Neonatal Resuscitation: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations

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Special Report—Neonatal Resuscitation: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations

Jeffrey M. Perlman, Co-Chair*, Jonathan Wyllie, Co-Chair*, John Kattwinkel, Dianne L. Atkins, Leon Chameides, Jay P. Goldsmith, Ruth Guinsburg, Mary Fran Hazinski, Colin Morley, Sam Richmond, Wendy M. Simon, Nalini Singhal, Edgardo Szyld, Masanori Tamura, Sithembiso Velaphi, on behalf of the NEONATAL RESUSCITATION CHAPTER COLLABORATORS

KEY WORDS
Arrhythmia, cardiopulmonary resuscitation, pediatrics, resuscitation


Note From the Writing Group: Throughout this article, the reader will notice combinations of superscripted letters and numbers (eg, “Peripartum Suctioning NRP-011A, NRP-012A”). These callouts are hyperlinked to evidence-based worksheets, which were used in the development of this article. An appendix of worksheets, applicable to this article, is located at the end of the text. The worksheets are available in PDF format and are open access.

Approximately 10% of newborns require some assistance to begin breathing at birth, and <1% require extensive resuscitation (LOE 41, 2). Although the vast majority of newborn infants do not require intervention to make the transition from intrapartum to extrauterine life, the large number of births worldwide means that many infants require some assistance to achieve cardiorespiratory stability. Newborn infants who are born at term and are breathing or crying and have good tone must be dried and kept warm. These actions can be provided with the baby lying on the mother’s chest and should not require separation of mother and baby.

All others need to be assessed to determine their need for one or more of the following actions in sequence:

A. Initial steps in stabilization (dry and provide warmth, position, assess the airway, stimulate to breathe)
B. Ventilation
C. Chest compressions
D. Medications or volume expansion

Progression to the next step is initially based on simultaneous assessment of 2 vital characteristics: heart rate and respirations. Progression occurs only after successful completion of the preceding step. Approximately 30 seconds is allotted to complete each of the first 2 steps successfully, reevaluate, and decide whether to progress to the next (see Figure: Newborn Resuscitation Algorithm).

Since publication of the 2005 International Consensus on CPR and ECC Science With Treatment Recommendations,3,4 several controversial neonatal resuscitation issues have been identified. The literature was researched and a consensus was reached on the assessment of oxygenation and role of supplementary oxygen, peripartum management of meconium, ventilation strategies, devices to confirm placement of an advanced airway (eg, tracheal tube or laryngeal mask airway), med-
ications, maintenance of body temperature, postresuscitation management, and considerations for withholding and discontinuing resuscitation. Educational techniques for teaching, assessing, and maintaining resuscitation knowledge and skills and issues regarding the personnel needed at cesarean sections were also debated. The following are the major new recommendations:

- Progression to the next step following the initial evaluation is now defined by the simultaneous assessment of 2 vital characteristics: heart rate and respirations. Oximetry should be used for evaluation of oxygenation because assessment of color is unreliable.
For babies born at term it is best to begin resuscitation with air rather than 100% oxygen.

Administration of supplementary oxygen should be regulated by blending oxygen and air, and the concentration delivered should be guided by oximetry.

The available evidence does not support or refute the routine endotracheal suctioning of infants born through meconium-stained amniotic fluid, even when the newborn is depressed.

The chest compression-ventilation ratio should remain at 3:1 for newborns unless the arrest is known to be of cardiac etiology, in which case a higher ratio should be considered.

Therapeutic hypothermia should be considered for infants born at term or near-term with evolving moderate to severe hypoxic-ischemic encephalopathy, with protocol and follow-up coordinated through a regional perinatal system.

It is appropriate to consider discontinuing resuscitation if there has been no detectable heart rate for 10 minutes. Many factors contribute to the decision to continue beyond 10 minutes.

Cord clamping should be delayed for at least 1 minute in babies who do not require resuscitation. Evidence is insufficient to recommend a time for clamping in those who require resuscitation.

**INITIAL ASSESSMENT AND INTERVENTION**

**Assessment of Cardiorespiratory Transition and Need for Resuscitation**

**Consensus on Science**

A prompt increase in heart rate remains the most sensitive indicator of resuscitation efficacy (LOE 5). Of the clinical assessments, auscultation of the heart is the most accurate, with palpation of the umbilical cord less so. However, both are relatively insensitive (LOE 2<sup>s</sup> and LOE 4<sup>t</sup>). Several studies have addressed the accuracy of pulse oximetry in measuring heart rate in the delivery room and have shown the feasibility of pulse oximetry during newborn resuscitation. However, none of these studies examined the impact of these measurements on resuscitation outcomes (LOE 4<sup>t</sup>). Pulse oximetry (SpO<sub>2</sub>) and heart rate can be measured reliably after 90 seconds from birth with a pulse oximeter designed to reduce movement artifact and a neonatal probe (LOE 4<sup>10</sup>). Preductal values, obtained from the right wrist or hand, are higher than postductal values<sup>8,11</sup> Applying the oximeter probe to the subject before connecting it to the instrument will produce reliable results more quickly (LOE 4<sup>10</sup>). There is clear evidence that an increase in oxygenation and improvement in color may take many minutes to achieve, even in uncompromised babies. Furthermore, there is increasing evidence that exposure of the newly born to hyperoxia is detrimental to many organs at a cellular and functional level. For this reason color has been removed as an indicator of oxygenation or resuscitation efficacy. The oximeter can be used to adjust the increase in oxygenation to that of the uncompromised baby born at term.

**Treatment Recommendations**

Heart rate should remain the primary vital sign by which to judge the need for and efficacy of resuscitation. Auscultation of the precordium should remain the primary means of assessing heart rate. There is a high likelihood of underestimating heart rate with palpation of the umbilical pulse, but this is preferable to other palpation locations.

For babies who require ongoing resuscitation or respiratory support or both, the goal should be to use pulse oximetry. The sensor should be placed on the baby’s right hand or wrist before connecting the probe to the instrument. Because of concerns about the ability to consistently obtain accurate measurements, pulse oximetry should be used in conjunction with and should not replace clinical assessment of heart rate during newborn resuscitation.

**Use of Supplementary Oxygen**

In term infants receiving resuscitation with intermittent positive-pressure ventilation, 100% oxygen conferred no advantage over air in the short term and resulted in increased time to first breath or cry or both (LOE 2<sup>12,13</sup>). Meta-analyses of these studies showed a decrease in mortality with the group for whom resuscitation was initiated with air.<sup>14,15</sup> There is evidence in newborn animal models of asphyxia that exposure to high concentrations of oxygen at resuscitation does not confer any clinical advantage and is potentially harmful to the cellular level.<sup>16,17</sup> Two animal models of hypoxia-ischemia and persistent bradycardia found that those resuscitated with room air rather than 100% oxygen developed untoward biochemical changes in the brain (LOE 5<sup>18,19</sup>). In preterm infants at <32 weeks’ gestation, if attempting to mimic the gradual rise in oxygen saturation of healthy term babies in the first 10 minutes after birth by titrating the concentration to the baby’s saturation, initial use of air or 100% oxygen is more likely to result in hypoxemia or hyperoxemia, respectively, than initiation of resuscitation with 30% or 90% oxygen and titration to oxygen saturation (LOE 2<sup>11,20</sup>). There is insufficient evidence in babies...
born at 32 to 37 weeks’ gestation to define the appropriate oxygen administration strategy.

**Treatment Recommendation**

In term infants receiving resuscitation at birth with positive-pressure ventilation, it is best to begin with air rather than 100% oxygen. If despite effective ventilation there is no increase in heart rate or if oxygenation (guided by oximetry) remains unacceptable, use of a higher concentration of oxygen should be considered.

Because many preterm babies of <32 weeks’ gestation will not reach target saturations in air, blended oxygen and air may be given judiciously and ideally guided by pulse oximetry. Both hyperoxemia and hypoxemia should be avoided. If a blend of oxygen and air is not available, resuscitation should be initiated with air.

**Peripartum Suctioning**

Peripartum suctioning was examined from 2 perspectives: (1) suctioning of the airway in depressed neonates born through clear amniotic fluid and (2) tracheal suctioning in depressed neonates born through meconium-stained amniotic fluid.

**Suctioning of the Upper Airway**

**Consensus on Science**

There is no evidence to support or refute suctioning of the mouth and nose of depressed neonates at birth when the infant is born through clear amniotic fluid. In healthy neonates suctioning of the mouth and nose is associated with cardiorespiratory complications (LOE 121,22). In infants who are intubated, sedated, or paralyzed following resuscitation, endotracheal suctioning in the absence of secretions may result in a decrease in oxygenation, an increase in cerebral blood flow and intracranial pressure, and a decrease in compliance (LOE 525).

**Treatment Recommendation**

Routine intrapartum oropharyngeal and nasopharyngeal suctioning for infants born with clear or meconium-stained amniotic fluid is no longer recommended.

**Tracheal Suctioning**

**Consensus on Science**

Depressed infants born through meconium-stained amniotic fluid are at increased risk of developing meconium aspiration syndrome (LOE 428,29). Although these infants are at increased risk of developing meconium aspiration syndrome, the use of tracheal suctioning has not been associated with a reduction in the incidence of meconium aspiration syndrome or mortality (LOE 436, LOE 527). No randomized controlled studies have compared intubation and tracheal suctioning and no tracheal suctioning in depressed infants.

**Treatment Recommendation**

The available evidence does not support or refute the routine endotracheal suctioning of depressed infants born through meconium-stained amniotic fluid.

**VENTILATION STRATEGIES**

Ventilation strategies were examined from 4 perspectives: (1) characteristics of the initial assisted breaths and the role of positive end-expiratory pressure (PEEP), (2) continuous positive airway pressure (CPAP) during or following resuscitation, (3) devices to assist ventilation, and (4) strategies when resources are limited.

**Initial Breaths**

**Consensus on Science**

Both longer and shorter inspiratory times are in clinical use for initial ventilation in term infants, but there are no randomized controlled trials comparing these 2 approaches. In a small case series in term infants, a prolonged initial inflation of 5 seconds produced a 2-fold increase in functional residual capacity compared with historic controls (LOE 428). A single randomized controlled trial in preterm infants of a 10-second sustained inflation followed by nasal CPAP compared with face mask ventilation demonstrated decreased need for intubation in the first 72 hours, shorter duration of ventilatory support, and reduced bronchopulmonary dysplasia (LOE 129). Two other randomized controlled trials failed to show a benefit from delivery room application of a sustained initial inflation followed by nasal CPAP (LOE 128,117). Multiple variables among the 3 randomized controlled trials, including mode of intervention (nasopharyngeal tube versus face mask, T-piece versus self-inflating bag), as well as the use of CPAP in the delivery room make it difficult to determine the effect of the initial sustained inflation on establishing a functional residual capacity in very preterm infants.

**Pressure**

There is no evidence to support the use of inflation pressures higher than those that are necessary to achieve improvement in heart rate or chest expansion. This can usually be achieved in term infants with an inflation pressure of 30 cm H₂O (LOE 428,32) and in preterm infants with pressures of 20 to 25 cm H₂O (LOE 435). Occasionally higher pressures are required (LOE 434). In immature animals, ventilation at birth with high tidal volumes associated with the generation of high peak inflation pressures for a few minutes causes lung injury, impaired gas exchange, and reduced lung compliance (LOE 535).

**Positive End-Expiratory Pressure**

There is no evidence to support or refute the value of PEEP during resuscitation of term infants. In preterm infants 1 small study did not show a
benefit from PEEP during initial stabilization in reducing the number of infants who required intubation in the delivery room (LOE 136). In studies of intubated immature animals the use of PEEP during initial stabilization after birth improved functional residual capacity, oxygenation, and lung compliance and reduced lung injury (LOE 537,38), but high levels of PEEP (8 to 12 cm H₂O) may reduce pulmonary blood flow and increase the risk of pneumothorax (LOE 539,40).

**Treatment Recommendation**

To establish initial lung inflation in apneic newborn infants, initiation of intermittent positive-pressure ventilation at birth can be accomplished with either shorter or longer inspiratory times. Initial peak inflating pressures necessary to achieve an increase in heart rate or movement of the chest are variable and unpredictable and should be individualized with each breath. If pressure is being monitored, an initial inflating pressure of 20 cm H₂O may be effective in preterm babies, but a pressure of 30 to 40 cm H₂O may be necessary in some term babies. If pressure is not being monitored, the minimal inflation required to achieve an increase in heart rate should be used. Providers should avoid creation of excessive chest wall movement during ventilation of preterm infants immediately after birth.

Although measured peak inflation pressure does not correlate well with volume delivered in the context of changing respiratory mechanics, monitoring of inflation pressure may help provide consistent inflations and avoid unnecessarily high pressures. If positive-pressure ventilation is required, an initial inflation pressure of 20 to 25 cm H₂O is adequate for most preterm infants. If prompt improvement in heart rate or chest movement is not obtained, then higher pressures to achieve effective ventilation may be needed. PEEP is likely to be beneficial during initial stabilization of apneic preterm infants who require positive-pressure ventilation and should be used if suitable equipment is available.

**Continuous Positive Airway Pressure**

**Consensus on Science**

For spontaneously breathing preterm infants at ≥25 weeks’ gestation who have signs of respiratory distress, there is no significant difference between starting CPAP or intubation and mechanical ventilation in the delivery room when considering death or oxygen requirement at 36 weeks postmenstrual age. In spontaneously breathing infants at 25 to 28 weeks’ gestation, CPAP compared with intubation reduced the rates of mechanical ventilation from 100% to 46% and surfactant use from 77% to 38% (LOE 141). In the same trial infants on CPAP had a significantly increased rate of pneumothorax (9% versus 3%) (LOE 141). There is no evidence to support or refute the use of CPAP in the term baby.

For very preterm infants, a multifaceted intervention, including PEEP, giving a sustained inflation and starting CPAP in the delivery room reduces the need for intubation and rate of mechanical ventilation within 72 hours and reduces incidence of bronchopulmonary dysplasia compared with positive-pressure ventilation with a self-inflating bag via a face mask (LOE 139). When compared with historic controls, use of delivery room CPAP for very premature infants was associated with a decrease in the requirement for intubation, days on mechanical ventilation, and use of postnatal steroids (LOE 435), although a small underpowered feasibility trial of delivery room CPAP/PEEP versus no CPAP/PEEP did not show a significant difference in immediate outcomes (LOE 139).

**Treatment Recommendation**

Spontaneously breathing preterm infants who have respiratory distress may be supported with CPAP or intubation and mechanical ventilation. The most appropriate choice may be guided by local expertise and preferences.

**Assisted Ventilation Devices**

**Consensus on Science**

There are no clinical studies in newborns requiring positive pressure during resuscitation to support or refute the superiority of the T-piece resuscitator over bag-mask ventilation in improving outcome. In mechanical models target inflation pressures are delivered more consistently when using T-piece resuscitators than with self-inflating bags or flow-inflating bags (LOE 542,43). In mechanical models PEEP is maintained more consistently with T-piece resuscitators compared with self-inflating bags or flow-inflating bags (LOE 544). In mechanical models the ability to deliver a sustained inflation is better with either a T-piece resuscitator or flow-inflating bag than with a self-inflating bag (LOE 542,45).

**Treatment Recommendation**

Ventilation of the newborn can be performed effectively with a flow-inflating bag, a self-inflating bag, or a pressure-limited T-piece resuscitator.

**Laryngeal Mask Airway**

**Consensus on Science**

In 1 randomized controlled trial (LOE 146) providers had similar success providing effective ventilation with either the laryngeal mask airway or face mask among newborns in the delivery room. In 1 retrospective cohort study (LOE 247) and 3 large case series (LOE 449) effective ventilation was achieved quickly using a laryngeal mask airway in newborns weighing >2000 g or delivered at ≥34 weeks’ gestation. In 1 randomized controlled trial (LOE 149) and 1 retrospective cohort study (LOE 250) providers had similar success providing effective ventilation using either...
the laryngeal mask airway or endotracheal tube among newborns in the delivery room. Although a single cohort study (LOE 2B) suggests that newborns resuscitated with a laryngeal mask may require less respiratory support after initial resuscitation, this conclusion is subject to significant selection bias. In multiple small case reports effective ventilation was achieved with a laryngeal mask airway when both face mask ventilation and endotracheal intubation were unsuccessful. There is limited evidence to evaluate the effectiveness of the laryngeal mask airway for newborns weighing <2000 g delivered at <34 weeks’ gestation, in the setting of meconium-stained amniotic fluid, during chest compressions, or for administration of emergency intratracheal medications.

Treatment Recommendation

The laryngeal mask airway should be considered during resuscitation of the newborn if face mask ventilation is unsuccessful and tracheal intubation is unsuccessful or not feasible. The laryngeal mask airway may be considered as an alternative to a face mask for positive-pressure ventilation among newborns weighing >2000 g or delivered at ≥34 weeks’ gestation. There is limited evidence, however, to evaluate its use for newborns weighing <2000 g or delivered at <34 weeks’ gestation. The laryngeal mask airway may be considered as an alternative to endotracheal intubation as a secondary airway for resuscitation among newborns weighing >2000 g or delivered at ≥34 weeks’ gestation. The laryngeal mask airway has not been evaluated in the setting of meconium-stained amniotic fluid, during chest compressions, or for administration of emergency intratracheal medications.

Upper Airway Interface Devices NRP-003A, NRP-003B

Consensus on Science

Within classes of interfaces, reports conflict about the ability to maintain a seal with an anatomically shaped mask compared with a soft round mask (LOE 5A). Delivery of positive-pressure ventilation via nasal prongs has been shown to be superior to delivery via a triangular face mask for outcomes of chest compressions and intubation (LOE 2C). It is likely that differences in clinical outcomes that have been reported in several studies may be attributable to the targeted intervention (ie, CPAP versus intermittent positive-pressure ventilation) rather than the interface. Nasal prongs may be a more effective device than face masks for providing respiratory support after birth (LOE 2B). There is insufficient evidence to support or refute the use of one type of mask over another for achieving clinical outcome, except that the Rendell-Baker style mask is suboptimal in achieving an adequate seal when used for newborns (LOE 5A).

Treatment Recommendations

Nasal prongs are an alternative way of giving respiratory support. Whichever interface is used, providers should ensure that they are skilled in using the interface devices available at the institution. Different masks must be held in different ways to appropriately reduce leak.

Exhaled Air Ventilation NRP-004A, NRP-004B

Consensus on Science

Mouth-to-mouth ventilation is less effective than a self-inflating bag or tube and mask in improving survival rates in newborns with birth asphyxia (LOE 3B). Use of mouth-to-mask ventilation at 30 inflations per minute is as effective as self-inflating bag-mask ventilation in increasing heart rate in the first 5 minutes after birth (LOE 2B). Mask-to-tube ventilation may cause infection in newborn infants (LOE 5B). Two studies (LOE 5A,5B) demonstrated that tube-to-mask ventilation can be easily taught and acceptable breaths delivered. However, tube-to-mask ventilation was more difficult to use (LOE 5A; LOE 3B).

Treatment Recommendation

Bag-mask ventilation is preferable to mouth-to-mask ventilation or tube-to-mask ventilation during neonatal resuscitation, but one of the latter two should be used when bag-mask devices are not available. Precautions must be taken because mouth-to-mask and mouth tube–to-mask ventilation are less comfortable and more tiring than bag-mask ventilation for the newborn at birth and may be associated with increased risk of infection in the infant and healthcare provider.

Monitoring During and After Intubation

Gas Monitoring Devices

Measurement of Tidal Volume NRP-005A, NRP-005B, NRP-005C

Consensus of Science

There are no studies that compare clinical outcomes in newborns after resuscitation with or without monitoring of tidal volume. In preterm animal models the tidal volume used during initial ventilation after birth may alter subsequent lung function and induce inflammation, but other factors, including the use and level of PEEP, appear to interact with tidal volume in determining specific effects (LOE 5A,62). It is unclear whether the absolute tidal volumes used affected outcomes. Studies in manikins and animals (LOE 5A,63) suggest that providers cannot maintain constant pressures or assess delivered volume during manual ventilation. The position of the mask and degree of leak may be improved by the use of a volume monitor (LOE 5A).
**Treatment Recommendations**

Ventilation during newborn resuscitation should aim to adequately inflate the lung while avoiding overinflation. There is insufficient evidence to recommend routine use of tidal volume monitoring in neonates receiving positive-pressure ventilation during resuscitation.

**Use of Exhaled CO₂ Detectors to Confirm Tracheal Tube Placement**

**Consensus on Science**

Studies (LOE 2) suggest that detection of exhaled CO₂ confirms tracheal intubation in neonates with cardiac output more rapidly and accurately than clinical assessment alone. False-negative readings have been reported during cardiac arrest (LOE 4) despite models suggesting efficacy (LOE 5). False-positive readings may occur with colorimetric devices contaminated with epinephrine (adrenaline), surfactant, and atropine (LOE 5). Neonatal studies have excluded infants who need extensive resuscitation. There is no comparative information to recommend any one method for detection of exhaled CO₂ in the neonatal population.

**Treatment Recommendation**

Detection of exhaled CO₂ in addition to clinical assessment is recommended as the most reliable method to confirm endotracheal placement in neonates with spontaneous circulation.

**Colorimetric CO₂ Detection to Assess Ventilation in Nonintubated Patients**

**Consensus on Science**

The use of colorimetric exhaled CO₂ detectors during face mask ventilation of small numbers of preterm infants in the intensive care unit (LOE 4) and the delivery room (LOE 4) has been reported and may help identify airway obstruction. It is unclear whether the use of exhaled CO₂ detectors during face mask ventilation confers additional benefit over clinical assessment alone. No risks attributed to the use of exhaled CO₂ detectors have been identified. The use of exhaled CO₂ detectors with other interfaces (eg, nasal airways, laryngeal masks) during positive-pressure ventilation in the delivery room has not been reported.

**Treatment Recommendation**

There is insufficient evidence to recommend routine use of colorimetric exhaled CO₂ detectors during mask ventilation of newborns in the delivery room.

**Circulatory Support**

**Chest Compressions**

**Consensus on Science**

In animal studies of asphyxial models of cardiac arrest, piglets resuscitated with a combination of chest compressions and ventilations had better outcomes than those resuscitated with ventilations or compressions alone (LOE 4). A further study in piglets suggested that sustained chest compressions had a deleterious effect on myocardial and cerebral perfusion, especially during prolonged resuscitation.

A physiologic mathematical modeling study suggested that using higher compression-ventilation ratios would result in underventilation of asphyxiated infants (LOE 5). The model predicts that between 3 and 5 compressions to 1 ventilation should be most efficient for newborns.

Manikin studies confirm that the 3:1 compression-ventilation ratio provides more ventilations per minute when compared with higher ratios, but the resuscitation is perceived as being more physically taxing, especially when performed by a lone rescuer (LOE 5). Adult manikin studies using 2 rescuers have shown that a 5:1 ratio provides better-quality chest compressions than a 15:2 ratio (LOE 5) but can result in more missed ventilations per cycle (LOE 5). A pediatric manikin study of mouth-to-mouth ventilation by a lone lay rescuer found equivalent minute ventilation for both the 15:2 and 5:1 ratios, but the 15:2 ratio produced more chest compressions per minute (LOE 5). With 2-rescuer CPR provided by nursing students, however, minute ventilation and compressions per minute were increased with the 5:1 ratio compared with the 10:2 and 15:2 ratios (LOE 5). When the 15:2 ratio was compared with the 30:2 ratio in a 1-rescuer model of medical personnel using adolescent, child, and infant manikins, more compression cycles could be achieved with the 30:2 ratio on all manikins with no apparent effect on quality of compressions (LOE 5). Effect on ventilation, however, was not assessed. One study in children suggested that CPR with rescue breathing is preferable to CPR alone when the arrest is of noncardiac etiology (LOE 5). There are no data regarding the optimum compression-ventilation ratios in neonates or neonatal models of primary cardiac versus predominantly asphyxial arrest.

Evidence from randomized studies in swine models (LOE 5), manikin studies (LOE 5), small case series (LOE 4), and cadavers (LOE 5) support the current practice of favoring the 2-thumb—encircling hands technique of chest compressions when compared with the 2-finger technique. The former method produces higher blood pressure, can sustain a consistent quality of compressions for a longer time, and is perceived as easier and less tiring for the provider. One manikin study involving a variety of medical or quasimedical personnel (LOE 5) found no difference in a number of qualitative measures between the 2 techniques other than significantly fewer compressions were judged as too shallow with the 2-thumb technique. One small case series in new-
borns found higher systolic blood pressure generated with the 2-finger technique when compared with the 2 thumb–encircling hands technique (LOE 4”). Both techniques, however, generated comparable and adequate diastolic pressures, a more important determinant of coronary perfusion. Compressions should be centered over the lower third of the sternum rather than the mid-sternum (LOE 509,34). Chest compression depth should favor one third the external anterior-posterior diameter of the chest rather than deeper compressions (LOE 506).

Treatment Recommendation
There is no evidence from quality human, animal, manikin, or mathematical modeling studies to warrant a change from the current compression-ventilation ratio of 3:1. Strategies should be considered for optimizing the quality of compressions and ventilations with as few interruptions as possible. Because ventilation is critical to reversal of newborn asphyxial arrest, any higher ratio that decreases minute ventilation should be introduced with caution. If the arrest is known to be of cardiac etiology, a higher compression-ventilation ratio should be considered (eg, 15:2).

Chest compressions in the newborn should be delivered by the 2 thumb—encircling hands method as the preferred option. Compressions should be centered over the lower third of the sternum and should compress the chest one third the anterior-posterior diameter. Any chest compressions should be performed in combination with adequate inflation breaths.

MEDICATIONS AND FLUID ADMINISTRATION
Epinephrine
Route and Dose of Epinephrine

Consensus on Science
Despite the widespread use of epinephrine during resuscitation, no controlled clinical trials have directly compared endotracheal and intravenous administration of epinephrine among neonates with a heart rate of <60 beats per minute despite adequate ventilation and chest compressions. Limited evidence from neonatal case series or case reports (LOE 496,97) indicates that epinephrine administered by the endotracheal route using a wide range of doses (0.003 mg/kg to 0.25 mg/kg) may result in return of spontaneous circulation (ROSC) or an increase in heart rate when intravenous access is not available. These case series are limited by inconsistent standards for epinephrine administration and are subject to both selection and reporting bias.

Evidence from 1 case series using rigorously defined standards for epinephrine administration and outcomes reporting indicates that endotracheal administration of epinephrine (0.01 mg/kg) is likely to be less effective than intravenous administration of the same dose (LOE 4”). This is consistent with evidence extrapolated from neonatal animal models indicating that higher doses (0.05 mg/kg to 0.1 mg/kg) of endotracheal epinephrine may be required to achieve increased blood epinephrine concentrations and a hemodynamic response equivalent to intravenous administration (LOE 509,19). Evidence extrapolated from adult animal models indicates that blood concentrations of epinephrine are significantly lower following endotracheal administration (LOE 509,101), and endotracheal doses ranging from 0.05 mg/kg to 0.1 mg/kg may be required to achieve ROSC (LOE 509).

Although it has been widely assumed that epinephrine can be administered faster by the endotracheal route than by the intravenous route, no clinical trials have evaluated this hypothesis. Two studies have reported cases of inappropriate early use of endotracheal epinephrine before airway and breathing are established (LOE 496,97). One case series describing in-hospital pediatric cardiac arrest suggested that survival was higher among infants who received their first dose of epinephrine by the endotracheal route; however, the time required for first dose administration using the endotracheal and intravenous routes was not provided (LOE 5103).

Despite the widespread use of epinephrine during resuscitation, no controlled clinical trials have evaluated the ideal dose of epinephrine among neonates with a heart rate of <60 beats per minute despite adequate ventilation and chest compressions. Evidence extrapolated from pediatric studies that included infants <1 year of age (LOE 5104,105) indicate no benefit from intravenous epinephrine doses ≥0.03 mg/kg. This is in contrast to a single pediatric case series using historic controls that indicated a marked improvement in ROSC using high-dose intravenous epinephrine (0.1 mg/kg) among children who had not responded to 2 doses of standard epinephrine (0.01 mg/kg) (LOE 5106). Further extrapolative evidence from a meta-analysis of 5 adult clinical trials indicates that high-dose intravenous epinephrine may increase ROSC but offers no benefit in survival to hospital discharge (LOE 5107). Evidence from a planned secondary analysis of a pediatric randomized controlled trial suggests an increased risk of mortality among children receiving high-dose intravenous epinephrine (0.1 mg/kg) (LOE 5104).

Additional evidence from 2 pediatric animal studies (LOE 5108,109) indicates that intravenous epinephrine ≥0.1 mg/kg increased risk of postresuscitation mortality and interfered with cerebral cortical blood flow and cardiac output. There are no published studies comparing standard- and high-dose endotracheal epinephrine in the neonatal population with hypoxic-hypercarbic arrest, and the ideal dose for endotracheal administration is unknown. Data from
neonatal case series and animal models suggest that higher doses (0.05 mg/kg to 0.1 mg/kg) of endotracheal epi
epinephrine may be required to achieve increased blood epinephrine concentrations and a hemodynamic response equivalent to intravenous administration (LOE 4\textsuperscript{19}).

**Treatment Recommendation**

If adequate ventilation and chest compressions have failed to increase the heart rate to >60 beats per minute, then it is reasonable to use epinephrine despite the lack of human neonatal data. If epinephrine is indicated, a dose of 0.01 to 0.03 mg/kg should be administered intravenously as soon as possible. If adequate ventilation and chest compressions have failed to increase the heart rate to >60 beats per minute and intravenous access is not available, then it is reasonable to administer endotracheal epinephrine. If epinephrine is administered by the endotracheal route, it is likely that a larger dose (0.05 mg/kg to 0.1 mg/kg) will be required to achieve an effect similar to that of the 0.01 mg/kg intravenous dose. Higher intravenous doses cannot be recommended and may be harmful.

**Volume Expansion**

**Consensus on Science**

Multiple case series support the use of volume expansion in babies with a history of blood loss, including some who are unresponsive to chest compressions (LOE 4\textsuperscript{19}). Many with pallor and tachycardia responded to volume expansion without having received chest compressions. In the absence of a history of blood loss there is limited evidence of benefit from administration of volume during resuscitation unresponsive to chest compressions/epinephrine (LOE 4\textsuperscript{11}) and some suggestion of potential harm from animal studies (LOE 5\textsuperscript{12,112}).

**Treatment Recommendation**

Early volume replacement with crystalloid or red cells is indicated for babies with blood loss who are not responding to resuscitation. There is insufficient evidence to support the routine use of volume administration in the infant with no blood loss who is refractory to ventilation, chest compressions, and epinephrine. Because blood loss may be occult, a trial of volume administration may be considered in babies who do not respond to resuscitation.

**Other Drugs**

Very rarely a narcotic antagonist (naloxone) may be useful after resuscitation. Naloxone is not recommended as part of the initial resuscitation for newborns born with respiratory depression in the delivery room. For the clinical situation of a newborn with respiratory depression after maternal opiate exposure, the focus needs to remain on effective ventilation and airway support for the persistently apneic newborn.

**Vascular Access**

**Consensus on Science**

Multiple clinical series and case reports suggest that fluids and medications can be successfully delivered by the intraosseous route during resuscitation of neonates when equipment or personnel skilled in establishing venous access are not available or if other vascular access sites (especially intravenous) cannot be successfully established within several minutes (LOE 4\textsuperscript{11,12}).

**Treatment Recommendation**

Temporary intraosseous access to provide fluids and medications to resuscitate critically ill neonates may be indicated following unsuccessful attempts to establish intravenous vascular access or when caregivers are more skilled at securing intraosseous access.

**SUPPORTIVE THERAPY**

**Temperature Control**

**Consensus on Science**

A large body of evidence supports the wrapping of newborn infants of <28 weeks’ gestation in polythene wraps or bags at birth without drying to reduce heat loss (LOE 1\textsuperscript{121,122}). Some of these infants were hyperthermic on admission to the neonatal intensive care unit, but it is unclear whether this is because they were born hot or be-
cause they became overheated during stabilization and transfer. In the absence of polythene wrapping, use of exothermic mattresses maintained the temperature of newborn infants weighing <1500 g within the normal range (LOE 2\textsuperscript{123}). A combination of exothermic mattresses and polythene wrapping during resuscitation is the most effective strategy to avoid hypothermia but may increase the risk of hyperthermia (LOE3\textsuperscript{124}). Delivery room temperatures of at least 26°C for newborns at <28 weeks' gestation should be maintained in a standard fashion. Infants with polythene wraps or bags maintained temperatures most effectively (LOE 4\textsuperscript{125}; LOE 3\textsuperscript{126}).

**Treatment Recommendation**

Newborn infants of <28 weeks' gestation should be completely covered in a polythene wrap or bag up to their necks without drying immediately after birth and then placed under a radiant heater and resuscitated or stabilized in a standard fashion. Infants should be kept wrapped until admission and temperature check. Hyperthermia should be avoided. Delivery room temperatures should be at least 26°C for infants of <28 weeks' gestation.

**POSTRESUSCITATION MANAGEMENT**

**Temperature**

**Hyperthermia** NRP-024A, NRP-024B

**Consensus on Science**

Infants born to febrile mothers have been reported to have a higher incidence of perinatal respiratory depression, neonatal seizures, cerebral palsy, and increased risk of mortality (LOE 4\textsuperscript{127,128}). There is no evidence to determine whether the fever or the cause of the fever increases the risk to the baby. In 1 study, neonatal fever at birth resolved spontaneously within 60 minutes (LOE 4\textsuperscript{129}). Adult animal trials show decreased central nervous system injury with antipyretic therapy for hyperthermia (LOE 5\textsuperscript{130}). In a randomized study high-dose corticosteroids lowered maternal temperature but were associated with an increased number of cases of asymptomatic bacteremia in neonates (LOE 2\textsuperscript{131}).

**Treatment Recommendation**

There is insufficient evidence to support or refute the routine use of interventions to lower maternal fever to reduce neonatal morbidity and mortality. There should be an increased awareness that the presence of maternal hyperthermia may lead to a need for neonatal resuscitation. The goal is to achieve normothermia and avoid iatrogenic hyperthermia.

**Therapeutic Hypothermia** NRP-024A, NRP-024B

**Consensus on Science**

A large body of evidence from 3 large randomized studies (LOE 1\textsuperscript{132–134}) and 2 small randomized trials (LOE 1\textsuperscript{135,136}) demonstrated that induced hypothermia (33.5° to 34.5°C) implemented within 6 hours of birth in term infants at highest risk for brain injury (as defined by specific protocols) and with further treatment in neonatal intensive care units is associated with significantly fewer deaths and less neurodevelopmental disability at 18-month follow-up. The number needed to treat is 9.\textsuperscript{137} Both cooling methods (systemic versus selective head cooling) were shown to be effective, but none of the studies compared them directly. The randomized trials produced remarkably consistent results despite using different methods of cooling.\textsuperscript{138}

**Treatment Recommendations**

Newly born infants born at or near-term with evolving moderate to severe hypoxic-ischemic encephalopathy should be offered therapeutic hypothermia. Whole body cooling and selective head cooling are both appropriate strategies. Cooling should be initiated and conducted under clearly defined protocols with treatment in neonatal intensive care facilities and with the capability for multidisciplinary care. Treatment should be consistent with the protocols used in the randomized clinical trials (ie, begin within 6 hours of birth, continue for 72 hours after birth, and rewarmed over at least 4 hours). Carefully monitor for known adverse effects of cooling, eg, thrombocytopenia and hypotension. All treated infants should be followed up longitudinally.

**General Supportive Care**

**Glucose** NRP-019A, NRP-019B

**Consensus on Science**

Newborns with lower blood glucose levels have a higher incidence of brain injury and adverse outcomes after a hypoxic-ischemic insult, although no specific level associated with worse outcome has been identified (LOE 4\textsuperscript{139}; LOE 3\textsuperscript{140}). Increased glucose levels after hypoxia-ischemia do not appear to have adverse effects in studies of pediatric patients (LOE 5\textsuperscript{141}) or in animal studies (LOE 5\textsuperscript{142}) and may be protective (LOE 5\textsuperscript{143}). However, no randomized controlled trials have examined this question. Due to the paucity of data, no specific target glucose concentration range can be identified at present.

**Treatment Recommendation**

Intravenous glucose infusion should be considered as soon as practical after resuscitation, with the goal of avoiding hypoglycemia.

**Timing of Cord Clamping** NRP-030A, NRP-030B, NRP-030C, NRP-030D

**Consensus on Science**

For the uncomplicated birth at term there is evidence of a benefit to delaying cord clamping for a minimum time ranging from 1 minute until the cord stops pulsating after delivery. Those with delayed clamping had improved iron status through early infancy but were more likely to receive phototherapy (LOE 1\textsuperscript{144}).
For an otherwise uncomplicated preterm birth, there is evidence of a benefit to delaying cord clamping for a minimum time ranging from 30 seconds to 3 minutes after delivery. Those who experienced delayed clamping in this group had higher blood pressures during stabilization and a lower incidence of intraventricular hemorrhage (LOE 1145) and received fewer blood transfusions but were more likely to receive phototherapy (LOE 2144). There are limited data on the hazards or benefits of delayed cord clamping in the nonvigorous infant.146,147

**Treatment Recommendation**

Delay in umbilical cord clamping for at least 1 minute is recommended for newborn infants not requiring resuscitation. There is insufficient evidence to support or refute a recommendation to delay cord clamping in babies requiring resuscitation.

**WITHHOLDING OR DISCONTINUING RESUSCITATIVE EFFORTS**

Noninitiation of Resuscitation

**Consensus on Science**

For neonates at the margins of viability or those with conditions which predict a high risk of mortality or morbidity, attitudes and practice vary according to region and availability of resources (LOE 4149). Social science studies indicate that parents would like a larger role in the decisions to start resuscitation and continue life support of severely compromised newborns. Opinions among neonatal providers vary widely regarding the benefits and disadvantages of aggressive therapies in such newborns (LOE 4149,150). Some data are available to help identify conditions associated with high mortality and poor outcome (LOE 4151,152). Such conditions may include extreme prematurity and anomalies that predict extreme morbidity or early death. Treatment and outcome of infants at the margins of viability may be influenced by factors in addition to gestational age and birthweight.153 Noninitiation of resuscitation and withdrawal of cardiorespiratory support are ethically equivalent.154

**Treatment Recommendation**

When gestation, birth weight, or congenital anomalies are associated with almost certain early death and an unacceptably high morbidity is likely among the rare survivors, resuscitation is not indicated. In conditions associated with a high rate of survival and acceptable morbidity, resuscitation is nearly always indicated. In conditions associated with uncertain prognosis, when there is borderline survival and a relatively high rate of morbidity and when the burden to the child is high, the parents’ views on resuscitation should be supported. There should be a consistent and coordinated approach from the obstetric and neonatal teams in applying these guidelines and in communicating with the parents in developing an agreed-upon management plan when possible. Once resuscitation is initiated it may be appropriate to subsequently decide to discontinue cardiorespiratory support and offer comfort care.

**Discontinuation of Resuscitation**

**Consensus on Science**

Available evidence, albeit from relatively small numbers of babies, suggests that babies born without a heart rate that has not returned by 10 minutes of age are likely to either die or have severe neurologic disability (LOE 4155,156). It is not known whether there was significant selection bias in many of these studies, nor indeed that the babies included in these studies did receive “good-quality resuscitation.” One study with a large contemporary cohort of infants (some randomized to postresuscitation hypothermia) indicates that in babies born without a detectable heart rate, the lack of ROSC after 10 minutes of age is associated with survival without severe neurologic deficit in a small number of the survivors (LOE 4157). Data are not available regarding the number of infants who were deemed too sick for study entry or who died before enrollment. These factors may have resulted in a significant over-estimation of the rate of intact survival among infants with an Apgar score of 0 at 10 minutes. In all reported series the cause of the asphyxia and the efficacy of the resuscitation process were not elucidated.

The evidence from 7 LOE 5 studies is insufficient to support or refute any recommendation regarding how much time should elapse with a heart rate of <60 but >0 beats per minute before discontinuing resuscitative efforts.

**Treatment Recommendation**

In a newly born baby with no detectable heart rate which remains undetectable for 10 minutes, it is appropriate to then consider stopping resuscitation. The decision to continue resuscitation efforts when the infant has a heart rate of 0 for longer than 10 minutes is often complex and may be influenced by issues such as the presumed etiology of the arrest, gestation of the baby, potential reversibility of the situation, and the parents’ previously expressed feelings about acceptable risk of morbidity.

The evidence of outcome when the heart rate is <60 beats per minute at birth and persists after 10 or 15 minutes of continuous and adequate resuscitative efforts at delivery is insufficient to guide decisions as to whether to withhold or to continue resuscitation.

**Personnel Needs at Elective Cesarean Sections**

**Consensus on Science**

Retrospective studies show that delivery by cesarean section at term under regional anesthesia is associated with a
small increase in risk of receiving assisted ventilation during neonatal resuscitation compared with unassisted vaginal birth. The number needed to treat equals 35 (LOE 4159,160). Five retrospective studies showed that delivery by cesarean section at term under regional anesthesia did not increase the risk of requirement for intubation during neonatal resuscitation compared with unassisted vaginal birth (LOE 4161,162). There is no evidence addressing this question in babies born at 34 to 36 weeks’ gestation.

**Treatment Recommendations**
When an infant without antenatally identified risk factors is delivered at term by cesarean section under regional anesthesia, a provider capable of performing assisted ventilation should be present at the delivery. It is not necessary for a provider skilled in neonatal intubation to be present at that delivery.

**EDUCATIONAL TECHNIQUES FOR TEACHING, ASSESSING, AND MAINTAINING RESUSCITATION KNOWLEDGE AND SKILLS**

**Simulation** NRP-033A, NRP-033B, EIT-001A, EIT-001B

**Consensus on Science**
There is a lack of uniformity in the definition of simulation as a learning methodology, determination of relevant outcomes, and use of appropriate measurement tools. Use of simulation as an adjunct to traditional education methodologies may enhance performance of healthcare professionals in actual clinical settings (LOE 1163; LOE 3164) and simulated resuscitations (LOE 1165; LOE 2166). Some studies did not show any difference in performance between standard training and simulation training in a clinical setting (LOE 1167) or using other means of evaluation (LOE 1168). No studies were found that revealed simulation-based training produced inferior results compared with traditional methodologies.

**Treatment Recommendations**
Simulation should be used as a methodology in resuscitation education. The most effective interventions and evaluation methodologies remain to be defined.

**Briefings and Debriefings**

**Consensus on Science**
Evidence from 1 prospective randomized controlled study (LOE 1169) and 17 other studies (LOE 3 to 4) of briefings and debriefings document improvement in the acquisition of content knowledge, technical skills, or behavioral skills required for effective and safe resuscitation. Only a single study (LOE 4170) revealed no effect of briefing/debriefing on performance, and no studies indicated the use of briefings and debriefings had any negative effects.

**Treatment Recommendations**
It is reasonable to recommend the use of briefings and debriefings during learning activities while caring for simulated patients and during clinical activities.

**ACKNOWLEDGMENTS**
We thank the following individuals (the Neonatal Resuscitation Chapter Collaborators) for their collaborations on the worksheets contained in this section: Khalid Aziz; David Boyle; Steven Byrne; Peter Davis; William A. Engle; Marilyn B. Escobedo; Maria Fernanda de Almeida; David Field; Judith Finn; Louis P. Halamek; Jane E. McGowan; Douglas D. McMillan; Lindsay Mildenhall; Rintaro Mori; Susan Niemeyer; Colm O’Donnell; Yacov Rabi; Steven A. Ringer; Jasmeet Soar; Benjamin J. Stenson; Enrique Udaeta; Dharmapuri Vidyasagar; Michael Watkinson; Gary M. Weiner; and Myra H. Wyckoff.
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<tbody>
<tr>
<td>Jeffrey M. Perlman</td>
<td>Weill Cornell Medical College—Professor of Pediatrics</td>
<td>NIH funding- Co-Investigator— Improving antimicrobial prescribing practices in the NICU</td>
<td>None</td>
<td>University of Miami, and Cook County Chicago</td>
<td>None</td>
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<tr>
<td>John Kattwinkel</td>
<td>University of Virginia—Professor of Pediatrics</td>
<td>*American Academy of Pediatrics research grant to study resuscitators detection of compliance while administering positive pressure ventilation by resuscitation bag</td>
<td>None</td>
<td>None</td>
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<td>None</td>
<td>*Curley vs Gordon et al. Boston, MA (still active)</td>
</tr>
<tr>
<td>Dianne L. Atkins</td>
<td>University of Iowa; Prof.</td>
<td>None</td>
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<tr>
<td>Leon Chameides</td>
<td>Emeritus Director, Pediatric Cardiology; Clinical Professor, University of Connecticut</td>
<td>None</td>
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<tr>
<td>Jay P. Goldsmith</td>
<td>Pediatric Medical Group—Single specialty multi-site group—Neonatologist</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Ruth Guinsburg</td>
<td>Federal University of Sao Paulo—Full Professor of Pediatrics</td>
<td>None</td>
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<tr>
<td>Mary Fran Hazinski</td>
<td>Vanderbilt University School of Nursing—Professor; AHA ECC Product Development— Senior Science Editor</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Colin Morley</td>
<td>Retired Professor of Neonatal Medicine</td>
<td>None</td>
<td>None</td>
<td>Honoraria *Japanese Neonatal Society *Neonatal Ventilation and Resuscitation— Zagreb, Croatia *UK Middlesborough Neonatal Symposium</td>
<td>None</td>
<td>*Drager Medical about equip design *Education video on neonatal CPAP</td>
<td>None</td>
</tr>
<tr>
<td>Sam Richmond</td>
<td>UK National Health Service—Consultant Neonatologist</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Wendy M. Simon</td>
<td>American Academy of Pediatrics—Director of Life Support Programs</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Nalini Singhal</td>
<td>University of Calgary—Professor</td>
<td>*AAP grant looking at effect of PEEP with and with oxygen on resuscitation Developing a International program for resuscitation, Helping Babies Breath</td>
<td>None</td>
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<tr>
<td>Edgardo Sylt</td>
<td>Fundasamn, Foundation for Womens and Infant Health—Executive Director of a non profit institution (NGO)</td>
<td>None</td>
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<tr>
<td>Masanori Tamura</td>
<td>Saitama Medical Center, Saitama Medical University—Professor and Chairman, Department of Pediatrics</td>
<td>None</td>
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<tr>
<td>Sithembeniso Velaphi</td>
<td>Univ of the Witwatersrand Univ—Lecturer; ChrisHan Baragwanath hosp Gnt hosp, principal specialist</td>
<td>None</td>
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*Modest.
†Significant.

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<tr>
<td>Khalid Aziz</td>
<td>University of Alberta—Associate Professor</td>
<td>None</td>
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<tr>
<td>David Boyle</td>
<td>Indiana University School of Medicine, Associate Professor of Pediatrics; University Pediatric Associates, Staff Neonatologist</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Steven Byrne</td>
<td>South Ties Hospital Foundation NHS Trust; National Health Service Trust</td>
<td>None</td>
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<tr>
<td>Peter Davis</td>
<td>The Royal Women’s Hospital, Melbourne, Australia—Staff Neonatologist</td>
<td>None</td>
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<td>William A Engle</td>
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<td>Marilyn Escobedo</td>
<td>University of Oklahoma—Professor of Pediatrics</td>
<td>None</td>
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<tr>
<td>Maria Fernanda de Almeida</td>
<td>Federal University of Sali Paulo: Full time work (40 h/week) at Neonatal Division—Department of Pediatrics—Assoc. Prof; Brazilian Pediatric Society: Voluntary work at Brazilian Neonatal Resuscitation Program-NRP Steering Committee—Co-chair</td>
<td>None</td>
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<td>David Field</td>
<td>University of Leicester: Higher educational institution—UK Government funded—Professor of Neonatal Medicine</td>
<td>None</td>
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<tr>
<td>Judith Finn</td>
<td>University of Western Australia—Professor</td>
<td>†Multiple National Health and Medical Research Grants NH &amp; MRD, National Heart Foundation Australia and State Government grants of &gt;$10,000 since 1999. A—No money came to me—all came to my University to employ research staff and meet research expenses. No grants were directly related to any topic on which I am undertaking a Worksheet and none involved the trialing of a commercial product</td>
<td>None</td>
<td>Less than $1000 from the Japanese Resuscitation Council to speak at their JRC Conference in Osaka in 2009</td>
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<td>Louis P. Halamek</td>
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<td>Lindsay Mildenhall</td>
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<td>Susan Niermeyer</td>
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<td>Steven A. Ringer</td>
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<td></td>
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<td>Jasmeet Soar</td>
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<tr>
<td>Benjamin J. Stenson</td>
<td>United Kingdom Public Health Service—Consultant Neonatologist</td>
<td>None</td>
<td>None</td>
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<td>None</td>
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<tr>
<td>Enrique Udaeta</td>
<td>Medica Sur Lomas—Private Maternity Hospital—Director Department of Neonatology</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Dharmapuri Vidyasagar Michael Watkinson</td>
<td>University of Illinois Professor emeritus Professor emeritus NHS Heart of England Foundation Trust, Birmingham, UK This is an NHS hospital in England Consultant neonatologist</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Gary M. Weiner</td>
<td>St. Joseph Mercy Hospital—Attending Neonatologist</td>
<td>None</td>
<td>$\text{†}$Received equipment on loan IS resuscitation mannequins, 2 sets of video recording equipment from Laerdal Medical Corporation to be used to complete a research project evaluating educational methods for teaching neonatal resuscitation. The value of the on loan equipment is approximately $35,000</td>
<td>None</td>
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<tr>
<td>Myra H. Wyckoff</td>
<td>UT Southwestern Medical Center at Dallas—Associate Professor of Pediatrics</td>
<td>$\text{†}$$\text{†}$, American Academy of Pediatrics Neonatal Resuscitation Program. The ergonomics of neonatal cardiac compressions. $71,000 January 2008–2009 The funding comes to the institution “Co-Investigator (Mentor), American Academy of Pediatrics Neonatal Resuscitation Program Young Investigator Grant. Effectiveness of Plastic Head Coverings for Hypothermia Prevention in Preterm Newborns. January 2009–January 2010, $10,000 The funding comes to the institution</td>
<td>Feb 5, 2009 Pediatric Grand Rounds. University of Oklahoma Health Sciences Center. OKC, OK</td>
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### APPENDIX

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<td>EIT</td>
<td>EIT-001A</td>
<td>For resuscitation teams (P), do briefings/debriefings (I), when compared to no briefings/debriefings (C), improve performance or outcomes (Q)? INTERVENTION</td>
<td>Debriefing of CPR performance</td>
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<td>In participants undergoing BLS/ALS courses (P), does the inclusion of more realistic techniques (eg. high-fidelity manikins, in-situ training) (I), as opposed to standard training (eg. low-fidelity, education centre) (C), improve outcomes (eg. skills performance on manikins, skills performance in real arrests, willingness to perform etc.) (O)?</td>
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<td>Jordan Duval-Arnould, Elizabeth A. Hurt</td>
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<td>High fidelity training</td>
<td>Judith Finn</td>
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<td>For neonates requiring resuscitation (P), is any adjunct measure (eg. CO₂ detection, pulse oximeter) as effective as the usual clinical findings (eg. heart rate, chest movement) effective to improve outcome (O)?</td>
<td>Adjuncts: CO₂ detection, pulse oximeter</td>
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<td>In the neonates infant (preterm and term) receiving respiratory support (P), does the use of CPAP (I) versus no CPAP or IPPV (C) improve outcome — specify (O)?</td>
<td>CPAP and IPPV</td>
<td>Colm O’Donnell</td>
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<td>CPAP and IPPV</td>
<td>Douglas D. McMillan</td>
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<td>In neonates receiving respiratory support (P) does the use of face mask interface (I) versus CPAP, NCPAP, NC (C) (excluding intubation) improve outcome (O)?</td>
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<td>Colin Morley</td>
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<td>In neonates receiving resuscitation (P) does the use of mouth-to-mouth, mouth-to-mask, mouth tube to mask (I) as compared to a self-inflating bag (C) give equivalent outcomes (stable spontaneous breathing) (O), when devices for delivering PPV are not available?</td>
<td>Self-inflating bag vs mouth techniques</td>
<td>Nalini Singhal</td>
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<td>Lindsay Mildenhall</td>
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<td>In neonates (P) receiving chest compressions does the two thumb (I) versus two finger (C) method of administration improve outcome (O)? In neonates (P) receiving chest compressions does the two thumb (I) versus two finger (C) method of administration improve outcome (O)?</td>
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<td>Among neonates (&lt;28 days) with a HR &lt; 60 bpm despite adequate ventilation and chest compressions, does the IV route compared with the ET route of epinephrine administration: 1. Increase heart rate &gt; 100 bpm faster, 2. Increase ROSC, or 3. Increase survival to discharge?</td>
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<td>Epinephrine dose</td>
<td>Jonathan Wyllie</td>
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<td>Marilyn B. Escobedo</td>
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<td>In depressed neonates with clear amniotic fluid (P) does suctioning of the mouth and nose (I) versus none (C) improve outcome (O)?</td>
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<td>Supplemental glucose</td>
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<td>Sodium bicarbonate</td>
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<td>Hypothermia (induced)</td>
<td>Jeffrey Perlman</td>
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<td>In term neonates at risk for hypoxic-ischemic encephalopathy secondary to intra-partum hypoxia (P) does selective/whole body cooling (O) versus standard therapy (C) result in improved outcome (D)?</td>
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<td>Peter Davis</td>
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<td>Duration of CPR with asystole and outcome</td>
<td>Steve Byrne</td>
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<td>Duration of CPR with bradycardia and outcome</td>
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<td>In neonates at the limits of viability or anomalies associated with lethal outcomes (P) does the non inflation (I) versus inflation (C) of resuscitation result in an outcome that is ethically justified (O)?</td>
<td>Futility resuscitation rules</td>
<td>Steve Byrne</td>
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<td>In depressed neonates requiring positive pressure ventilation (P) does the administration of longer inspiratory times, higher inflation pressures, use of PEEP (I) as compared to standard management (C) improve outcome (O)?</td>
<td>Ventilation times and pressures</td>
<td>David Boyle</td>
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<td>In neonates requiring resuscitation and unresponsive to chest compressions/epinephrine (P) does the administration of volume (G) versus no volume (C) improve outcome (O)?</td>
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<td>Susan Niemeyer</td>
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<td>In neonates born to febrile mothers (P) does intervention to normalize temperature (I), compared to standard care (C) improve outcome (O)?</td>
<td>Maternal fever</td>
<td>Jeffrey Perlman</td>
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<td>Impact of realistic training on skills performance</td>
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Jeffrey M. Perlman, Jonathan Wyllie, John Kattwinkel, Dianne L. Atkins, Leon Chameides, Jay P. Goldsmith, Ruth Guinsburg, Mary Fran Hazinski, Colin Morley, Sam Richmond, Wendy M. Simon, Nalini Singhal, Edgardo Szyld, Masanori Tamura, Sithembiso Velaphi and on behalf of the NEONATAL RESUSCITATION CHAPTER COLLABORATORS

*Pediatrics* 2010;126;e1319-e1344; originally published online Oct 18, 2010; DOI: 10.1542/peds.2010-2972B

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