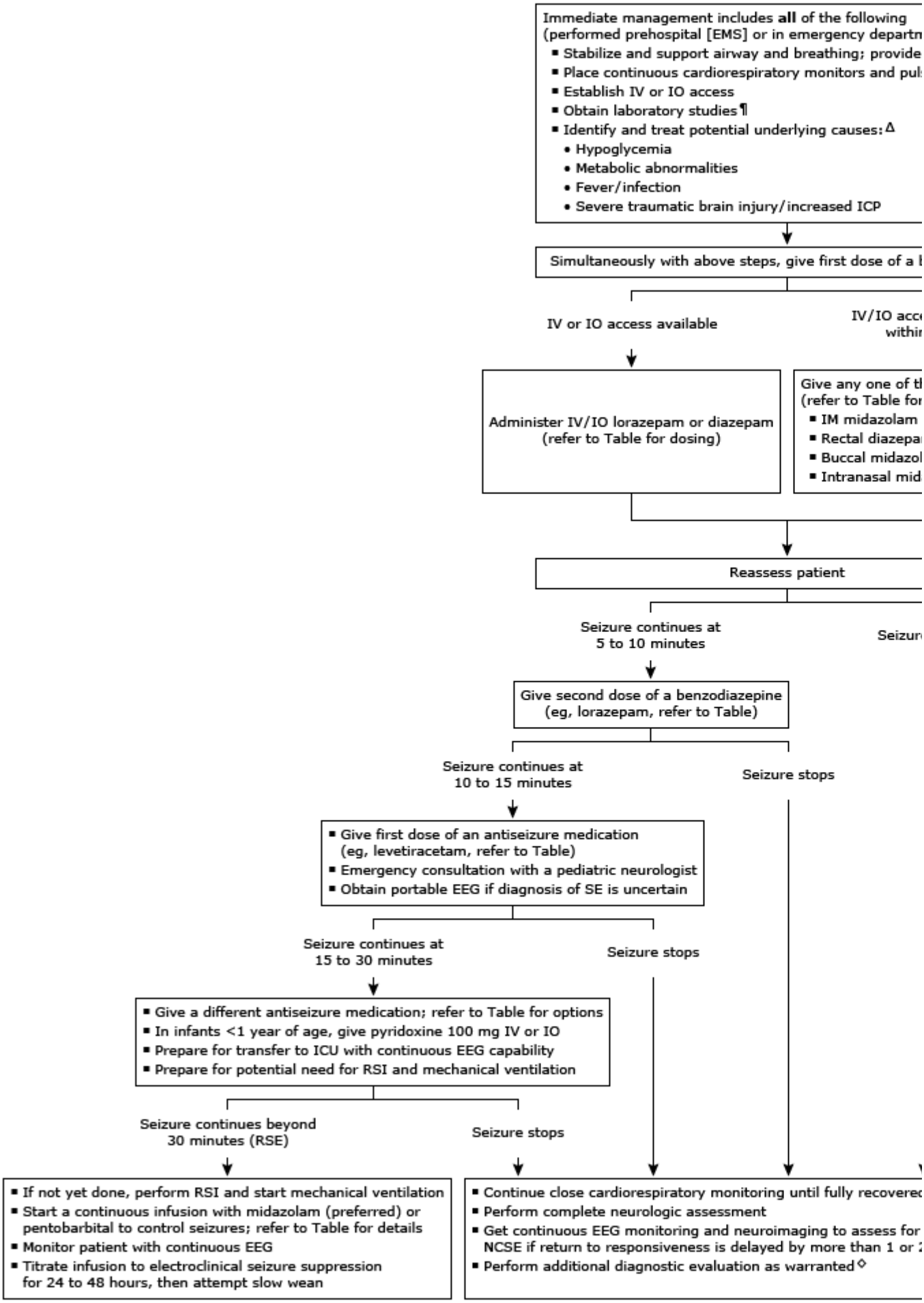
◇ Temporary therapeutic hyperventilation ($PaCO_2$ 30 to 35 mmHg) may be initiated under direction by a neurosurgeon for patients with signs of impending herniation in whom surgical intervention is planned. If used, avoid hyperventilation for longer than 2 hours.

§ Monitor total dose of lidocaine administered to avoid lidocaine toxicity.

Adapted from: Stevens RD, Shoykhet M, Cadena R. Emergency Neurological Life Support: Intracranial Hypertension and Herniation. Neurocrit Care 2015; 23 Suppl 2:S76.

Graphic 110947 Version 6.0

Approach to treatment of convulsive status epilepticus in children and adolescents



This algorithm summarizes our suggested approach to antiseizure treatment for convulsive status epilepticus (CSE) in children and adolescents. CSE is defined as a single unremitting seizure lasting >5 minutes or frequent clinical seizures without an interictal return to the baseline clinical state. Along

with immediate antiseizure therapy, children with CSE require simultaneous, rapid initiation of monitoring, including frequent core temperature measurement; supportive care of airway, breathing, and circulation; and rapid recognition and treatment of hypoglycemia and other potential underlying causes, such as complex febrile seizures, electrolyte disturbance, poisoning, central nervous system infection, sepsis, and traumatic brain injury. Refer to UpToDate topics on pediatric CSE for additional details.

EMS: emergency medical services; IV: intravenous; IO: intraosseous; ICP: intracranial pressure; IM: intramuscular; EEG: electroencephalogram; SE: status epilepticus; ICU: intensive care unit; RSI: rapid sequence endotracheal intubation; NCSE: nonconvulsive status epilepticus; RSE: refractory status epilepticus; PE: phenytoin equivalents.

* Rapid sequence intubation should be performed if airway, ventilation, or oxygenation cannot be maintained, or if the seizure becomes prolonged.

¶ For ancillary studies to obtain in children with status epilepticus, refer to UpToDate topics on status epilepticus in children.

Δ Common causes of pediatric CSE are listed here. If isoniazid poisoning is suspected, pyridoxine should be administered (70 mg/kg IV or IO; maximum 5 g). For further discussion of causes of CSE in children, refer to UpToDate's topic on pediatric CSE.

◇ Additional evaluation may include neuroimaging if CSE is the first presentation of epilepsy or if there are new focal neurologic findings, signs of head trauma, concern for increased ICP, or prolonged duration of depressed consciousness (ie, for >1 to 2 hours after the episode). For additional details regarding the diagnostic evaluation in children with CSE, refer to UpToDate topics on pediatric CSE.

§ Refer to text for dosing intranasal midazolam.

¥ Phenytoin and fosphenytoin may be less effective for the treatment of seizures due to toxins or drugs and may intensify seizures caused by cocaine, other local anesthetics, theophylline, or lindane. In such cases, levetiracetam, valproate, or phenobarbital should be used.

‡ With fosphenytoin administration, the rate of infusion should not exceed 2 mg PE/kg per minute (maximum rate: 150 mg PE per minute). If fosphenytoin is not available, IV phenytoin may be used (20 mg/kg IV; do not exceed 1 mg/kg per minute; maximum rate: 50 mg per minute). Both fosphenytoin and phenytoin require cardiac monitoring.

† When administering phenobarbital, the maximum infusion rate is 2 mg/kg per minute with a ceiling of 50 mg/min. Anticipate respiratory depression.

Graphic 131955 Version 1.0

Red flag injuries suggesting physical child abuse in infants and young children

Injury	Patient age			
	<6 months	6 to 12 months	1 year old	2 to 3 years old
Soft tissue injury	Frenulum tears or unexplained oral injuries (teeth, lips, palate)	Frenulum tears or unexplained oral injuries (teeth, lips, palate)	Frenulum tears or unexplained oral injuries (teeth, lips, palate)	Frenulum tears or unexplained oral injuries (teeth, lips, palate)
	Isolated subconjunctival hemorrhage outside of the newborn period			
	Any bruise	Unexplained bruises in non-cruising children		
		Bruises of the trunk, ear, neck, jawline, or cheek	Bruises of the trunk, ear, neck, jawline, or cheek	Bruises of the trunk, ear, neck, jawline, or cheek
		Patterned bruising	Patterned bruising	Patterned bruising
Burns	Unexplained burns	Unexplained burns	Unexplained burns	Unexplained burns
	Burns in the shape of a heated object	Burns in the shape of a heated object	Burns in the shape of a heated object	Burns in the shape of a heated object
	Immersion burns	Immersion burns	Immersion burns	Immersion burns
	Burns of the perineum **and** lower extremities	Burns of the perineum **and** lower extremities	Burns of the perineum **and** lower extremities	Burns of the perineum **and** lower extremities
Fractures	Multiple fractures in different stages of healing	Multiple fractures in different stages of healing	Multiple fractures in different stages of healing	Multiple fractures in different stage of healing
	Any fracture other than skull or clavicle fractures in the newborn period	**Any** fracture other than skull fracture Skull fractures without history or	**Any** rib fracture Humerus fracture, other than supracondylar	Fracture without traum history or presenting wit

		other than simple linear parietal type	Fractures of other long bones Fracture without trauma history or presenting with evidence of healing	evidence of healing
Intracranial	**Any** subdural hemorrhage/hygroma	**Any** subdural hemorrhage/hygroma	Unexplained subdural hematoma without history of high-energy trauma (eg, motor vehicle collision, long-distance fall)	
Visceral injury	**Any** visceral injury	**Any** visceral injury	Traumatic visceral injury unexplained by motor vehicle collision or verified history of accidental high-energy blow to the abdomen*	

In the absence of significant, independently verified trauma mechanisms like motor vehicle collisions, the listed injuries by age should prompt further evaluation for physical child abuse. Other injuries not listed may also warrant further investigation. Refer to UpToDate content on recognition of physical child abuse.

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* Proximal hollow-viscus and pancreatic injuries are more common in abuse than accidental trauma in young children and justify additional scrutiny of the given history.

Graphic 119441 Version 3.0

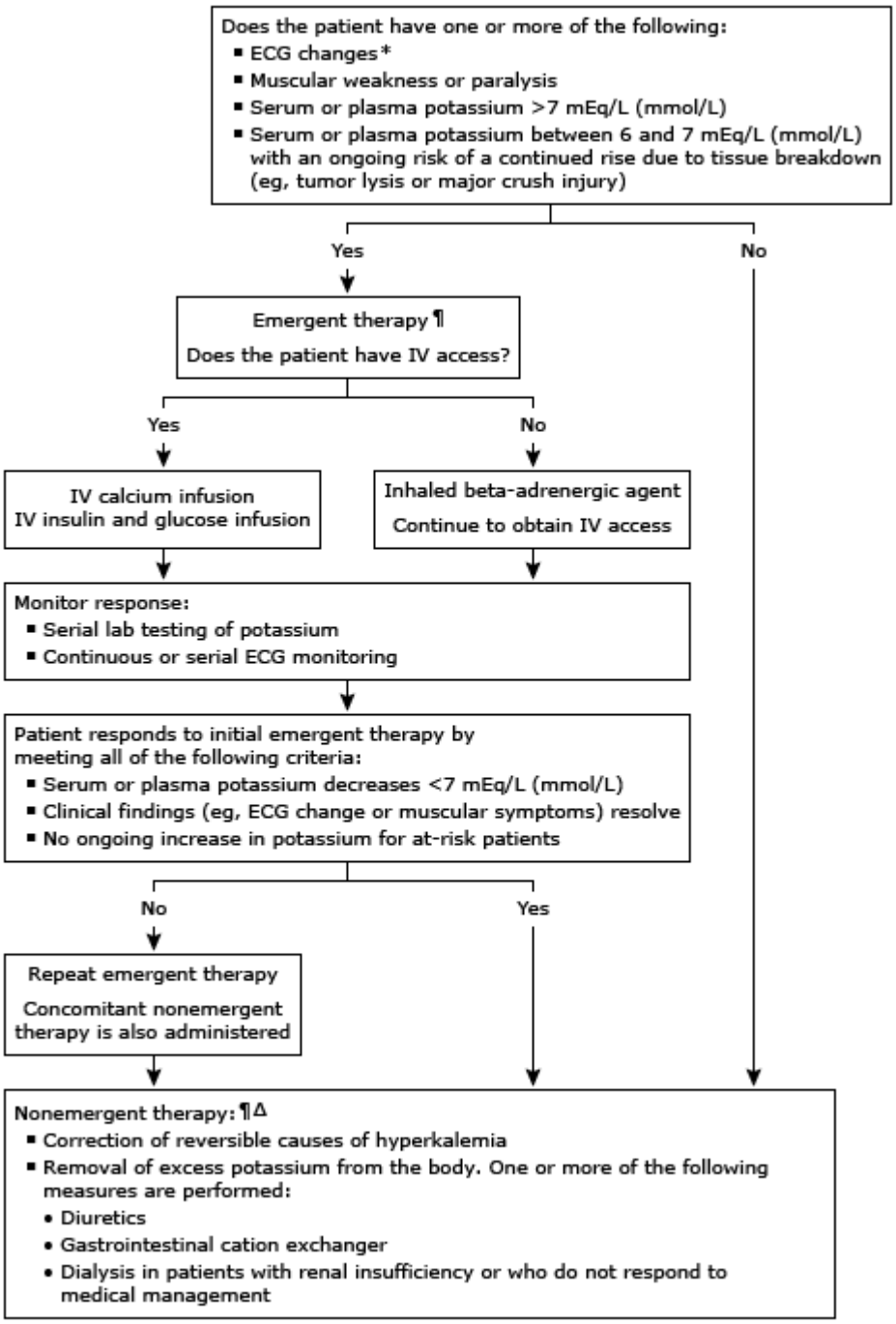
Red flag history for child physical abuse

▪ Caregiver offers no history or specifically denies history of trauma despite severe injury
▪ Implausible history for degree or type of injury*
▪ Unexplained or excessive delay in seeking care
▪ Injury attributed to in-home resuscitation efforts
▪ Caregiver histories that change with retelling or conflict with versions from other observers
▪ Severe injury explained as self-inflicted or blamed on other young children or pets

* Examples of implausible histories include major trauma attributed to a "fall down the stairs" or other short fall, such as a fall from a sitting position, or an injury mechanism that requires the child to have capability beyond his or her developmental level (eg, severe scald burns in a 12-month-old attributed to the patient "turning on the hot water faucet").

Graphic 109401 Version 4.0

Management of acute pediatric hyperkalemia



ECG: electrocardiogram; IV: intravenous.

* Electrocardiographic changes suggestive of hyperkalemia include widening of the QRS complex, loss of P waves, or arrhythmias, but not isolated peaked T waves.

¶ For details of therapy, please refer to UpToDate topics on the management of hyperkalemia in children.

Δ Nonemergent therapy given as adjunctive therapy to patients who receive emergent therapy and for patients with acute asymptomatic hyperkalemia with potassium levels <7 mEq/L not at risk for continued rise in potassium.

Graphic 111049 Version 1.0

Contributor Disclosures

Eric Fleegler, MD, MPH No relevant financial relationship(s) with ineligible companies to disclose. **Monica Kleinman, MD** Consultant/Advisory Boards: American Heart Association [Pediatric resuscitation]; International Liaison Committee on Resuscitation [Resuscitation]. All of the relevant financial relationships listed have been mitigated. **Susan B Torrey, MD** No relevant financial relationship(s) with ineligible companies to disclose. **James F Wiley, II, MD, MPH** No relevant financial relationship(s) with ineligible companies to disclose.

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