Considerations on the Use of Neonatal and Pediatric Resuscitation Guidelines for Hospitalized Neonates and Infants: On Behalf of the American Heart Association Emergency Cardiovascular Care Committee and the American Academy of Pediatrics

Taylor Sawyer, DO, MBA, MEd, FAAP,[a] Mary E. McBride, MD, MEd, FAAP,[b] Anne Ades, MD, MSEd, FAAP,[c] Vishal S. Kapadia, MD, MSCS, FAAP,[d] Tina A. Leone, MD, FAAP,[e] Satyan Lakshminrusimha, MD, FAAP,[f] Norjahan Ali, MD, MSc, FAAP,[d] Stephanie Marshall, MD,[g] Georg M. Schmölzer, MD, PhD,[h] Kelly D. Kadlec, MD, MEd, FAAP,[i] Martin V. Pusic, MD, PhD,[j] Blair L. Bigham, MD, MS,[k] Farhan Bhanji, MD, MSc Ed FRCPC,[l] Aaron J. Donoghue, MD, MSCE, FAHA, FAAP,[m] Tia Raymond, MD, FAAP, FAHA, FCCM,[n] Beena D. Kamath-Rayne, MD, MPH, FAAP,[o] Allan de CaenMD, FRCPC[p]

Between 0.25% and 3% of admissions to the NICU, PICU, and PCICU receive cardiopulmonary resuscitation (CPR). Most CPR events occur in patients <1 year old. The incidence of CPR is 10 times higher in the NICU than at birth. Therefore, optimizing the approach to CPR in hospitalized neonates and infants is important.

At birth, the resuscitation of newborns is performed according to neonatal resuscitation guidelines. In older infants and children, resuscitation is performed according to pediatric resuscitation guidelines. Neonatal and pediatric guidelines differ in several important ways. There are no published recommendations to guide the transition from neonatal to pediatric guidelines. Therefore, hospitalized neonates and infants can be resuscitated using neonatal guidelines, pediatric guidelines, or a hybrid approach.

This report summarizes the current neonatal and pediatric resuscitation guidelines, considers how to apply them to hospitalized neonates and infants, and identifies knowledge gaps and future priorities. The lack of strong scientific data makes it impossible to provide definitive recommendations on when to transition from neonatal to pediatric resuscitation guidelines. Therefore, it is up to health care teams and institutions to decide if neonatal or pediatric guidelines are the best choice in a given location or situation, considering local circumstances, health care team preferences, and resource limitations.

abstract

[a]*Division of Neonatology, Department of Pediatrics, University of Washington School of Medicine, Seattle, Washington;* [b]*Divisions of Pediatric Cardiology and Pediatric Critical Care Medicine, Department of Pediatrics, and* [g]*Neonatology, Department of Pediatrics, Northwestern University Ann and Robert H Lurie Children's Hospital of Chicago, Chicago, Illinois;* [c]*Divisions of Neonatology and* [m]*Pediatric Intensive Care, Department of Pediatrics, Children's Hospital of Philadelphia, Philadelphia, Pennsylvania;* [d]*Division of Neonatal-Perinatal Medicine, Department of Pediatrics, University Southwestern Medical Center, Dallas, Texas;* [e]*Division of Neonatology, Department of Pediatrics, Columbia University, New York, New York;* [f]*Department of Pediatrics, UC Davis Children's Hospital, Sacramento, California;* [h]*Divisions of Neonatology and* [p]*Pediatric Critical Care, Department of Pediatrics, University of Alberta, Edmonton, Canada;* [i]*Division of Critical Care, Department of Pediatrics, University of Nebraska Medical Center, Omaha, Nebraska;* [j]*Division of Emergency Medicine, Department of Pediatrics, Harvard Medical School, Boston, Massachusetts;* [k]*Division of Critical Care, Department of Anesthesia, Stanford University, Palo Alto, California;* [l]*Division of Pediatric Critical Care, Department of Pediatrics, McGill University, Montreal, Quebec, Canada;* [n]*Department of Pediatrics, Pediatric Cardiac Intensive Care, Medical City Children's Hospital, Dallas, Texas; and* [o]*Global Child Health and Life Support, American Academy of Pediatrics, Itasca, Illinois*

Dr Sawyer conceptualized and drafted the initial manuscript; Drs McBride, Ades, Kapadia, Leone, Lakshminrusimha, Ali, Marshall, Schmölzer, Kadlec, Pusic, Bigham, Bhanji, Donoghue, Raymond, Kamath-Rayne, and DeCaen conceptualized the (Continued)

To cite: Sawyer T, McBride ME, Ades A, et al. Considerations on the Use of Neonatal and Pediatric Resuscitation Guidelines for Hospitalized Neonates and Infants: On Behalf of the American Heart Association Emergency Cardiovascular Care Committee and the American Academy of Pediatrics. *Pediatrics*. 2024;153(1):e2023064681

INTRODUCTION

Optimizing the approach to cardiopulmonary resuscitation (CPR) in hospitalized neonates and infants is an important issue. Many neonates and infants in the ICU experience cardiopulmonary instability or cardiopulmonary arrest. Cardiopulmonary arrest requiring CPR with chest compressions occurs in 0.25% to 1% of NICU admissions, 1.4% of PICU admissions, and 3.1% of pediatric cardiac ICU (PCICU) admissions.[1–8] Most CPR events in the NICU, PICU, and PCICU occur in patients <1 year old.[1–8] The incidence of CPR with chest compressions in the NICU is 10 times higher than the 0.06% to 0.12% incidence of CPR reported at birth.[9,10]

Resuscitation practices vary based on a patient's age, physiology of arrest, and location of care. At birth, the resuscitation of newborns is performed according to neonatal resuscitation guidelines.[10] In older infants and children, resuscitation is performed according to pediatric resuscitation guidelines.[11] Hospitalized neonates and infants can be resuscitated using neonatal guidelines, pediatric guidelines, or a hybrid approach.[12–16] Neonatal and pediatric guidelines differ in several important ways. For example, neonatal guidelines focus on effective ventilation of the newborn lung.[10] Pediatric guidelines focus on treating the etiology of arrest (respiratory, shock, arrhythmias) and providing effective cardiac compressions.[11] Neonatal and pediatric guidelines also differ in the CPR sequence, chest compression-to-ventilation ratios, coordination of breaths with compressions, and medications and other therapies.[10,11]

At some point after birth, the optimal resuscitation protocols for neonates and infants change from neonatal to pediatric.[12–16] However, there are no published recommendations to guide the transition from neonatal to pediatric resuscitation protocols.[14,16] This lack of guidance is because of the lack of evidence suggesting when—and under what circumstances—it is better to use neonatal or pediatric resuscitation protocols. Thus, in clinical practice, the choice of which guidelines to use is in the hands of the health care team or the institution.[12–14] This lack of standardization inevitably leads to variability in resuscitation practice. There is concern that variability in resuscitation practice negatively impacts the quality of care and contributes to suboptimal resuscitation outcomes.[16–18]

This report summarizes the current neonatal resuscitation and pediatric advanced life support guidelines, considers how to apply the guidelines to hospitalized neonates and infants, and identifies knowledge gaps and future priorities. We begin with a review of resuscitation guideline development. We then explore the neonatal and pediatric guidelines and examine the differences between the two. Next, we describe the use of neonatal and pediatric guidelines for hospitalized neonates and infants. Finally, we examine how systems issues can impact decision-making and discuss knowledge gaps and future directions.

RESUSCITATION GUIDELINE DEVELOPMENT

Resuscitation guidelines are developed to standardize clinical practice and improve patient outcomes. The guideline development process includes an international effort to create treatment recommendations and regional efforts to translate those recommendations into guidelines. The International Liaison Committee on Resuscitation (ILCOR) continuously evaluates the published literature and reports the findings as systematic reviews, scoping reviews, and evidence updates.[19] ILCOR findings are also published as the *Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations*.[20] In the United States, as of 2021, the American Heart Association (AHA) is jointly developing guidelines with the American Academy of Pediatrics (AAP). Before this time, the American Heart Association developed guidelines with pediatric input from the AAP and others. The guidelines are developed based on the ILCOR consensus on science and evidence reviews conducted by the Writing Group. A class of recommendation and level of evidence is assigned to each recommendation to guide clinical practice and provide an evidence-based rationale for each recommendation.[19] The guidelines are published as the *Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care*.[10,11] As part of the resuscitation guideline development process, the AHA and AAP continually assess the evidence and generate focused updates when breaking science occurs.

Using the resuscitation guidelines, the AHA and AAP have worked together for decades to jointly create educational courses. The educational courses applicable to neonates and infants are the Neonatal Resuscitation Program (NRP) and the Pediatric Advanced Life Support (PALS) course. The NRP is based on the Neonatal Resuscitation Guidelines.[10] The PALS course is based on the Pediatric Basic and Advanced Life Support Guidelines.[11] Because of the close connection between the guidelines and the courses, the resuscitation guidelines are often called the "NRP Guidelines" and "PALS Guidelines." In this report, we use "neonatal resuscitation guidelines" and "pediatric resuscitation guidelines" to indicate recommendations included in the 2020 Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care.[10,11]

NEONATAL RESUSCITATION GUIDELINES

The neonatal resuscitation guidelines apply primarily to the newborn transitioning from the fluid-filled environment of the womb to the air-filled environment of the birthing room.[10] This transition starts before the time of birth and ends after the perinatal transition period. However, the concepts in the neonatal guidelines may be applied to newborns during the neonatal period (birth to 28 days) and, according to the guidelines, may be used for neonatal resuscitation anytime during the initial hospital stay.[10,11]

To survive the birth process, the newborn must establish adequate lung inflation and ventilation after birth.[10] Therefore, the neonatal resuscitation guidelines focus on managing acute respiratory compromise at birth and delivering effective positive pressure ventilation (PPV). PPV is the primary method for supporting newborns who are apneic, bradycardic, or demonstrate inadequate respiratory effort.[10] Improvements in heart rate and the establishment of spontaneous breathing or crying are signs of effective PPV in the newborn.[10]

The neonatal guidelines are presented as themes, including anticipation and preparation, cord management, initial actions, assessment of heart rate, PPV, oxygen therapy, chest compressions, vascular access, medications, volume expansion, and withholding and discontinuing resuscitation.[10] Additionally, the guidelines include recommendations on human and system performance related to neonatal resuscitation. The neonatal guidelines contain a single resuscitation algorithm (Fig 1). The algorithm describes the steps to follow to evaluate and resuscitate the newborn. Some key components of the neonatal resuscitation algorithm and neonatal resuscitation guidelines include:

- Initial evaluation: at birth, the newborn should be warmed and dried to help maintain a normal temperature. Tactile stimulation is reasonable in infants with ineffective respiratory effort after birth.[10] Auscultation is the preferred method for the initial assessment of the heart rate, but electrocardiography use may be reasonable for the rapid and accurate measurement of the newborn's heart rate.[10]
- Airway: the airway should be optimally positioned and secretions cleared if needed. PPV should be provided without delay to newborn infants who are gasping or apneic after birth or persistently bradycardic (heart rate less than 100 per min) despite appropriate initial actions (including tactile stimulation).[10]
- Breathing: providing PPV at 40 to 60 breaths per minute is reasonable.[10] Ventilation should be optimized with endotracheal intubation, if possible, before starting chest compressions.[10] Reasonable initial supplemental oxygen concentrations are 21% in newborns $\geq$35 weeks' gestation and 21% to 30% in newborns $\leq$35 weeks' gestation with subsequent oxygen titration based on pulse oximetry.[10]
- Circulation: if the heart rate remains at less than 60 beats per minute, despite adequate ventilation that results in lung inflation for at least 30 seconds, initiating chest compressions is reasonable.[10] It may be reasonable to deliver 3 compressions followed by 1 inflation (3:1 ratio) when providing chest compressions in a newborn.[10]
- Drugs and other therapies: if the heart rate has not increased to 60 beats per minute or more after optimizing ventilation and chest compressions, it may be reasonable to administer intravascular epinephrine.[10] The recommended intravascular doses of epinephrine are 0.01 to 0.03 mg/kg intravenous or intraosseous and 0.05 to 0.1 mg/kg endotracheally. Volume expansion with 10 to 20 mL/kg of normal saline (0.9% sodium chloride) or blood may be reasonable in cases of suspected hypovolemia.[10]
- Postresuscitation care: therapeutic hypothermia should be offered to newborn infants at $\geq$36 weeks estimated gestational age with evolving moderate-to-severe hypoxic-ischemic encephalopathy (HIE).[10]

PEDIATRIC BASIC AND ADVANCED LIFE SUPPORT GUIDELINES

The pediatric life support guidelines are a resource for lay rescuers and health care practitioners to identify and treat infants and children. The guidelines include pediatric basic and advanced life support and cover prearrest, intra-arrest, and postarrest states. The guidelines apply to the community, prehospital, and hospital environments.[11]

Pediatric advanced life support guidelines apply to neonates (less than 30 days old) after hospital discharge, infants, children, and adolescents up to 18 years of age.[11] The pediatric guidelines exclude newborns and recommend that neonatal guidelines be used at birth and during the first hospitalization after birth.[11] Previous guidelines suggested that it was reasonable to resuscitate newborns with a primary cardiac etiology of arrest, regardless of location, according to pediatric guidelines.[21] The 2018 AHA scientific statement on the resuscitation of infants and children with cardiac disease suggests that professionals resuscitating infants and children with cardiac disease use pediatric guidelines.[22] However, the statement acknowledges the limited data regarding the effects of resuscitative strategies on neonates and infants with cardiac disease.[22]

The pediatric guidelines primarily focus on managing 3 pathophysiologic states: respiratory failure, shock, and arrhythmias. Primary cardiac arrest is uncommon in pediatrics, and the etiologies of cardiopulmonary arrest are distinct from those for adults.[11] Cardiopulmonary arrest in pediatrics is usually caused by progressive respiratory failure or shock, resulting in bradycardia and cardiopulmonary failure.[11] Therefore, rapid recognition and immediate initiation of both high-quality chest compressions and effective ventilations are critical to improving outcomes in pediatric cardiopulmonary arrest.[11] However, according to the pediatric guidelines, when CPR is initiated, it may be reasonable to use a sequence of compressions first, followed by airway and breathing.[11]

In addition to the content on managing respiratory failure, shock, and arrhythmias, the pediatric guidelines also contain recommendations on treating a variety of pathophysiologic states. The pediatric guidelines include several algorithms. Figure 2 shows the 2020 Pediatric Cardiac Arrest Algorithm, and Fig 3 shows the 2020

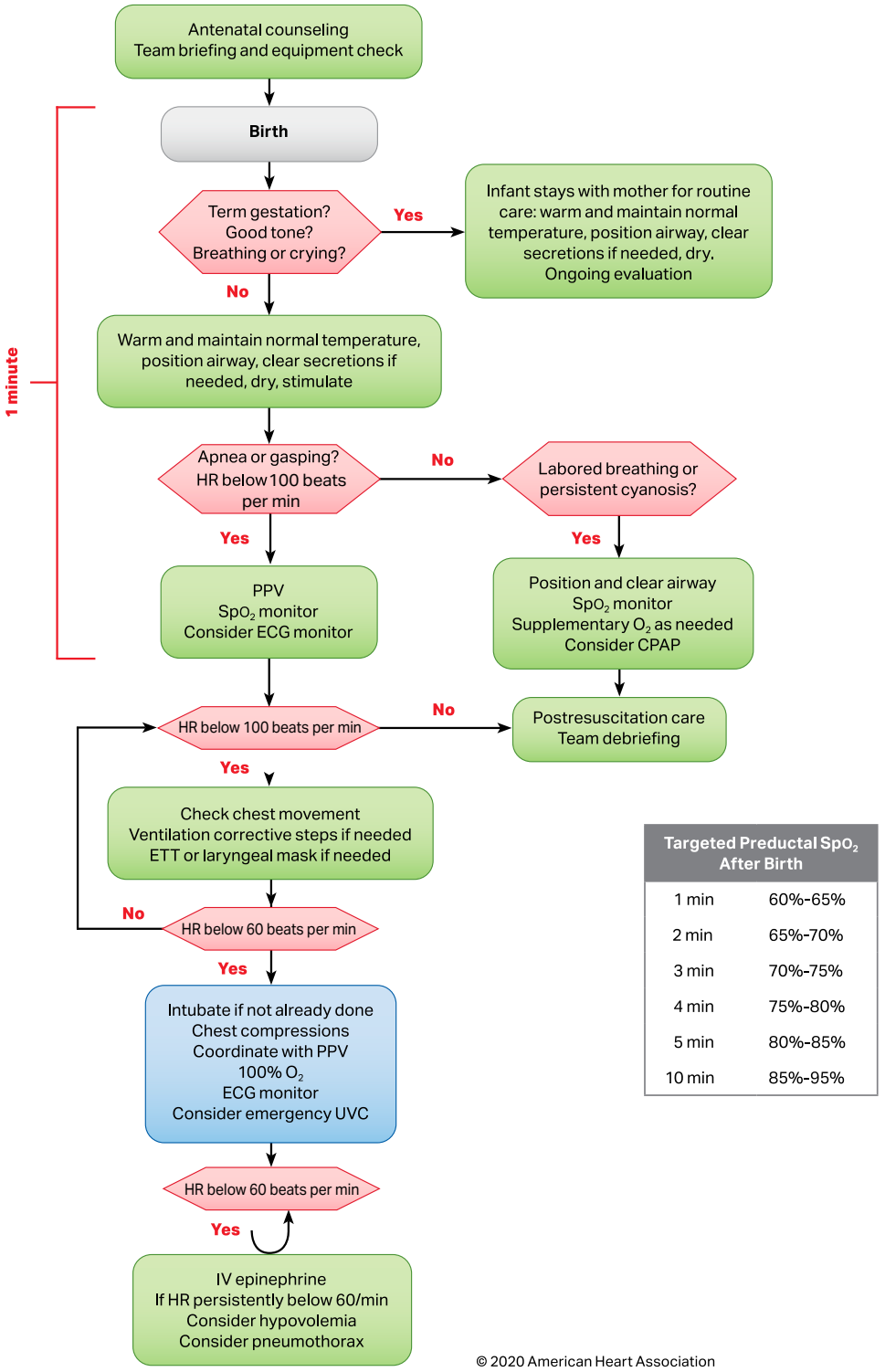

FIGURE 1
Neonatal resuscitation algorithm.

Pediatric Bradycardia With a Pulse Algorithm. Some key components of the pediatric resuscitation guidelines are noted below. Table 1 provides a high-level comparison of the neonatal and pediatric resuscitation guidelines.

- Initial evaluation: in infants and children who are unresponsive, with no breathing or only gasping, it is reasonable for health care professionals to check for a pulse for up to 10 seconds and begin compressions if no definite pulse is felt.[11]

- Circulation: when CPR is initiated, the sequence is compressions-airway-breathing.[11] Chest compressions are indicated for pulseless arrest (Fig 2) and bradycardia (heart rate <60 beats per minute) with a pulse and cardiopulmonary compromise despite effective oxygenation and ventilation (Fig 3).[11] In the absence of an advanced airway, it is reasonable for 1 rescuer to use a compression-to-ventilation ratio of 30:2 and for 2 rescuers to use a compression-to-ventilation ratio of 15:2.[11] With an advanced airway in place, it is reasonable to give 100 to 120 continuous compressions per minute with no pause for ventilation and 1 breath every 2 to 3 seconds (20–30 breaths per minute).
- Airway: bag-mask ventilation is reasonable compared with advanced airway interventions in managing children during out-of-hospital cardiopulmonary arrest.[11] Data are insufficient to support a recommendation for advanced airway use in in-hospital cardiopulmonary arrest (IHCA).[11] There may be specific circumstances or populations in which early advanced airway interventions are beneficial.[11]

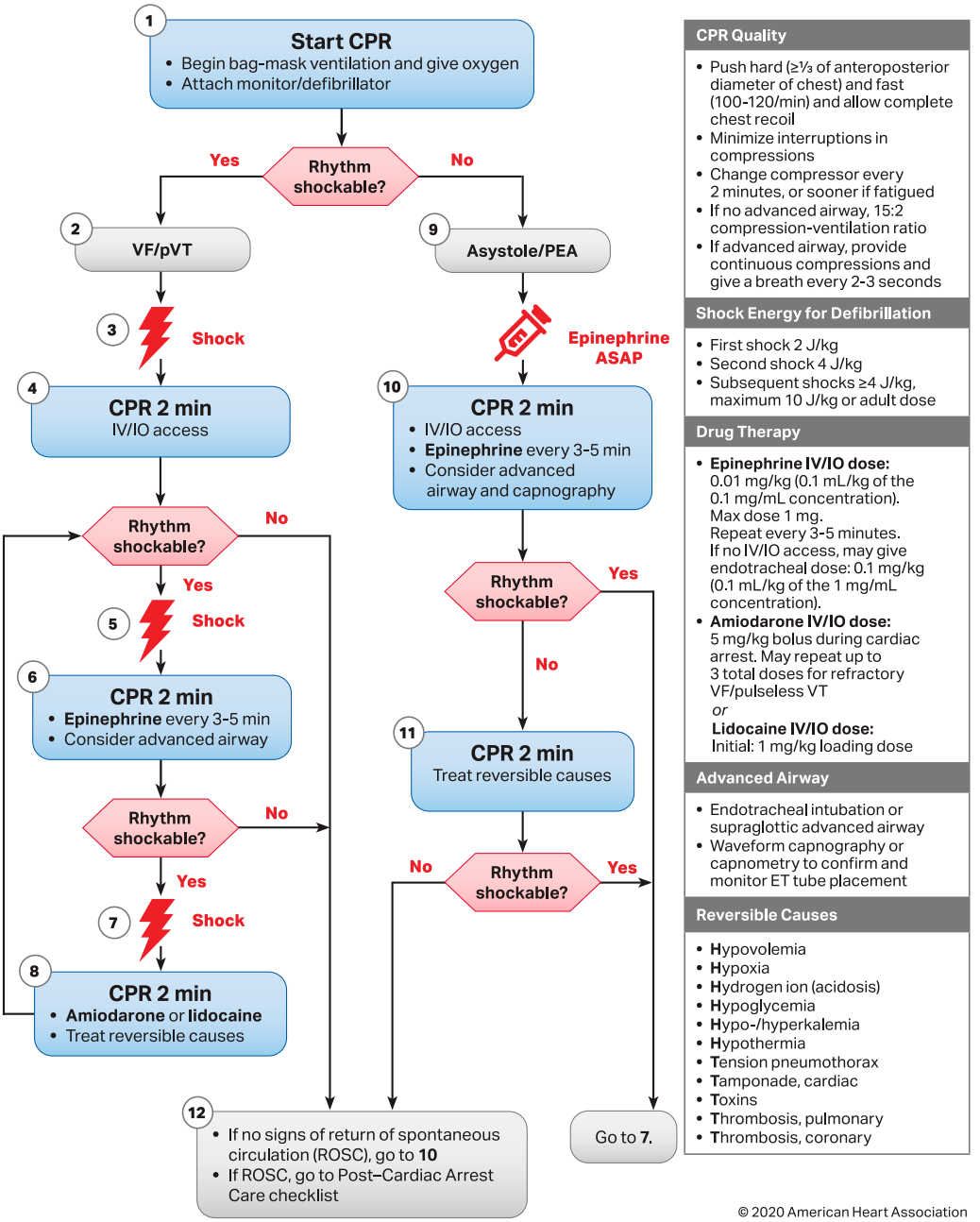

FIGURE 2
Pediatric cardiac arrest algorithm. IO, intraosseous; IV, intravenous; PEA, pulseless electrical activity.

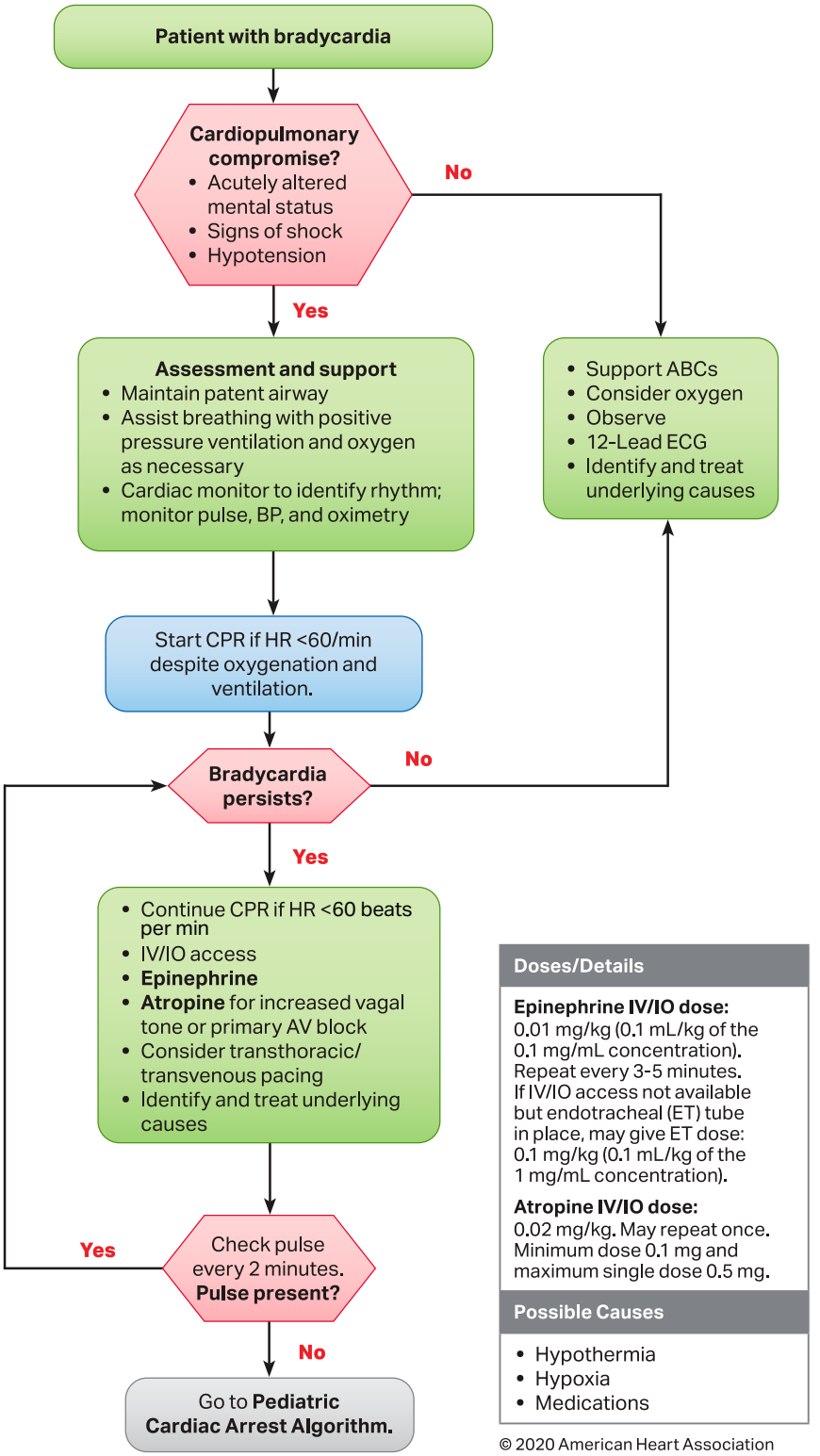

FIGURE 3
Pediatric bradycardia with a pulse algorithm. AV, atrioventricular; BP, blood pressure; IO, intraosseous; IV, intravenous.

TABLE 1 Comparison of Neonatal and Pediatric Resuscitation Guidelines

	Neonatal[10]	Pediatric[11]
Focus	Resuscitation and stabilization at birth	Life support for infants and children outside the newborn period with respiratory failure, shock, arrhythmias, and cardiopulmonary arrest
Patient population	Newborns at birth and neonates and during the first hospitalization after birth	Pediatric advanced life support guidelines apply to neonates (less than 30 d old) after hospital discharge, infants, children, and adolescents up to 18 y of age.
Chest compression initiation	Chest compressions should be initiated if the heart rate remains less than 60 beats per minute despite 30 s of adequate PPV	When CPR is initiated, the sequence is chest compressions-airway-breathing
Compression-to-ventilation ratios	• 3:1 ratio with 90 compressions and 30 breaths per minute; • pause for ventilation regardless of rescuer number or advanced airway	Bag-mask ventilation: • 1 rescuer: 30:2; • 2 rescuers: 15:2; • pause for ventilation; advanced airway: • 100–120 continuous compressions per minute; • 1 breath every 2–3 s (20–30 breaths per min); • no pause for ventilation
Algorithms	• Neonatal resuscitation algorithm	• Pediatric Basic Life Support Algorithm for Healthcare Providers—single rescuer; • Pediatric Basic Life Support Algorithm for Healthcare Providers—2 or more rescuers; • Pediatric Cardiac Arrest Algorithm; • Pediatric Bradycardia with a Pulse Algorithm; • Pediatric Tachycardia with a Pulse Algorithm; • Opioid-Associated Emergency for Lay Responders Algorithm; • Opioid-Associated Emergency for Healthcare Providers Algorithm
Drugs and other therapies	Epinephrine; normal saline; emergency O neg blood	Drug classes: • antiarrhythmic; • vasopressors; • inotropes; • pulmonary vasodilators; • sedation or reversal agents; defibrillation, cardioversion, transcutaneous pacing, vagal maneuvers
Vascular access	UVC or IO	PIV, IO, central line
Postresuscitation temperature management	Newborns 36 wk or more estimated gestational age at birth with evolving moderate-to-severe HIE should be offered therapeutic hypothermia under clearly defined protocols	For infants and children between 24 h of age and 18 y of age who remain comatose after in-hospital cardiac arrest, it is reasonable to use either TTM of 32°C–34°C followed by TTM of 36°C–37.5°C or only TTM of 36°C–37.5°C

IO, intraosseous; PIV, peripheral IV; TTM, targeted temperature management; UVC, umbilical venous catheter.

- Breathing: when performing CPR in infants and children with an advanced airway, it may be reasonable to target a respiratory rate range of 1 breath every 2 to 3 seconds (20–30 breaths per minute), accounting for age and clinical condition.[11]
- Drugs and therapies: giving the initial dose of 0.01 mg/kg intravenous or intraosseous epinephrine within 5 min from the start of chest compressions for pediatric patients in any setting is reasonable.[11] In cases of ventricular fibrillation (VF) or pulses ventricular tachycardia (pVT), an initial dose of 2 to 4 J/kg of monophasic or biphasic energy for defibrillation is reasonable.[11]
- Postresuscitation care: for infants and children between 24 hours old and 18 years old who remain comatose after cardiopulmonary arrest, it is reasonable to use either targeted temperature management (TTM) of 32°C to 34°C followed by TTM of 36°C to 37.5°C, or only TTM of 36°C to 37.5°C.[11]

KEY DIFFERENCES BETWEEN NEONATAL AND PEDIATRIC GUIDELINES

Compression-to-Ventilation Ratios

In both neonatal and pediatric cardiopulmonary arrest, coronary perfusion is essential. The recommendations in the pediatric guidelines are aimed at directly improving coronary perfusion using higher chest compression rates and limiting pauses in compressions. The recommendations in the neonatal guidelines are aimed at indirectly improving coronary perfusion by first improving lung aeration and pulmonary perfusion using slower compression rates and pausing compressions for breaths. The different approaches to coronary perfusion explain the differences in the approach to resuscitation between the neonatal and pediatric guidelines (Table 1).

For pediatric patients in cardiopulmonary arrest, multiple, sequential chest compressions increase diastolic pressure and enhance coronary perfusion.[23] In a prospective multicenter study in the PICU, diastolic blood pressure ≥25 mm Hg during CPR was associated with a greater likelihood of survival to hospital discharge and survival with a favorable neurologic outcome.[24] The goal of increasing coronary perfusion pressure explains the prioritization of IV epinephrine in the pediatric guidelines, with the initial dose administered within 5 minutes from the start of chest compressions.[11]

The pulmonary arterial blood pressure in the fetus is high, and blood flow through the pulmonary circulation is limited. After delivery, lung expansion results in a drop

in pulmonary vascular resistance and a concomitant increase in pulmonary blood flow. Increased pulmonary blood flow, combined with alveolar expansion and oxygenation, increases the flow of oxygenated blood back to the left ventricle. This flow of oxygenated blood improves coronary artery perfusion.

In the newborn, a patent ductus arteriosus may inhibit an increase in diastolic pressure during CPR. Animal data suggest that an increase in diastolic pressure is less critical to the successful return of spontaneous circulation in newborns.[25,26] Hence, slower compression rates and interrupting compressions for ventilations may be tolerated. Data from animal models are inconclusive in terms of the optimal chest compression-to-ventilation ratio in neonatal asphyxia cardiopulmonary arrest. Ratios of 2:1, 3:1, 4:1, 5:1, 9:3, 15:2, and continuous chest compressions with asynchronous PPV are associated with similar times to return of spontaneous circulation and mortality rates.[10,27–29]

The 2020 pediatric guidelines include an updated ventilation rate of 1 breath every 2 to 3 seconds (20–30 breaths per minute) for infants and children receiving CPR with an advanced airway in place.[11] This new recommendation was based on a multicenter observational study demonstrating higher rates of return of spontaneous circulation and survival in children <1 year of age who received higher ventilation rates than previously recommended.[30] This change "narrows the gap" between neonatal and pediatric guidelines for intubated patients. However, differences persist in managing nonintubated patients, the overall number of compressions per minute (100–120 vs 90), and recommendations to synchronize compressions and pause for ventilation.

The Sequence of Resuscitation Efforts

A notable difference between the neonatal and pediatric guidelines is the sequence of steps taken during CPR. The pediatric guidelines recommend that initiating CPR with a compressions-airway-breathing (C-A-B) approach may be reasonable.[11] The C-A-B approach for pediatric resuscitation was first adopted in 2010.[31] Before that, the pediatric guidelines recommended an airway-breathing-compressions (A-B-C) approach. The reason for the change was to expedite improvements in coronary perfusion with chest compressions. Using an A-B-C approach, compressions may be delayed while preparing respiratory equipment.[31] Since chest compressions only require the hands of a willing rescuer, the C-A-B sequence allows for the immediate start of chest compressions while a second rescuer prepares for ventilation.[31] The C-A-B sequence aligns with the adult resuscitation guidelines and offers consistency in teaching rescuers that care for both children and adults.[31] It is hoped that consistency across the pediatric and adult guidelines increases the frequency of bystander pediatric CPR.[31] A recent study from Japan showed an increased rate of bystander CPR over time; however, a study from the United States showed no change.[32,33]

The neonatal guidelines state that the most important priority for newborn survival is the establishment of adequate lung inflation and ventilation after birth.[10] Thus, a primary focus of neonatal resuscitation is lung ventilation. The neonatal guidelines do not include specific language on the sequence of resuscitation efforts or make any explicit recommendations for an A-B-C approach.[10] However, according to the neonatal guidelines, ventilation should be optimized with endotracheal intubation, if possible, before starting chest compressions (Fig 1).[10]

Other Content

Since pediatric guidelines cover a wide range of life support topics, they are much broader in scope compared with neonatal guidelines. In addition to the content on respiratory failure, shock, and arrhythmias, content covered in the pediatric guidelines include the management of various arrhythmias, including VF, pVT, bradycardia, and supraventricular tachycardia; the treatment of myocarditis and cardiomyopathy; resuscitation of the patient with a single ventricle; recommendations for treating children with pulmonary hypertension; and guidelines on extracorporeal cardiopulmonary resuscitation.[11]

Postresuscitative Care

The neonatal and pediatric guidelines differ in their recommendations for postresuscitation care. The neonatal guidelines contain recommendations on the postresuscitation care of newborns who receive prolonged PPV or advanced resuscitation (eg, intubation, chest compressions ± epinephrine). The neonatal guidelines suggest that these newborns be closely monitored after stabilization in a NICU or a monitored triage area because they are at risk for further deterioration.[10] All infants ≥36 weeks estimated gestational age who receive advanced resuscitation should be examined for evidence of HIE to determine if they meet the criteria for therapeutic hypothermia.[10] Therapeutic hypothermia should be provided to newborns with moderate to severe HIE using protocols like those used in published clinical trials in facilities capable of multidisciplinary care and longitudinal follow-up.[10]

The pediatric resuscitation guidelines include recommendations on postresuscitation care outside the newborn period and contain information on postcardiopulmonary arrest syndrome.[11] The components of postcardiopulmonary arrest syndrome include brain injury, myocardial dysfunction, systemic ischemia and reperfusion response, and persistent precipitating pathophysiology.[11] The pediatric guidelines provide recommendations on TTM, blood

pressure management, oxygenation and ventilation, EEG monitoring, and seizure management.[11] Two potential strategies of postarrest temperature management are recommended for infants and children between 24 hours and 18 years of age who remain comatose after arrest.[11] Table 1 compares pediatric and neonatal postarrest temperature management guidelines.

CONSIDERATIONS ON THE USE OF NEONATAL AND PEDIATRIC GUIDELINES FOR HOSPITALIZED NEONATES AND INFANTS

What Chest Compression-to-Ventilation Ratios Should be Used?

The neonatal guidelines apply to newborns at birth and in the days after birth during the first hospitalization.[10,11] This suggests that the 3:1 compression-to-ventilation ratio recommended in the neonatal guidelines may be applied anytime during the initial hospital stay in the nursery, NICU, PICU, or PCICU. After hospital discharge and upon readmission to the hospital, the compression-to-ventilation ratios recommended by the pediatric guidelines (Table 1) may be applied.[11] The current guidelines only mention hospital discharge and do not address transfers within the hospital (eg, transfer from the NICU to the PICU or PCICU).[10,11]

There are limited data on what chest compression-to-ventilation ratios are used during the resuscitation of hospitalized neonates and infants. Survey studies in the United States suggest a location-based approach to resuscitation practice, where the choice of neonatal or pediatric compression-to-ventilation ratios is influenced more by the patient's location within the hospital (NICU, PICU, PCICU) than by first hospitalization or postdischarge status.[12,13] This location-based practice complements typical training schemes. Health care teams in the nursery and NICU typically receive NRP training. Thus, following the neonatal guidelines aligns with their training. Health care teams in the PICU and PCICU typically receive PALS training, so following the pediatric guidelines aligns with their training.

What Sequence of Resuscitation Efforts Should be Followed?

Most children receiving cardiopulmonary resuscitation in the ICU have an initial rhythm of bradycardia and poor perfusion with signs of cardiopulmonary compromise.[1,6,34] In cases of bradycardia and cardiopulmonary compromise, the initial management, according to the pediatrics guidelines, is a simultaneous assessment of the etiology and treatment by managing the airway and providing ventilation and oxygenation.[11] If bradycardia and cardiopulmonary compromise persist despite effective oxygenation and ventilation, CPR should be initiated (Fig 3).[11]

Since their inception, the neonatal guidelines have focused on lung recruitment and ventilation as the cornerstone of resuscitation at birth. This is accomplished through effective ventilation, either spontaneously or assisted via PPV. When providing facemask PPV to a newborn, mask leaks and upper airway obstruction are common and can result in ineffective ventilation.[35] Thus, neonatal resuscitation focuses on optimizing PPV and performing ventilation-corrective steps, including advanced airway placement, to promote effective ventilation before starting chest compressions.[10] In the NICU, over 80% of cardiopulmonary arrests start as an acute respiratory compromise.[1,2] Therefore, focusing on effective ventilation is critical in both the delivery room and the NICU. Simulation-based studies suggest that starting chest compressions early, before ensuring effective ventilation, may subject newborns to unneeded compressions and shift the team's focus away from establishing effective ventilation.[36]

There is no evidence that attempting ventilation-corrective steps in the newborn, including intubation if needed, before starting chest compressions is inferior to initiating chest compressions first. According to the pediatric guidelines, there are not sufficient data to support a recommendation for advanced airway use in IHCA.[11] However, there may be some situations in which early advanced airway interventions are beneficial.[11] In most CPR events in the hospital, chest compressions and ventilations are started simultaneously because most neonates and infants that undergo CPR are already intubated.[1–7] Thus, for IHCA, the differences between using the pediatric C-A-B approach or a neonatal approach, focusing on ventilation and intubation first, are likely minimal.

Can Pediatric Resuscitation Guidelines Content be Applied to the NICU?

Prior studies suggest that the content in the pediatric resuscitation guidelines applies to some patients in the NICU. For example, in a multicenter study of CPR in quaternary NICUs, Ali et al found that the etiologies of cardiopulmonary arrest associated with decreased survival to discharge included multisystem organ failure, septic shock, and pneumothorax.[1] Many of those etiologies are not explicitly addressed in neonatal guidelines. In addition, a cross-sectional survey of NICUs in Israel found that medications, diagnostic approaches, and procedures blended neonatal and pediatric guidelines.[14] Based on these reports, it seems reasonable that some pediatric resuscitation guidelines may apply in the NICU in some situations. Table 2 lists some content in the pediatric resuscitation guidelines applicable to the care of neonates and infants in the NICU.

Should Health Care Teams Receive Training in Both NRP and PALS?

A common question around resuscitation training is whether some health care teams should take both NRP

and PALS. The answer to this question depends on many factors. A key consideration is the need for the health care team to have the knowledge and skills taught in the 2 courses. Suppose health care professionals working in the emergency department, PICU, or PCICU may be called upon to participate in the resuscitation of newborns at birth. In that case, they should consider taking an NRP course. Similarly, if health care professionals working in the NICU could be called upon to participate in the resuscitation of a neonate or infant suffering from shock or an arrhythmia not covered in NRP, they should consider taking PALS.[14–16]

There are no data to suggest that attending both NRP and PALS courses improves CPR outcomes for hospitalized neonates and infants. Therefore, the decision on life support training requirements is up to the health care teams and their institutions, considering the breadth of patient age ranges that practitioners are expected to care for.

Studies suggest there is currently little cross-training of health care professionals in both NRP and PALS. A national survey of NICUs, PICUs, and PCICUs by Ali et al found that only 15% of NICU attending physicians took PALS, and only 5% of PICU attending physicians took NRP.[13] In the PCICU, 0% of attending physicians took NRP. In a study of academic neonatologists in the Midwest United States, 99% maintained NRP, but only 37% maintained PALS.[37] Data on the training of nonphysicians are limited. According to a study by Sawyer et al, only 3% of PICU nurses maintained NRP, and only 5% of NICU nurses maintained PALS.[12]

Some argue that attending formal NRP and PALS training courses is unnecessary to gain the knowledge and skills required to perform the critical components of neonatal and pediatric resuscitation competently. For example, NICU teams could learn how to treat VF or pVT with defibrillation without participating in a PALS course, and PICU teams could learn how to manage a newborn at birth without taking NRP. Informal training opportunities such as simulation-based workshops[38] and resuscitation "mini-courses"[15] have been described as ways to gain resuscitation knowledge and skills without attending a formal life support course. The impact on patient outcomes from attending such informal training is yet to be determined.

TABLE 2 Content in the Pediatric Resuscitation Guidelines Applicable to Neonates and Infants in the NICU

• Management of respiratory failure outside the newborn period
• Management of VF or pVT
• Management of bradycardia with a pulse
• Management of tachyarrhythmias, including supraventricular tachycardia
• Treatment of myocarditis and cardiomyopathy
• Resuscitation of the patient with congenital heart disease
• Treatment of pulmonary hypertension
• Extracorporeal cardiopulmonary resuscitation
• Postresuscitation care outside the newborn period

When Should Teams Transition From Neonatal to Pediatric Resuscitation Guidelines?

As the cardiopulmonary physiology of the newborn transitions to that of the neonate and infant, the evidence upon which the neonatal resuscitation guidelines are based becomes less applicable. Therefore, it makes sense to transition from neonatal to pediatric resuscitation guidelines at some point during the first days, weeks, or months after birth.[16,18] In addition to the maturational changes in cardiopulmonary physiology necessitating a change from neonatal to pediatric guidelines, some have expressed concerns about the limited scope of the neonatal resuscitation guidelines.[14,16,18] As seen in Table 1, the pediatric guidelines cover a broader array of life support and cardiopulmonary arrest topics than the neonatal guidelines. This expanded scope may be important in the NICUs when caring for neonates and infants with premorbid conditions and cardiopulmonary arrest etiologies not covered in the neonatal guidelines.[1–5]

There are no scientific data to answer the question of when to transition from neonatal to pediatric resuscitation guidelines. However, prior reports have described unit-based approaches to this issue. For example, Harer et al described their experience in a level IV NICU where pediatric guidelines were used for infants >44 weeks' postmenstrual age, those with a previous non-PDA cardiac surgery or intervention, and those with an obvious identified cardiac arrhythmia.[15] Using that strategy, 29% of NICU patient days qualified for pediatric guidelines.

Since there are no data on which to base recommendations, health care systems need to determine an approach that works best for their situation. Table 3 provides some potential approaches to transitioning from neonatal to pediatric resuscitation guidelines for hospitalized neonates and infants.

What Postresuscitative Care Guidelines Should be Followed?

The neonatal guidelines recommend therapeutic hypothermia for infants 36 weeks or older who receive prolonged PPV or advanced resuscitation at birth and have evidence of moderate to severe HIE.[10] This recommendation is based on the findings of several randomized clinical trials of neonatal therapeutic hypothermia.[39] The recommendations were not based on data from neonates treated after cardiopulmonary arrest in the nursery or NICU. According to the pediatric guidelines, it is reasonable for infants and children 24 hours or older who remain comatose after cardiopulmonary arrest to be treated with either TTM of 32°C to 34°C followed by TTM

of 36°C to 37.5°C, or only TTM of 36°C to 37.5°C.[11] There are no guidelines on the optimal postresuscitative temperature management of neonates outside the immediate newborn period who are less than 24 hours of age.

SYSTEM ISSUES TO CONSIDER

Avoiding Confusion on the Guideline to Follow

Confusion may result when either neonatal or pediatric resuscitation guidelines could be followed. For example, suppose a NICU uses neonatal guidelines for some patients and pediatric guidelines for others. In that case, team members may become confused about which resuscitation guidelines to use for a particular neonate. Evidence suggests that shared mental models correlate positively with superior performance and communication patterns.[40,41] Thus, clarity on the approaches to resuscitative practices and ensuring a shared mental model within the health care team on which resuscitation guidelines to follow is likely an important factor in improving outcomes from CPR.

Confusion around resuscitation guideline choice can be mitigated in several ways. The first and most important is having clear policies.[16] Ideally, the policies would be rooted in outcomes-based data. Unfortunately, there are no current data to guide decision-making in this area. Thus, policymakers should select the most appropriate approach for their specific situation (Table 3). Based on the policies, patients should be proactively identified, and signage should be used that specifies the recommended resuscitation guideline. Harer et al describe such an approach in a level IV NICU where pediatric resuscitation guidelines were used in select circumstances.[15]

After policies are developed and patient inclusion processes are in place, educational programs can be used for team training. Training can include case discussions and simulations. Team training events can help teams optimize

TABLE 3 Potential Approaches to Transitioning From Neonatal Resuscitation to Pediatric Advanced Life Support Guidelines for Hospitalized Neonates and Infants

Approach	Meaning	Example	Pros and Cons
Location-based	Resuscitation guidelines are based on the location of the patient in the hospital	Neonatal guidelines are used in the NICU; pediatric guidelines are used in the PICU and PCICU	Pros: easy to implement strategy; easier to conduct and maintain training; low likelihood of team confusion. Cons: older neonates in the NICU are resuscitated using neonatal guidelines designed for newborns; newborns in the PICU and PCICU are resuscitated using pediatric guidelines designed for infants; may not support neonates in the NICU with significant congenital heart disease or arrhythmias
Age-based	Resuscitation guidelines are based on the patient's age	Patients over 44 wks postmenstrual age[a] are resuscitated using pediatric guidelines; younger patients are resuscitated using neonatal guidelines	Pros: allows a transition between guidelines based on maturity of the patient. Cons: arbitrary cut point for transition; challenges conducting and maintaining training; risk of confusion among health care teams; may not support young neonates with significant congenital heart disease or arrhythmias
Patient-based	Resuscitation guidelines are based on the most likely etiology of arrest	Patients with arrhythmia and cardiac arrest are resuscitated using pediatric guidelines; Patients with respiratory arrest are resuscitated using neonatal guidelines	Pros: provides a physiologic-based approach, with an emphasis on high-quality CPR in patients with a primary cardiac etiology of arrest, and an emphasis on effective ventilation in patients with a primary respiratory etiology of arrest. Cons: it may be difficult to identify the etiology of arrest (eg, cardiac versus respiratory); challenges conducting and maintaining training; risk of confusion among health care teams
Provider-based	Resuscitation guidelines are based on the health care team's training and experience	Neonatal guidelines are used in the NICU, where providers are only required to take NRP; Pediatric guidelines are used in the PICU or PCICU, where providers are only required to take PALS; A hybrid approach may be used in units where providers take both NRP and PALS	Pros: aligns the resuscitation approach to the knowledge and skills of the health care team; Low likelihood of team confusion. Cons: older neonates in the NICU are resuscitated using neonatal guidelines designed for the newborn; young neonates in the PICU and PCICU are resuscitated using pediatric guidelines designed for infants; may not support neonates in the NICU with significant congenital heart disease or arrhythmias

[a] 44 wks postmenstrual age includes full-term gestation plus the 28 d of the "neonatal" period.

decision-making and avoid confusion in the details of resuscitation (eg, compression-to-ventilation ratios, etc). As part of a continuous quality improvement process, institutional resuscitation committees should review resuscitation performance to ensure policies are followed and determine if changes are needed. A robust system for postresuscitation debriefings is integral to CPR quality improvement and can help refine and improve resuscitative practices.[42]

Challenges in Maintaining Skills in Both Neonatal and Pediatric Resuscitation

Performing neonatal or pediatric resuscitation according to published guidelines is challenging for health care teams. Audiovisual recordings of real neonatal resuscitations by NRP-trained delivery teams have found clinically significant errors in patient assessment, PPV, and chest compressions.[43] Observations of PALS-trained residents managing a high-fidelity simulation of pVT found errors in starting compressions within 1 min of pulselessness, never starting compressions, and not defibrillating in ≤3 min after the onset of pVT.[44]

Additional training opportunities should be offered outside the standard NRP and PALS courses where health care teams are expected to maintain both neonatal and pediatric resuscitation skills. One option is in situ simulation-based training.[45] Another option is high-frequency, low-dose booster training.[45] Additionally, training sessions on PPV, chest compressions, and other technical skills using deliberate practice with a mastery learning approach should be considered.[45] Monitoring resuscitation team performance through chart audits or clinical debriefing can help identify specific high-yield opportunities for improvement.

The Cost of Training Health Care Teams in Both NRP and PALS

As noted by Doroba, maintaining both NRP and PALS provider status can be expensive and time-consuming.[16] These costs can be prohibitive for health care systems that employ hundreds of nurses, physicians, respiratory therapists, and other team members. In estimating training costs, the direct costs of course attendance (registration fees and books) and the indirect costs of salary and benefits paid to the employee while attending the course must be considered.

Some centers have attempted to overcome the challenges in crosstraining in both NRP and PALS by developing custom-made courses. For example, Harer et al reported a model where only nursing leaders in the NICU received formal PALS training.[15] A separate "Mini PALS" course was developed for other nurses. The Mini PALS course was given during nursing annual education sessions. Nurses also completed brief hands-on bedside simulations to practice PALS skills. Although this approach may be cost-effective, the outcomes of such training are unknown.

KNOWLEDGE GAPS AND FUTURE DIRECTIONS

Resuscitation science has advanced significantly in the past few decades.[10,11] Although scientific advancements have led to improvements in neonatal and pediatric resuscitation guidelines, there is still much to learn about the resuscitation of hospitalized neonates and infants. The neonatal resuscitation guidelines acknowledge gaps in the optimal approach to resuscitating newborns in the NICU and other settings outside the delivery room.[10] The pediatric resuscitation guidelines cite knowledge gaps on the appropriate age and setting to transition from neonatal to pediatric resuscitation protocols and the optimal ventilation and chest compression rates during CPR.[11] The authors of this report identified several other knowledge gaps. More data are needed on the incidence and etiologies of IHCA of neonates and infants in the NICU, PICU, and PCICU and outside the ICUs. The best airway management methods and pediatric anesthesia providers' role for IHCA need further clarification. Studies are needed on the optimal resuscitation approach for extremely premature infants, neonates with sudden unexpected postnatal collapse, bronchopulmonary dysplasia, pulmonary hypertension, congenital heart disease, ductal physiology, shock, and other pathophysiologic states common in the ICU. Finally, long-term, outcomes-based research is needed to explore the impact of using different resuscitation approaches on hospitalized neonates and infants.

CONCLUSIONS

The lack of robust scientific data makes it impossible to provide definitive recommendations on when to transition from neonatal to pediatric resuscitation guidelines for hospitalized neonates and infants. In this report, we have provided an overview and summary of the existing neonatal and pediatric guidelines and described some potential approaches to consider when addressing this issue. This report is intended for general consideration, is based primarily on expert opinion and clinical experience, and will not apply to all circumstances. Therefore, it is up to health care teams and institutions to decide if neonatal or pediatric guidelines are the best choice in a given location or situation. Each center and health system must determine its approach to the resuscitation of hospitalized neonates and infants, considering local circumstances, health care team preferences, and resource limitations.

ACKNOWLEDGMENTS

We thank the following American Heart Association (AHA) and American Academy of Pediatrics (AAP) personnel for their assistance and support in the development of this

work: Melissa Mahgoub, PhD, AHA Science and Health Advisor; Comilla Sasson, MD, PhD, AHA Vice President for Health Science, Healthcare Business Solutions; Ryan Morgan, MD, MTR, AHA Science Subcommittee of Emergency Cardiovascular Care Committee and Chair of ECC Pediatric Emphasis Group; Dianne Atkins, MD, AHA Chair of Emergency Cardiovascular Care Committee; Amber Rodriguez, PhD, AHA Senior Science and Health Advisor; Amber Hoover RN, MSN, AHA Science and Health Advisor; and Kaitlin Butterfield, MEd, AAP Senior Manager, Neonatal Resuscitation Program.

ABBREVIATIONS

AAP: American Academy of Pediatrics
AHA: American Heart Association
CPR: cardiopulmonary resuscitation
NRP: neonatal resuscitation program
PALS: pediatric advanced life support
PCICU: pediatric cardiac intensive care unit
pVT: pulseless ventricular tachycardia
VF: ventricular fibrillation

manuscript; and all authors critically reviewed and revised the manuscript, approved the final manuscript as submitted, and agree to be accountable for all aspects of the work.

DOI: https://doi.org/10.1542/peds.2023-064681

Address correspondence to Taylor Sawyer, DO, MBA, MEd, FAAP. E-mail: tlsawyer@uw.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FUNDING: No external funding.

CONFLICT OF INTEREST DISCLOSURES: Dr Schmölzer has disclosed principal investigator relationships with the Canadian Institute of Health Research (CIHR), Canadian Paediatric Society, Eunice Kennedy Shriver National Institute of Child Health & Human Development, and NIH. Dr Raymond has disclosed a consultant relationship with the Pediatric Heart Network and New England Research Institutes, Inc. Any relevant disclosures have been mitigated through a process approved by the AAP Board of Directors.

REFERENCES

1. Ali N, Lam T, Gray MM, et al. Cardiopulmonary resuscitation in quaternary neonatal intensive care units: a multicenter study. *Resuscitation.* 2021;159:77–84
2. Foglia EE, Langeveld R, Heimall L, et al. Incidence, characteristics, and survival following cardiopulmonary resuscitation in the quaternary neonatal intensive care unit. *Resuscitation.* 2017;110:32–36
3. Ahmad KA, Velasquez SG, Kohlleppel KL, et al. The characteristics and outcomes of cardiopulmonary resuscitation within the neonatal intensive care unit based on gestational age and unit level of care. *Am J Perinatol.* 2020;37(14):1455–1461
4. Hornik CP, Graham EM, Hill K, et al. Cardiopulmonary resuscitation in hospitalized infants. *Early Hum Dev.* 2016;101:17–22
5. Barr P, Courtman SP. Cardiopulmonary resuscitation in the newborn intensive care unit. *J Paediatr Child Health.* 1998;34(6):503–507
6. Berg RA, Nadkarni VM, Clark AE, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network. Incidence and outcomes of cardiopulmonary resuscitation in PICUs. *Crit Care Med.* 2016;44(4):798–808
7. Alten JA, Klugman D, Raymond TT, et al. Epidemiology and outcomes of cardiac arrest in pediatric cardiac ICUs. *Pediatr Crit Care Med.* 2017;18(10):935–943
8. Perlman JM, Risser R. Cardiopulmonary resuscitation in the delivery room. *Arch Pediatr Adolesc Med.* 1995;149(1):20–25
9. Barber CA, Wyckoff MH. Use and efficacy of endotracheal versus intravenous epinephrine during neonatal cardiopulmonary resuscitation in the delivery room. *Pediatrics.* 2006;118(3):1028–1034
10. Aziz K, Lee HC, Escobedo MB, et al. Part 5: neonatal resuscitation: 2020 American Heart Association Guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2020;142(16_suppl_2):S524–S550
11. Topjian AA, Raymond TT, Atkins D, et al; Pediatric Basic and Advanced Life Support Collaborators. Part 4: pediatric basic and advanced life support; 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2020;142(16_suppl_2):S469–S523
12. Sawyer T, Clark A, Ridout R. Infant resuscitation outside the delivery room in neonatal-perinatal and pediatric critical care fellowship programs: NRP or PALS? Results of a national survey. *J Neonatal Perinatal Med.* 2009;2(2):95–102
13. Ali N, Sawyer T, Barry J, Grover T, Ades A. Resuscitation practices for infants in the NICU, PICU and CICU: results of a national survey. *J Perinatol.* 2017;37(2):172–176
14. Gover A, Levy PT, Zaltsberg-Barak T, et al. Neonatal resuscitation in the NICU; challenges beyond NRP. *Acta Paediatr.* 2021;110(12):3269–3271
15. Harer MW, Konkol LJ, Limjoco JJ. Transitioning from NRP to a combined PALS-NRP resuscitation model at a level IV NICU. *J Perinatol.* 2022;42(11):1533–1534
16. Doroba JE. NRP versus PALS for infants outside the delivery room: not if, but when? *Crit Care Nurse.* 2021;41(6):22–27

17. Handley SC, Passarella M, Raymond TT, Lorch SA, Ades A, Foglia EE. Epidemiology and outcomes of infants after cardiopulmonary resuscitation in the neonatal or pediatric intensive care unit from a national registry. *Resuscitation.* 2021;165:14–22

18. Kalaniti K, Schmölzer GM, McNamara PJ. Neonatal resuscitation beyond the delivery room - does one protocol fit all? *Acta Paediatr.* 2015;104(10):971–973

19. Magid DJ, Aziz K, Cheng A, et al. Part 2: evidence evaluation and guidelines development: 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2020;142(16_suppl_2):S358–S365

20. Wyckoff MH, Greif R, Morley PT, et al; Collaborators. 2022 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: summary from the Basic Life Support; Advanced Life Support; Pediatric Life Support; Neonatal Life Support; Education, Implementation, and Teams; and First Aid Task Forces. *Circulation.* 2022;146(25):e483–e557

21. Kleinman ME, Chameides L, Schexnayder SM, et al. Part 14: pediatric advanced life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2010;122(18 Suppl 3):S876–S908

22. Marino BS, Tabbutt S, MacLaren G, et al; American Heart Association Congenital Cardiac Defects Committee of the Council on Cardiovascular Disease in the Young; Council on Clinical Cardiology; Council on Cardiovascular and Stroke Nursing; Council on Cardiovascular Surgery and Anesthesia; and Emergency Cardiovascular Care Committee. Cardiopulmonary resuscitation in infants and children with cardiac disease: a scientific statement from the American Heart Association. *Circulation.* 2018;137(22):e691–e782

23. Paradis NA, Martin GB, Rivers EP, et al. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. *JAMA.* 1990;263(8):1106–1113

24. Berg RA, Sutton RM, Reeder RW, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network (CPCCRN) PICqCPR (Pediatric Intensive Care Quality of Cardio-Pulmonary Resuscitation) Investigators. Association between diastolic blood pressure during pediatric in-hospital cardiopulmonary resuscitation and survival. *Circulation.* 2018;137(17):1784–1795

25. Vali P, Chandrasekharan P, Rawat M, et al. Hemodynamics and gas exchange during chest compressions in neonatal resuscitation. *PLoS One.* 2017;12(4):e0176478

26. Sobotka KS, Polglase GR, Schmölzer GM, Davis PG, Klingenberg C, Hooper SB. Effects of chest compressions on cardiovascular and cerebral hemodynamics in asphyxiated near-term lambs. *Pediatr Res.* 2015;78(4):395–400

27. Pasquin MP, Cheung PY, Patel S, et al. Comparison of different compression to ventilation ratios (2: 1, 3: 1, and 4: 1) during cardiopulmonary resuscitation in a porcine model of neonatal asphyxia. *Neonatology.* 2018;114(1):37–45

28. Solevåg AL, Dannevig I, Wyckoff M, Saugstad OD, Nakstad B. Extended series of cardiac compressions during CPR in a swine model of perinatal asphyxia. *Resuscitation.* 2010;81(11): 1571–1576

29. Solevåg AL, Dannevig I, Wyckoff M, Saugstad OD, Nakstad B. Return of spontaneous circulation with a compression:ventilation ratio of 15:2 versus 3:1 in newborn pigs with cardiac arrest due to asphyxia. *Arch Dis Child Fetal Neonatal Ed.* 2011;96(6):F417–F421

30. Sutton RM, Reeder RW, Landis WP, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network (CPCCRN). Ventilation rates and pediatric in-hospital cardiac arrest survival outcomes. *Crit Care Med.* 2019;47(11):1627–1636

31. Berg MD, Schexnayder SM, Chameides L, et al. Part 13: pediatric basic life support; 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2010;122(18 Suppl 3):S862–S875

32. Naim MY, Griffis HM, Berg RA, et al. Compression-only versus rescue-breathing cardiopulmonary resuscitation after pediatric out-of-hospital cardiac arrest. *J Am Coll Cardiol.* 2021;78(10):1042–1052

33. Goto Y, Funada A, Goto Y. Conventional versus chest-compression-only cardiopulmonary resuscitation by bystanders for children with out-of-hospital cardiac arrest. *Resuscitation.* 2018;122:126–134

34. Morgan RW, Reeder RW, Meert KL, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development/ Collaborative Pediatric Critical Care Research Network (CPCCRN) Pediatric Intensive Care Quality of Cardio-Pulmonary Resuscitation (PICqCPR) Investigators. Survival and hemodynamics during pediatric cardiopulmonary resuscitation for bradycardia and poor perfusion versus pulseless cardiac arrest. *Crit Care Med.* 2020;48(6):881–889

35. Schmölzer GM, Dawson JA, Kamlin CO, O'Donnell CP, Morley CJ, Davis PG. Airway obstruction and gas leak during mask ventilation of preterm infants in the delivery room. *Arch Dis Child Fetal Neonatal Ed.* 2011;96(4):F254–F257

36. Huynh T, Hemway RJ, Perlman JM. Assessment of effective face mask ventilation is compromised during synchronised chest compressions. *Arch Dis Child Fetal Neonatal Ed.* 2015;100(1):F39–F42

37. Panchangam C, Rodriguez C, Dyke Ii PC, Ohler A, Vachharajani A. A survey of academic neonatologists on neonatal electrical cardioversion and defibrillation. *Am J Perinatol.* 2021;40(13):1425–1430

38. Sawyer T, Strandjord T. Simulation-based procedural skills maintenance training for neonatal-perinatal medicine faculty. *Cureus.* 2014;6(4):e173

39. Jacobs SE, Berg M, Hunt R, Tarnow-Mordi WO, Inder TE, Davis PG. Cooling for newborns with hypoxic ischaemic encephalopathy. *Cochrane Database Syst Rev.* 2013;2013(1):CD003311

40. Espevik R, Johnsen BH, Eid J. Outcomes of shared mental models of team members in cross training and high-intensity simulations. *J Cogn Eng Decis Mak.* 2011;5(4):352–377

41. Mathieu JE, Heffner TS, Goodwin GF, Salas E, Cannon-Bowers JA. The influence of shared mental models on team process and performance. *J Appl Psychol.* 2000;85(2):273–283

42. Sawyer T, Loren D, Halamek LP. Post-event debriefings during neonatal care: why are we not doing them, and how can we start? *J Perinatol.* 2016;36(6):415–419

43. Yamada NK, Yaeger KA, Halamek LP. Analysis and classification of errors made by teams during neonatal resuscitation. *Resuscitation.* 2015;96:109–113

44. Hunt EA, Vera K, Diener-West M, et al. Delays and errors in cardiopulmonary resuscitation and defibrillation by pediatric residents during simulated cardiopulmonary arrests. *Resuscitation.* 2009;80(7):819–825

45. Cheng A, Magid DJ, Auerbach M, et al. Part 6: resuscitation education science: 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2020;142(16_suppl_2):S551–S579