Emergency Neurological Life Support: Resuscitation Following Cardiac Arrest

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Abstract

Cardiac arrest is one of the most common causes of death in high-income nations. An organized bundle of neurocritical care can improve chances of survival and neurological recovery in patients resuscitated from cardiac arrest. Therefore, resuscitation following cardiac arrest was chosen as an Emergency Neurological Life Support (ENLS) protocol. Key aspects of successful post-arrest management include identification of treatable causes of arrest in need of emergent intervention, prevention of secondary brain injury, and timely neurological prognostication. Treatable precipitants of arrest that require emergent intervention include, but are not limited to, acute coronary syndrome, intracranial hemorrhage, pulmonary embolism, and major trauma. Secondary brain injury can be attenuated through targeted temperature management (TTM); avoidance of hypoxia and hypotension; avoidance of hyperoxia, hyperventilation or hypoventilation; and treatment of seizures. Accurate neurological prognostication is not possible for several days after cardiac arrest, so early aggressive care should not be limited based on perceived poor neurological prognosis.

Key words: Resuscitation, Cardiac Arrest, Targeted Temperature Management, Hypothermia

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1 Introduction

Cardiac arrest (CA) is the most common causes of death in both North America and throughout high-income nations.[1] In the United States (US), for example, more than 500,000 adult patients suffer a cardiac arrest each year.[2] With advances in care, rates of both return of spontaneous circulation (ROSC) and long-term survival with favorable neu- rological outcome continue to improve over time.[2] Among those who survive to hospital treatment after cardiac arrest, withdrawal of life-sustaining therapy, based on perceived neurological prognosis, is the most common proximate cause of death.[3]

2 Management Protocol

The ENLS algorithm for initial management following resuscitation from cardiac arrest is shown in Figure 1. Early priorities after ROSC are 1) to identify and treat the suspected cause of the arrest, and 2) to stabilize the patient's cardiopulmonary function to prevent re-arrest and provide adequate coronary and cerebral perfusion. Patients who achieve ROSC, and for whom goals of care support aggressive intervention should be rapidly evaluated for coronary intervention and targeted temperature management (TTM). Transfer to a specialty center that sees a high volume of patients after cardiac arrest and has experience in post-arrest cardiac and neurocritical care should be considered. Patients resuscitated from cardiac arrest typically require intubation, mechanical ventilation, close cardiac and invasive hemodynamic monitoring, and attentive general critical care. The implementation of structured pathways following cardiac arrest has improved neurologic outcomes for survivors of cardiac arrest.[4] Suggested items to complete within the first hour of resuscitation following cardiac arrest are shown in Table 1.

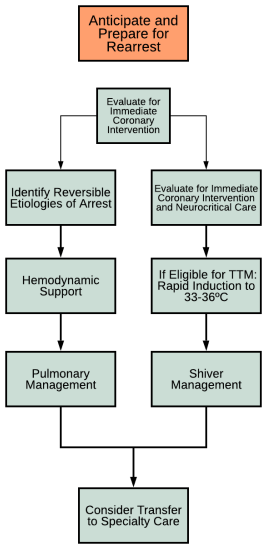

FIGURE 1
ENLS Resuscitation Following Cardiac Arrest protocol

TABLE 1
Resuscitation following cardiac arrest checklist for the first hour

Checklist
☐ Initiate hemodynamic and ventilatory support
☐ Assess for common treatable causes of arrest, consider coronary angiography
☐ Determine targeted temperature management goal and strategy
☐ Begin induction to target temperature
☐ Consider transfer to specialty center

3 Prehospital Care and Immediate Stabilization

Resuscitation from cardiac arrest should follow the American Heart Association (AHA) and/or International Liaison Committee on Resuscitation (ILCOR) guidelines.[5–7] Optimal cardiopulmonary resuscitation (CPR) including chest compressions of adequate rate and depth, few interruptions, and early defibrillation are all associated with faster ROSC and improved outcomes.[8] Further studies are needed to establish the best methods to prevent primary anoxic brain injury during and immediately after arrest.

There have been numerous excellent randomized controlled trials studying various aspects of prehospital cardiac arrest management,[9–14] most of which have been neutral and are beyond the scope of the ENLS curriculum to review in detail. Among patients that initially regain pulses after advanced cardiovascular life support (ACLS), re-arrest within minutes is common, occurring in about 1 in 5 cases.[7,15,16] Thus, providers should anticipate the potential for rearrest and cardiopulmonary instability in the immediate post-arrest period. Both hypotension and hypoxia are common and independently associated with worse outcomes.[17] During this immediate post-arrest phase, blood pressure and oxygenation goals should be chosen to maintain cerebral perfusion and prevent secondary brain injury (see Prevention of Secondary Brain Injury below). Intubation and mechanical ventilation, as well as volume resuscitation, inotropes and vasopressors may be needed to achieve physiologic targets. There is evidence of harm without increased benefit of secondary brain injury prevention when TTM induction is begun in the prehospital setting regardless of the temperature goal.[18,19] Other studies of prehospital TTM suggest it might be safe,[20,21] but there is insufficient evidence to recommend prehospital induction of TTM at this time.

4 Identification of Treatable Causes of Cardiac Arrest

During and immediately after a cardiac arrest, several parallel workflows are necessary to support successful resuscitation. Concurrently with CPR and stabilization, providers should diligently search for the underlying etiology of arrest. Initial diagnostic evaluation after ROSC should include a focused history, physical examination, electrocardiogram (EKG) and imaging as appropriate. Prioritization should be given to identifying those etiologies (such as myocardial infarction or pulmonary embolus) that require specific time-sensitive interventions beyond general resuscitative measures.

4.1 Cardiac Causes

Cardiac etiologies of arrest are decreasing over time and may cause only a minority of arrests in the population of patients that achieve ROSC and survive to hospital care.[22] However, cardiac diseases including acute coronary syndrome should remain the primary consideration in sudden cardiac arrest. Electrical arrhythmias due to electrolyte metabolic abnormalities and pulmonary embolism must also be considered. Acute coronary syndrome may result in myocardial infarction, which may cause malignant dysrhythmias and cardiac arrest. All patients with cardiac arrest should be evaluated for immediate coronary intervention with EKG and troponin evaluation, regardless of the primary rhythm associated with the arrest. Percutaneous coronary intervention is associated with improved neurological outcome.[23–25]

4.2 Neurologic causes

CT imaging of the brain is warranted in the post-arrest patient. Up to 5-10% of post-arrest patients demonstrate intracranial hemorrhage.[26–28] In addition to identifying potential causes of arrest, early brain imaging can have prognostic value as cerebral edema appreciated early after cardiac arrest strongly predicts poor outcomes.[26–28]

4.3 Other causes

Pulmonary embolism (PE) is a treatable cause of cardiac arrest and empiric treatment should be considered based on clinical suspicion.[29] Trauma (e.g. high cervical spine fracture after ground-level falls), gastrointestinal hemorrhage, toxic ingestion or overdose, tension pneumothorax, septic shock, and anaphylaxis are other possible etiologies of cardiac arrest that may require specific management.

4.4 Stabilization and Transfer

Post-arrest patients cared for at high-volume centers have improved short- and long-term outcomes.[30–34] A recent international systematic review and meta-analysis of studies including over 61,000 patients demonstrated that transportation to cardiac resuscitation centers [with on-site percutaneous coronary intervention (PCI) and TTM capability] was associated with increased survival (OR=1.95, 95% CI, 1.47-2.59, P<0.001).[33] For this reason, transfer of comatose post-arrest patients to a specialty center offering PCI, cardiac critical care, TTM, and neurocritical care may be prudent. When available, engagement of a critical care transport team should be considered when arranging interfacility transport of patients resuscitated from cardiac arrest.

5 Prevention of Secondary Brain Injury

In parallel with identification and treatment of cardiac arrest, post-resuscitation support should be focused on minimization of secondary brain injury.

5.1 Hemodynamic Management for Neuroprotection

After ROSC, cerebral hypoperfusion develops within hours and may last days.[35–38] During this time, cerebral vascular resistance is increased resulting in decreased blood flow and oxygen delivery. Increased perfusion pressure is often needed to sustain microvascular cerebral blood flow.[38–43] Observational studies show an association between lower post-arrest blood pressure and mortality.[17,44,45] Data regarding the exact MAP goals is somewhat contradictory. Maintaining a mean arterial pressure (MAP) >80 mmHg is associated with improved neurologic outcomes, even if achieved at the expense of vasopressor dependence.[44,46–48] Targeting higher MAPs (85-100) improves cerebral oxygenation but not neurologic outcome.[49] AHA guidelines recommend maintaining an SBP > 90.

5.2 Pulmonary Management for Neuroprotection

Post-arrest patients should be intubated and mechanically ventilated. Although cerebral pressure autoregulation may be impaired after resuscitation, response to carbon dioxide (CO_2) usually remains intact. Hyperventilation may result in cerebral vasoconstriction and inadequate blood flow, and a Phase II randomized controlled trial showed better outcomes when a $PaCO_2$ of 50-55mmHg was targeted compared to $PaCO_2$ of 35-45mmHg.[50] The most recent guidelines published by the AHA in 2020 recommend a $PaCO_2$ of 35-45mmHg in post cardiac arrest patients.

Both hypoxia and hyperoxia have been independently associated with adverse neurologic outcome after cardiac arrest, presumably because of secondary brain injury caused by inadequate cerebral oxygen delivery and oxidative stress, respectively.[17,51–53] Both should be avoided, and a temperature corrected PaO2 of 80-120 mmHg is reasonable. The most recent AHA 2020 ACLS guidelines recommend a target Sp02 of 92-98%.[7]

Blood gas measurements are affected by body temperature. Some blood gas analyses techniques make this correction automatically, but many do not. If the analysis technique does not correct for temperature, approximate correction can be calculated as follows (alpha-stat method):[54–56]

- For every degree below 37˚C, subtract 5 mmHg from the PaO2 value
- For every degree below 37˚C, subtract 2 mmHg from the PaCO2 value
- For every degree below 37˚C, add 0.012 units to the pH value

5.3 Targeted Temperature Management for Neuroprotection

TTM is an important intervention to minimize secondary brain injury after cardiac arrest. However, the definition of TTM and the optimal target temperature has evolved over time. TTM is broadly understood to include interventions to decrease the body temperature below normal and includes interventions to prevent and treat fever. Reducing core body temperature decreases cerebral oxygen demand and attenuates multiple cellular pathways involved in ongoing brain injury in the hours and days after cardiac arrest.[54,57]

5.4 Out-of-hospital cardiac arrest

Clinical trials first demonstrated improved survival and neurological outcomes with induced hypothermia to a core temperature of 32-34^{o}C in selected patients resuscitated from out-of-hospital cardiac arrest (OHCA) due to ventricular tachycardia or fibrillation (VT/VF).[58,59] Follow up trials suggest a benefit in all patients resuscitated from cardiac arrest, [60,61] including a randomized control trial evaluating patients with initial asystole or pulseless electrical activity (PEA) which suggested TTM at 33C for at least 24 hours increased survival with favorable neurologic outcomes. [62] However, additional studies have shown that overall outcomes are equivalent when a core temperature of 36^{o}C is targeted rather than 33^{o}C.[63–65] Most recently, TTM-2 trial published in 2021 assessed adults with OHCA with presumed cardiac or unknown cause and compared oucomes between targeted hypothermia to 33^{o}C and targeted normothermia to 37.8˚C and found no difference in the incidence of death or neurologic outcome between groups.{Dankiewicz, , Hypothermia versus Normothermia after Out-of-Hospital Cardiac Arrest} Multiple studies, including two randomized controlled trials, have demonstrated that TTM to 33-36 ^{o}C significantly improved outcomes after cardiac arrest when implemented with a well-defined post-arrest bundle of care.[47,58,59,66] The AHA, ILCOR, the American Academy of Neurology, and the Neurocritical Care Society all recommend instituting TTM at a target temperature between 32^{o}C-36^{o}C (strong recommendation, low quality of evidence).[7,67–69]

TTM with a goal temperature of 33-36^{o}C is strongly recommended for patients with an OHCA of suspected cardiac origin.[67] Data on patients with cardiac arrest from other causes are mixed. While an outcome benefit is less clear in these populations, TTM may offer some benefit. Clinicians are advised to weigh the benefits and risk of initiating TTM at 33-36^{o}C in this patient population. The AHA and ILCOR guidelines support TTM for adults with OHCA with an initial non-shockable rhythm (weak recommendation, very low-quality evidence).[7,67]

Data supporting TTM after in-hospital cardiac arrest (IHCA) are also mixed. A small cohort study using data from the Get With the Guidelines-Resuscitation database suggested worse outcomes when TTM 33-36 is applied to patients who experienced an IHCA.[70] This study should be interpreted with caution given the database nature of the study and potential selection bias. A more recent case-control study suggested similar survival and favorable neurologic outcomes between IHCA and OHCA survivors managed with TTM 33-36.[71] The AHA and ILCOR guidelines suggest that TTM at 33-36^{o}C should be considered for patients who experience an IHCA (weak recommendation, very low-quality evidence).[7,67] Further studies are needed in this patient population to determine the best role of TTM in patients with IHCA.

5.5 When is Targeting 36^{o}C Preferable to 33^{o}C?

Because significant hypothermia may potentiate coagulopathy and surgical bleeding, findings of intracranial bleeding or anticipated hemorrhagic diathesis should prompt a multidisciplinary risk-benefit discussion prior to initiating TTM and choosing a target temperature of 33¯36^{o}C. Since targeting 36^{o}C has less impact on coagulation, TTM at 36˚C rather than 33˚C should be considered in patients with coagulopathy and bleeding.[72]

There is some suggestion that patients maintained at a lower target temperature may experience more hemodynamic instability.[73] In patients requiring significant vasopressor support after ROSC, a target temperature of 36°C may be considered.

In the absence of active temperature control, most post-arrest patients will develop fever after resuscitation.[59] Several studies have suggested that a move from TTM at 33°C to 36°C may decrease the proportion of patients receiving active cooling, thus increasing the possibility of fever rates and worse overall outcomes.[75,76] However it should be noted that TTM at 36°C should still be considered active temperature management, and thus this is unlikely to occur. The TTM-2 trial compared 33°C versus normothermia with early treatment of fever ≥ 37.8°C. and found no difference in 6 month mortality.{Dankiewicz, , Hypothermia versus Normothermia after Out-of-Hospital Cardiac Arrest} Aggressive active temperature management with shivering prevention, and a comprehensive bundle of care is required regardless of whether 36°C or a lower target temperature is selectedre. Developing systems to safely and effectively deliver TTM requires significant institutional support, particularly to ensure that intervention is continuously available.[66,77]

5.6 Considerations

There are few absolute contraindications to TTM at 33-36°C. Aggressive fever management may still be beneficial in these scenarios.[78–80] Patients that rapidly awaken after cardiac arrest (e.g., they able to follow verbal commands) are unlikely to derive benefit from TTM at 33-36. Similarly, patients with do not resuscitate (DNR) orders or preexisting illnesses that preclude meaningful recovery should have discussions with family or proxies regarding goals of care early in the hospital course. Finally, patients who are more than 12 hours after cardiac arrest are less likely to benefit from TTM at 33-36°C.

The need for acute coronary revascularization is not a contraindication. TTM at 33-36°C can and should be initiated prior to or during percutaneous coronary intervention. There is some evidence that having a lower core temperature at the moment of coronary reperfusion can mitigate myocardial reperfusion injury.[81,82]

6 Management of TTM

6.1 Induction

Immediately after reviewing the considerations discussed above, eligible patients should undergo immediate TTM to 33-36°C, and all other patients should receive aggressive interventions to treat and minimize fever. Core temperature monitoring is essential and can be accomplished with endovascular, esophageal, bladder, or rectal devices. Axillary, oral, tympanic, and temporal temperature monitoring can be unreliable.[55,83,84]

Rapid induction of TTM at 33-36 is best accomplished by several cooling methods including surface, intravascular, intranasal, or esophageal.[85] Automated cooling devices can be used concurrently with cold IV fluid administration. In patients without significant heart failure, rapid infusion of up to 40 mL/kg of cold (4°C) saline or Ringer's lactate decreases the core body temperature by approximately 1°C for each liter of fluid

administered.[55,86–88] Some facilities keep saline in refrigerators for this purpose.[66,77] Fluid should be peripherally infused rapidly to ensure that the fluid does not re-warm during infusion. Of note, one trial found prehospital administration of cold fluids increases risk of pulmonary edema and rearrest.[18] Such potential complications may be better managed when the patient is in the emergency department or ICU.

Limited information is available regarding comparison of the efficacy of surface versus intravascular cooling methods. Important features of any device are good contact to ensure adequate heat exchange (a simple cooling blanket is seldom sufficient) and continuous monitoring of the patient's core temperature. Air cooling blankets, cooling fans, and cooling packs are not advised, as they take longer to achieve target temperature and lack a controlled thermoregulation mechanism.[85] However, when automated cooling devices are unavailable, especially in resource-limited settings, TTM induction and maintenance using a combination of cold fluids and ice packs remain a reasonable option. For patients requiring extracorporeal membrane oxygenation (ECMO), body temperature may be managed through the ECMO circuit.

Many patients are mildly hypothermic following resuscitation from cardiac arrest, thus maintaining this temperature may be all that is required.[18,86,89]

TABLE 2
Special considerations for hypothermia induction

Special considerations for hypothermia induction
Patients may be hypothermic at baseline in setting of neurogenic shock. If so, allow for passive hypothermia.
Do not warm to target temperature if patient is passively hypothermic to a temperature that is acceptable to the clinical team.
Active TTM should be continued during diagnostic procedures as able (e.g., CT scan).
Hydrogel pads are radiolucent and safe to use in MRI, CT, X-RAY or Cath Lab.
One leg hydrogel pad may be removed to gain access to the groin area for line insertion.
TTM at 33-36oC can and should be initiated prior to or during percutaneous coronary intervention.

6.2 Sedation and Shivering

Many patients shiver during cooling induction because the shivering response is maximal at temperatures of approximately 35°C.[54] Shivering may hinder the beneficial effects of hypothermia. Of note, the shivering response may be more pronounced when the goal is 36°C because the patients' thermoregulatory defenses, which are partly suppressed at 32-33°C, may be more active at 36°C.[54,55] A validated tool such as the Bedside Shiver Assessment Score (BSAS) is useful to monitor shiver response. A stepwise approach to shiver management that incorporates non-pharmacological interventions and non-sedating medication can help treat shivering while minimizing neuromuscular blockade.[85] See the ***ENLS Pharmacotherapy*** module for BSAS, a shiver management algorithm, and medications.

Skin counter-warming (i.e., warming of the non-cooled areas of the skin with a warm

air blanket) markedly reduces the shivering response and should be considered first line, even when surface cooling methods are used.[55,90,91] Initial drug therapy should include scheduled acetaminophen (650mg q4h) and buspirone (30mg q8h), magnesium therapy (4g IV q4h to maintain serum levels 3-4 mg/dl or infusion of 0.5-1mg/hr), followed by bolus doses of fentanyl (12.5-100 mcg or 1-2mcg/kg IV push prn) with or without concomitant infusion of fentanyl (25-150mcg/hr), or meperidine boluses (12.5-100 mg IV q 4-6 h prn). If shivering is still not controlled, dexmedetomidine, propofol (50-75 mcg/kg/min) or midazolam (2–5 mg IV prn or 1-10mg/hr infusion) may be initiated.[54,55,92]

While adequate sedation may be provided by buspirone, meperidine, dexmedetomidine, or fentanyl, the primary purpose of these agents is to prevent shivering. If the patient is hemodynamically stable, propofol is effective for ensuring adequate sedation, and allows for meaningful serial neurologic examinations due to its short half-life.[93] Dexmedetomidine is an alternative since it directly lowers the shivering threshold via central alpha-2 agonism, however, bradycardia can be a dose-dependent side effect.[94] If a midazolam infusion is used, the half-life of midazolam is prolonged by hypothermia and residual sedation may reduce the accuracy of any subsequent neurologic examination.[95] Morphine should not be used because of prolonged time to onset and risk of hypotension.[55]

Finally, neuromuscular blockade (NMB) may be used to abate refractory shivering. A single dose of short-acting neuromuscular blockade can be helpful in patients who are already appropriately sedated with continuous infusions. When used, intermittent dosing is preferred to continuous infusions. Continuous NMB infusion was not associated with improved outcomes in one small randomized controlled trial.[96] A larger retrospective multi-center cohort study found that intermittent NMB was associated with improved outcomes when compared to continuous neuromuscular blockade.[97] Additionally, NMB obscures any convulsive activity that is typically detected by the neurological evaluation.

6.3 Expected physiological changes induced by hypothermia

Hypothermia produces several predictable, dose-dependent physiological changes. [54] We will focus briefly on physiological changes particularly relevant to the first hours after resuscitation. A heart rate of 35-40 beats per minute is common at a temperature of 33^{o}C and generally does not warrant therapy unless associated with hypotension. [54] Bradycardia may be more pronounced at lower target temperatures .[98] Atropine is generally ineffective in hypothermia-induced bradycardia. Instead, symptomatic bradycardia may be treated with beta agonists. [54]

A cold diuresis occurs after hypothermia induction which may result in hypokalemia, hypomagnesaemia, and hypophosphatemia. Hypothermia also shifts potassium from the extracellular to intracellular space resulting in further hypokalemia. Frequent assessment of electrolytes and repletion are indicated. Overly aggressive repletion of potassium should be avoided since serum potassium levels will predictably rise during rewarming. A goal potassium level of 3.0-3.5 mmol/L is reasonable during induction and maintenance of TTM.[85] Magnesium and phosphorus should be maintained in the high—normal range. Arrhythmias may develop due to electrolyte disorders. QT prolongation can occur during

hypothermia, and concomitant QT prolonging drugs should be used with caution.[54]

6.4 Seizure Detection and Treatment

EEG monitoring is indicated in patients post-cardiac arrest , particularly in those who are comatose or receiving heavy sedation. [99] The incidence of non-convulsive status epilepticus in the patients after cardiac arrest ranges from 12–24 %, [100–102] and up to 47% in pediatrics.[99] Abnormal EEG patterns are found in up to 40% of patients and some are amenable to early, aggressive therapy.[101] Seizures may directly worsen brain injury, and should be treated. Continuous EEG monitoring during the cooling and rewarming phase should be strongly considered[103] especially if paralysis is used for shivering management.[104] More details can be found in the **ENLS Status Epilepticus module**.

7 TTM Duration and Rewarming

ENLS focuses primarily on the first few hours of patient management. Discussion of the duration and particular considerations for rewarming is beyond the scope of this paper. We refer readers to guidelines and reviews on TTM . [85,105] Generally speaking, after induction , patients are maintained at their target temperature for 24 hours , although durations from 12-48 hours have been used. [85] Subsequent rewarming should be slow and controlled in order to avoid critical complications. Active TTM at 37ºC is typically maintained for 24-48 hours after rewarming is completed.

8 Neurological Prognostication

Accurate and timely neurological prognostication after cardiac arrest is challenging. A detailed discussion of post-arrest prognostication is beyond the scope of this manuscript. It is critical to understand that in the first 72 hours after cardiac arrest, no sign, symptom or combination of findings short of brain death precludes favorable recovery. [68,106,107] Even clinical findings compatible with brain death are not definitive for at least 24 hours following resuscitation or rewarming, whichever comes later.[108] A stepwise multimodal approach to prognostication should occur post arrest.

Early limitations in care may be appropriate in some patients, for example those with preexisting advanced directives or severe concomitant medical comorbidities. However, early aggressive care should not be limited or withheld based solely on perceived poor neurological prognosis. Premature withdrawal of life-sustaining therapy based on perceived neurological prognosis has been linked to thousands of preventable deaths after cardiac arrest annually.[3,109]

9 Pediatric Considerations

Pediatric cardiac arrest affects nearly 20,000 children each year in the United States. Overall, survival to hospital discharge has improved over the last two decades for IHCA,

but not for OHCA. [110,111] IHCA occurs primarily in pediatric ICUs. [112] The incidence of IHCA is 1.4 to 1.8%, with 78% of children achieving return of circulation and 45% surviving to hospital discharge. Nearly 90% of survivors of IHCA have favorable neurologic outcomes. [113,114] Although longer durations of CPR are associated with lower survival and worse neurologic outcome, 90% of children who survive after receiving more than 30 minutes of CPR still have favorable outcomes. [113,115,116] The initial rhythm in pediatric IHCA is most commonly bradycardia with poor perfusion, or PEA, which is often preceded by tissue hypoxia from respiratory failure or shock. [113,117] Shockable rhythms (VF or pulseless VT) are less common and occur only in 10-15% of pediatric cardiac arrests. [117–119] OHCA is usually precipitated by drowning, sudden infant death syndrome, and arrythmias.[120]

Improved outcomes after IHCA are in part due to a focus on delivering high quality CPR in compliance with Pediatric Advanced Life Support (PALS) guidelines and advances in post-resuscitation care. [121–124,125] Recent changes to the PALS guidelines include utilizing a respiratory rate of 20-30 breaths per minute for children who have an advanced airway and administering epinephrine for patients with non-shockable rhythms within 5 minutes from the start of CPR.[7] Improved outcomes have also been associated with the use of individualized physiologic monitoring to guide intra-arrest therapies, [8,126] interdisciplinary debriefing programs, [127] and ECMO as a rescue therapy for refractory cardiac arrest. [128,129] OHCA systems of care focus on encouraging bystander CPR and basic life support therapies. For OHCA, bag-mask ventilation yields the same outcomes as placement of an advanced airway during CPR.[7] Survival rates from OHCA are lower than IHCA and range from 3-16%, with higher survival rates for older children.[124,130,131] Favorable neurologic outcomes are present in 37-62% of survivors.[118,131–133]

While respiratory failure is the most common etiology of pediatric cardiac arrest, children can have other primary causative mechanisms.[118,132,134] Children with an unclear etiology of cardiac should undergo evaluation for the cause of cardiac arrest including EKG and ECHO, neuroimaging with CT, toxicology screens, infectious work-up, and occult trauma. Patients with an arrhythmogenic cause of cardiac arrest should be evaluated for channelopathies and cardiomyopathy.[135]

Similar to adults, the post–resuscitation phase should focus on limiting secondary end-organ injury. The post-cardiac arrest syndrome consists of hypoxic-ischemic brain injury, myocardial dysfunction, systemic ischemia/reperfusion response, and persistent precipitating pathophysiology.[136] Myocardial dysfunction and arterial hypotension are common after pediatric cardiac arrest [137–139] and hypotension (i.e., SBP $<5^{th}$ percentile for age) is associated with increased mortality and lower rates of survival with favorable neurologic outcome. [140,141142,143] The PALS guidelines recommend that hypotension (i.e., SBP $<5^{th}$ percentile for age) be treated with parenteral fluids, inotropes, and vasopressors, and when appropriate resources are available, invasive arterial pressure should be monitored continuously. [123,125] Mechanical ventilations should be titrated to avoid extremes of oxy- genation and ventilation, with hypoxemia strictly avoided (goal SaO2 <100%, but >94%), and targeting a PaCO2 that is appropriate to the specific patient condition. [123,144,145] There is insufficient evidence regarding glucose management in children after ROSC. In general, blood glucose concentrations should be monitored carefully, avoiding both hy-

perglycemia (>180 mg/dL) and hypoglycemia (<80 mg/dL). Seizures and status epilepticus are common (47% and 32%, respectively) in the post-ROSC period. When resources are available, PALS guidelines recommend continuous EEG monitoring for patients with persistent encephalopathy.[125,136] Seizures should be treated with careful attention to potential hemodynamic side-effects of anticonvulsants, although it remains unclear whether treatment improves outcomes. [99]

Hyperthermia after pediatric cardiac arrest is common and associated with poor neurologic outcomes. [146] Two large prospective, randomized studies of comatose children post-ROSC from both IHCA and OHCA (i.e., Therapeutic Hypothermia After Cardiac Arrest (THAPCA) trials) found no benefit in survival with favorable functional outcomes at 1 year in patients treated with therapeutic hypothermia (32˚C to 34˚C) compared to those treated with normothermia (36˚C to 37.5˚C). [147,148] Thus, PALS guidelines for temperature management in comatose children after cardiac arrest recommends continuous core temperature monitoring and either maintenance of 5 days of TTM of 36˚C to 37.5˚C or 2 days of TTM of 32˚C to 34˚C followed by 3 days of TTM of 36˚C to 37.5˚C.[123125,136] Fever should be prevented and treated aggressively.

Similar to adults, accurate neurological prognostication after cardiac arrest is challenging and no single variable for prognostication has been established and validated. Many observational studies have demonstrated pre-arrest, intra-arrest, and post-arrest assessments and factors that are associated with outcomes.[136] PALS guidelines recommend that providers consider multiple factors when predicting outcomes after pediatric cardiac arrest.[125,136]

10 Nursing Considerations

Nursing care for a patient with cardiac arrest includes delivery of high-quality CPR. After ROSC, nursing care is essential to help achieve the goal of maintaining cerebral perfusion and preventing secondary brain injury. Nurses are responsible for close neurologic, hemodynamic, and respiratory monitoring of the post-cardiac arrest patient. They play key roles in initiation of TTM, as well as close following the patient's core temperature, vital signs, and neurological examination. Nurses are key stakeholders in hospital-based systems to ensure TTM resources are available and readily deployable during post-cardiac arrest care. Nurses monitor patients for TTM complications including hemodynamic changes such as bradycardia, shivering, bleeding, and electrolyte abnormalities.[138] Care of patients undergoing TTM also includes minimizing immobility, prolonged sedation, and mechanical ventilation. Nurses should partner with providers to ensure the hospital's TTM algorithm, including the target and duration of temperature management, is followed. The nursing based BSAS scoring tool can be used to prevent and treat shivering. Nurses should perform frequent skin assessments prevent injury relating to temperature management devices and immobility. Nurses should be familiar with timing of post-cardiac arrest prognostication to ensure that clinical decision making is in concert with current science, as well as to provide accurate psychosocial support to families of their patients.

11 Communication

When communicating to an accepting or referring physician about patients resuscitated from cardiac arrest, consider including the key elements listed in Table 3.

TABLE 3
Resuscitation following cardiacarrest-communication regarding assessment and referral

Communication
☐ Patient age, pre-arrest circumstances
☐ Duration of cardiac arrest and initial arrest rhythm
☐ Most likely etiology of arrest, if known
☐ Neurological examination on first assessment
☐ PCI eligibility
☐ Time TTM started and target temperature
☐ Current core temperature
☐ Current drug infusions (especially sedative and vasoactive agents)

Clinical Pearls
Intra-arrest management (cardiopulmonary resuscitation) should follow AHA/ILCOR guidelines
Early re-arrest is common and should be prepared for in all patients who achieve ROSC
Early after ROSC, time-sensitive etiologies of arrest should be actively investigated, including acute myocardial infarction, stoke, pulmonary embolism, etc.
Patient outcomes after cardiac arrest may be improved by transfer to a high-volume cardiac arrest center
Comatose post-arrest patients should undergo TTM at 33oC or 36oC with few exceptions
Careful attention to electrolytes, shiver monitoring and prevention, and hemodynamic and pulmonary management during TTM is critical
Additional post-arrest care should be minimized secondary injury through optimizing cerebral perfusion, avoiding hyperoxia and detecting and treating seizures

12 Starred References

33: *This is a seminal paper of an RCT for hypothermia after cardiac arrest demonstrating efficacy of this treatment*.

#34. *The HACA study is a seminal paper of an RCT of hypothermia after cardiac arrest demonstrating efficacy of this treatment*.

#39. *The TTM study is the largest study of post-arrest care to date and demonstrated equivalent efficacy of temperature management to 33ºC compared to 36ºC after out-of-hospital cardiac arrest*.

{Dankiewicz, 2021} *The TTM-2 study is the largest study of post-arrest care to date and demonstrated equivalent efficacy of temperature management to 33oC compared to targeted normothermia to 37.8˚C and found no difference*

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