Pitfalls in Neonatal Resuscitation

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Before the 1960s, no consistent technique was used for newborn resuscitations. Efforts to standardize the process began with the 1966 National Conference on Cardiopulmonary Resuscitation. This resulted in the publication of a standardized methodology of newborn resuscitation by the American Heart Association in 1974 \cite{1}. In the 1980s, the American Heart Association collaborated with the American Academy of Pediatrics to formalize the technique that is known as the Neonatal Resuscitation Program (NRP). The program was based upon earlier educational materials that were developed at the Drew Postgraduate Medical School in Los Angeles by Bloom and Cropley \cite{2}. A system was developed to disseminate NRP throughout the United States and the course was offered to community hospitals in 1987 \cite{3}. Although modifications and clarifications were made to NRP in 1990 \cite{4}, 1994 \cite{5}, and 2000 \cite{6}, the fundamental principles that were developed in the 1970s and 1980s remain in use today.

Since its introduction, NRP has been accepted widely and rapidly became the authoritative technique for neonatal resuscitation. NRP has been taught in more than 80 countries; there are more than 1,500,000 trained providers in the United States. NRP is taught to resuscitators of newborns in virtually every hospital in the United States.

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This article is not intended to teach or review the specific techniques of newborn resuscitation; the complete program has been published elsewhere [6,14]. Rather, this article considers some of the most common errors of newborn resuscitation with strategies and tactics to reduce these errors. This article emphasizes those pitfalls that have a serious adverse effect on the infant, but will not address those that may be common but of little, if any, clinical significance. Specifically, the article discusses the need for skilled resuscitators; correct and incorrect intubation techniques; suctioning of meconium stained infants; and management of the postresuscitator problems of hypoglycemia, hypocarbia, and hypotension. By following the recommendations of this article, one can improve the likelihood for a successful outcome of a neonatal resuscitation.

Unskilled resuscitators

Approximately 10% of all newborns require resuscitation at birth [6]. Most of these resuscitations can be anticipated from risk factors that are associated with the pregnancy, labor, and delivery. The need for significant resuscitation is unanticipated in approximately 1% to 3% of “low-risk” deliveries. Annibale and colleagues [15] reviewed almost 12,000 low-risk deliveries. Approximately 1% of the low-risk vaginal births had a 1-minute Apgar score of three or less and a similar number required positive pressure ventilation during the resuscitation. Approximately 2% of the low-risk Cesarean births had a 1-minute Apgar score of three or less and 3% required positive pressure ventilation. Mitchell and colleagues [16] developed a prospective self-reporting chart audit to determine the frequency of resuscitation interventions in Canada. Of the 783 resuscitations that were reported to the audit, the need for resuscitation was not anticipated in 596 (76%). Because of the need for vigorous resuscitation efforts in a significant number of low-risk deliveries, a fundamental principle of the NRP requires that at least one skilled resuscitator be immediately available at every delivery.

At every delivery, there should be at least one person whose primary responsibility is the baby and who is capable of initiating resuscitation. That person—or someone else who is immediately available—should have the skills that are required to perform a complete resuscitation, including endotracheal intubation and administration of medications. It is not sufficient to have someone “on call” (either at home or in a remote area of the hospital) for newborn resuscitations in the delivery room. When resuscitation is needed, it must be initiated without delay. In the case of an anticipated high-risk birth, two, three, or even four people who have varying degrees of resuscitation skills may be needed
at the delivery [6]. The delivering obstetrician and obstetric nursing staff must be aware of this standard and be prepared to serve as the resuscitation team leader or arrange for the immediate availability of a skilled resuscitator at every delivery.

It also is the hospitals’ responsibility to develop systems to assure that skilled resuscitators are available at every delivery. The Guidelines for Perinatal Care, published jointly by the American Academy of Pediatrics and The American College of Obstetricians and Gynecologists, states that “the provision of services and equipment for resuscitation should be planned jointly by the directors of the departments of obstetrics, anesthesia, and pediatrics, with the approval of the medical staff” [14]. The NRP text states that “each hospital is responsible for determining the level of competence and qualifications required for someone to assume clinical responsibility for neonatal resuscitation” [6].

It is a common misconception that the skilled resuscitator who serves as the team leader must be a pediatrician. Obstetricians, anesthesiologists [17], family practitioners [18], staff nurses [19], respiratory therapists [20,21], pediatric residents [22], nurse midwives, advanced practice neonatal nurses, and nurse-anesthetists can master the techniques of NRP and can serve as the team leader [14]. After vaginal births, the obstetrician, family practitioner, or nurse midwife can leave the mother to perform the newborn resuscitation. During a Cesarean section, however, the operating physician usually is not available to perform the resuscitation and another skilled resuscitator must be present.

Frequently, pediatricians are called upon to serve as the primary newborn resuscitator at Cesarean sections. Levine and colleagues [23] reviewed 17,867 deliveries and compared Apgar scores from three groups: low-risk vaginal deliveries, Cesarean sections with regional anesthesia without fetal distress, and Cesarean sections with general anesthesia or a concern for fetal well-being. The 1-minute Apgar score was three or less in 1.1%, 1.6%, and 5.8% of the samples, respectively. The investigators concluded that it was desirable to have a skilled resuscitator at every delivery and that a pediatrician should serve as the skilled resuscitator for Cesarean deliveries if there was general anesthesia or concerns about the fetal well-being.

Other studies also found that low-risk Cesarean deliveries have an incidence of newborn resuscitation that is comparable to low-risk vaginal births. High-risk Cesarean deliveries were more likely to require neonatal resuscitation compared with low-risk Cesarean sections and vaginal births. High-risk Cesarean sections included Cesarean deliveries with general anesthesia [23,24], fetal distress [23–27], breach presentation [24–26], and multiple births [27]. Each study recommended that a pediatrician attend high-risk Cesarean deliveries and serve as the resuscitation team leader, although no study provided the reasoning or logic for concluding that a pediatrician is more capable than some other skilled provider.

Often, anesthesiologists are called upon to perform neonatal resuscitations; this is especially true in hospitals that perform less than 1000 deliveries per year [17]. If the hospital has less than 1000 deliveries per year, the probability of the anesthesiologist having to perform neonatal resuscitation is 11 times greater than if the hospital had more than 1000 deliveries per year. Gaiser and colleagues
recently surveyed physicians who practicing obstetric anesthesia. Although 65% were involved routinely in newborn resuscitation, only 16% had received formal NRP training.

Completing the NRP training does not assure skill or competence in newborn resuscitation, it only signifies successful completion of the training. NRP purposefully avoids using the term “certified” for those who have completed the course so as not to imply clinical competency. “The Neonatal Resuscitation Program is an educational program that introduces the concepts and basic skills of neonatal resuscitation. Completion of the program does not imply that an individual has the competence to perform neonatal resuscitation” [6].

After completing NRP training, much of the acquired knowledge may be lost within a few months. Levitt and colleagues [28] tested family practice resident NRP providers 6 to 8 months after completion of the course and found a significant deterioration of resuscitation knowledge and skills. The residents were given a pretest of standard NRP examination questions and then trained in NRP. They were given a posttest immediately after completion of the NRP course and another follow-up test 6 months later. The mean scores were 61% upon pretesting, 91% at posttesting, and 75% at the 6-month follow-up test. The same investigators then attempted to improve retention of resuscitation skills by providing a video or a hands-on “booster” refresher course 3 to 5 months after completion of the NRP course [18]. Those who received the “booster” course were compared with controls who received traditional NRP instruction but had no “booster.” Both groups received a written follow-up test 6 to 8 months after taking the NRP course. There was no significant difference in the results of the follow-up testing between the two groups which indicated that the “booster” course did not result in retention of NRP knowledge.

Cats [29] and manikins [30,31] are used commonly to acquire and maintain resuscitation techniques. There are no data to assess the effectiveness of these techniques.

Many institutions use mock codes [32,33] to maintain clinical skills. Sixteen pediatric residents participated in mock codes, whereas 17 other residents served as controls [34]. Residents who participated in mock codes had more confidence in their ability to supervise resuscitations and felt less of a need for more knowledge before supervising resuscitations. They also felt more confident in obtaining intravenous access and performing intubations during a code situation. Although the attitudes and confidence of the residents improved after the mock codes, no data were presented to determine if the clinical performance or clinical outcomes of their subsequent resuscitations improved.

Carbine and colleagues [35] reported another innovative method to maintain resuscitation skills. A video recorder was mounted to a radiant warmer in the delivery room to record all resuscitations. The video recordings were reviewed critically and the resuscitation techniques were scored. Fifty-four of the first 100 resuscitations that were reviewed had deviations from NRP guidelines. The most common deviations were poor chest expansion (24%), poor suctioning technique (22%), no bag and mask re-evaluation (17%), incorrect oxygen use
(15%), incorrect bag and mask rate (11%), overly aggressive stimulation (10%), and improper free-flow oxygen technique (10%). The video recording tool now serves as a quality improvement technique with group and individual providers.

Another strategy to improve resuscitation performance is to limit the procedure to a small number of people to avoid “diluting” the experience. The incidence of an intensive newborn resuscitation is small. Only 1% to 3% of low-risk deliveries require positive pressure ventilation [15]. The need for chest compressions or medications is even more rare event. At Parkland Memorial Hospital, Dallas, Texas only 39 of 30,829 (0.12%) infants required the use of chest compressions or epinephrine [36].

The staff at Parkland Memorial Hospital developed teams of doctors, nurses, and respiratory therapists who are dedicated to neonatal resuscitation and stabilization [37,38]. The use of these teams reduced neonatal morbidities of admission hypothermia and hypoglycemia compared with historical controls at the same institution. Other short-term and long-term outcomes were not provided [37,38]. Smaller, community hospitals also have organized in-house neonatal resuscitation teams [39].

The use of general pediatricians as the primary resuscitators seems to have decreased during the past decade. In 1995, Feigin et al [40] surveyed approximately 600 pediatricians and found that 70% were involved in the resuscitation, stabilization, and management of critically ill newborns. In rural areas, 81% of pediatricians performed neonatal endotracheal intubations, whereas in urban areas 51% of the pediatricians who were surveyed performed intubations. A national survey of residents who graduated in 1997 and were practicing pediatrics in 1999 found that 45% attend deliveries to serve as the primary newborn resuscitator [41]. A more recent survey by Falck and colleagues [22] found that only 36% of pediatricians routinely perform neonatal resuscitation.

The emergence of neonatal nurse practitioners [42] and pediatric hospitalist programs [43,44] provides an opportunity for community hospitals to concentrate the resuscitations among fewer individuals. Before the development of a pediatric hospitalist program at our primary hospital, any 1 of more than 30 community pediatricians might be called upon to perform a newborn resuscitation. Since the establishment of a pediatric hospitalist service, all resuscitations are led by 1 of only 6 individuals, all of whom obtain enough resuscitation experience to maintain confidence and competence.

In summary, a skilled resuscitator should be immediately available to serve as the team leader for every delivery. This does not have to be a pediatrician, but the resuscitator should be trained and skilled in the NRP technique. It is our opinion that the most effective method to maintain NRP resuscitation skills is to limit the role of the resuscitation team leader to as few individuals as possible. Hospitals should consider using neonatologists, hospitalists, nurse practitioners, respiratory therapists, or staff nurses to serve as the resuscitation team leader. Other physicians should continue to be trained in NRP techniques and be prepared to assist the team leader and to serve as the team leader in emergency situations.
Intubation errors

Unsuccessful endotracheal intubation is a common problem. In some communities, up to 80% of practicing pediatricians perform newborn resuscitation and endotracheal intubation [40], yet many pediatric residents complete their training without having acquired competent intubation skills. Falck and colleagues [22] observed 449 intubation attempts of pediatric residents. First-year residents performed successful intubations on the first or second attempt 50% of the time. Second-year residents were successful on the first or second attempt 54% of the time; third-year residents were successful 62% of the time. Thirty-five percent of the attempted intubations (160 of the 449 procedures) were not accomplished successfully by the residents. A follow-up survey of the residents after they became practicing pediatricians found that only 87% believed that their level of confidence with endotracheal intubation had been good or excellent at the completion of their residency.

Respiratory therapists and neonatal nurse practitioners may be more successful at neonatal intubation than pediatricians. Adams and colleagues [45] found that respiratory therapists had greater success than second- or third-year pediatric residents with neonatal and pediatric intubations. Respiratory therapists at one community hospital were successful in 37 of 38 (97.4%) neonatal intubations [21]. Resuscitations of preterm infants by neonatal nurse practitioners have been compared with similar resuscitations that were performed by pediatricians [46]. Babies who were resuscitated by nurse practitioners were no more likely to be intubated; however, they were intubated more quickly and received surfactant therapy sooner than babies who were resuscitated by physician-led teams.

Many reasons have been cited for the pediatricians’ problems in obtaining and maintaining intubation skills [47]. Today, fewer babies are intubated for the presence of meconium-stained amniotic fluid than in earlier years [6]. Physicians receive fewer opportunities to acquire resuscitation skills during their residency as a result of the current residency requirements of the Accreditation Council for Graduate Medical Education [22,48]. These residents then learn their delivery room resuscitation techniques from other residents [49] who may not be skilled adequately [22]. Finally, general pediatricians attend fewer deliveries because of the increased presence of neonatologists [50,51], nurse practitioners [42], and pediatric hospitalists in community hospitals [44].

Two common and serious errors of endotracheal intubation are malplacement of the endotracheal tube and the use of the wrong-sized tubes. Endotracheal tubes that are too small in diameter have high internal resistance [52]. This allows a large air leak that interferes with achieving desired pressures for ventilation and impaired effective suctioning. A 4.0-mm endotracheal tube has a cross-sectional area of 12.6 mm² and allows passage of a 10 French suction catheter. A 3.5-mm endotracheal tube has a cross-sectional area of 9.6 mm² and allows passage of an 8 French suction catheter. A 3.0-mm endotracheal tube has a cross-sectional area of 7.1 mm² and allows for a 6 French suction catheter. A 2.5-mm endotracheal tube has a cross-sectional area of only 4.9 mm² and allows for...
suctioning with a 6 French catheter. Clearly, to achieve maximal suctioning capabilities, one should avoid using an inappropriately small endotracheal tube. Care also should be taken to avoid using tubes that are excessively large because they can cause pressure necrosis of the mucosa of the airway.

Proper placement of the endotracheal tube is extremely important. Many intubators use the mnemonic “1-2-3 . . . 7-8-9” to determine the placement of the tube [6]. For a 1-kg newborn, the tube placement should be 7 cm at the lip level. For a 2-kg newborn, placement should be 8 cm at the lip level; for a 3-kg newborn, placement should be 9 cm at the lips. Tubes that are placed too high are prone to dislodgement. Tubes that are placed too low can cause atelectasis (usually of the left lung or the upper lobe of the right lung), barotrauma (usually of the right lung), and maldistribution of any medication that is administered intratracheally (eg, surfactant, epinephrine). Perlman and Risser [36] reported five newborns that required resuscitation with chest compressions and/or epinephrine in the delivery room due to improper position of the endotracheal tube. All five had immediate improvement of the heart rate upon repositioning of the tube to a proper position. Three of the five had received endotracheal epinephrine into the misplaced tube without significant benefit.

In the delivery room, endotracheal tube placement should be confirmed with a rise in the chest with each breath, breath sounds over both lungs but decreased or absent over the stomach, no gastric distention with ventilation, vapor condensation inside the tube during exhalation, and improving vital signs and color of the newborn [6]. Recently capnography [53,54] and colorimetric CO2 monitors [55,56] have been introduced to verify placement of the endotracheal tube.

Colorimetric CO2 monitors can detect carbon dioxide quickly in the endotracheal tube. These simple, inexpensive, and disposable devices are connected to the end of the endotracheal tube and change color from purple to yellow when the tube is in the trachea. If the detector remains purple, however, the tube is in the esophagus and should be removed. These devices may give incorrect readings for babies who have poor cardiac output and for those who weigh less than 1000 g.

Capnographs use a special electrode that is connected to the end of the endotracheal tube. The device will display a specific CO2 value. This value should be more than 2% to 3% CO2 if the endotracheal tube is in the trachea. These devices are more complex and significantly more expensive than the colorimetric monitors. The use of colorimetric CO2 monitors and capnographs are not considered to be a necessary component of the NRP technique; however, their use is increasing in frequency and it is anticipated that they soon will become established as a standard of care.

**Inadequate suctioning for meconium**

Before the mid-1970s, meconium aspiration syndrome (MAS) resulted in substantial neonatal morbidity and mortality. The prevalence of symptomatic
MAS was 1% to 3% of all births [57–60] with an associated mortality rate of approximately 25% [60–62]. MAS accounted for 2% of all perinatal deaths [61]. In 1973, Burke-Strickland and Edwards [63] reported reduced respiratory morbidity in meconium-stained infants who had immediate endotracheal intubation, suctioning, and lavage with saline. [63] One year later, Gregory et al [59] reported favorable outcomes of 88 meconium-stained infants who received oral suctioning and immediate intubation for meconium at birth. These infants had improved respiratory outcomes when compared with 15 infants who had MAS that had been admitted from other hospitals and had not received aspiration of the airways. Before institution of routine suctioning, Gregory et al.’s hospital experienced two or three deaths each year from MAS. After the introduction of routine suctioning, 5700 babies were born and 35 (0.6%) were admitted to the ICU for MAS; however, none required mechanical ventilation for respiratory support and there were no deaths due to MAS. Ting and Brady [60] also found that improved outcomes were associated with intratracheal suctioning in the delivery room. One hundred and twenty-five meconium-stained infants were admitted into the neonatal ICU. Of 28 who did not have intratracheal suctioning, 16 (57%) developed MAS and seven (25%) died. Of 97 who had been intubated and suctioned, only 27 (28%) developed MAS and only one (1%) died.

In 1976, Carson and colleagues [64] demonstrated the additional benefits of routine obstetric suctioning of the upper airway before endotracheal intubation and suctioning. With combined obstetric and pediatric suctioning, moderate or severe MAS was reduced from nine cases (0.12%) in 7585 births to 0 cases (0%) in 1681 births. Before instituting the combined obstetric and pediatric suction routine there were five deaths among the nine cases of moderate or severe MAS; there were no deaths from MAS after the combined obstetric and pediatric suctioning routine was established. Based primarily upon this report, obstetric suctioning of the upper airway before delivery of the shoulders became accepted as the standard of care.

Subsequent studies found conflicting results of the benefits of obstetric suctioning. Wiswell and colleagues [65] documented benefits of oropharyngeal suctioning before delivery of the shoulders in vigorous, meconium-stained infants. Infants who did not receive oropharyngeal suctioning were three times more likely to develop MAS compared with infants who were suctioned. The study was not designed to analyze the risks or benefits of oropharyngeal suctioning of meconium-stained infants who were not vigorous at birth. A recent large, multi-center, randomized, controlled trial of obstetric suctioning of the oropharynx and nasopharynx before delivery of the shoulders found no benefits from the procedure [66]. Obstetric suctioning of the upper airway did not result in decreases in the prevalence in MAS, the need for mechanical ventilation for MAS, or neonatal mortality. There also were no differences in the duration of ventilation or oxygen requirements between meconium-stained infants who received oropharyngeal suctioning and those who did not.

Following the reports of the mid-1970s, routine neonatal endotracheal suctioning was established as the standard of care. In 1977, the American
Academy of Pediatrics’ Standards and Recommendations for Hospital Care of Newborn Infants recommended that “infants who have meconium in the mouth and oro-pharynx require special attention. The meconium must be suctioned under direct vision by use of a laryngoscope” [67]. The 1980 technique of neonatal resuscitation that was taught by the American Heart Association recommended “thorough hypopharyngeal suctioning before initiation of respiration...and the trachea should be intubated to remove as much of the meconium as possible from the lower airway” [68]. This recommendation was made only for infants who had “particulate meconium staining...[while] the presence of watery or thin meconium does not routinely require endotracheal intubation.”

After the standard of combined obstetric and pediatric suctioning had been established, Wiswell and Henley [69] performed a large, retrospective review of intratracheal suctioning practices and meconium aspiration. Thirty-six infants developed MAS; delivery room tracheal suctioning had been performed in 24 of the 36, whereas the trachea was not suctioned in the other 12. Those infants who had tracheal suctioning had a milder course of MAS with statistically significant reductions in the need for mechanical ventilation and of death. There was a nonsignificant trend toward fewer pneumothoraces and less persistent pulmonary hypertension in the group that had tracheal suctioning.

Although there has not been a randomized, controlled trial of endotracheal suctioning of meconium-stained infants, there is no doubt that the severity of MAS is less than before the mid-1970s and there is considerably less mortality from MAS. Among infants who have MAS, today the mortality is less than 5% [70,71]. Although intratracheal suctioning has contributed substantially to the reduced mortality from MAS, improved ventilator management and advances in supportive care also may be contributing to the reduced morbidity and mortality of MAS [70–72].

In 1988, Linder and colleagues [73] questioned the need to intubate and suction meconium-stained infants who were considered “vigorous”. A total of 572 vigorous, meconium-stained infants were assigned randomly to a resuscitation that included routine intratracheal suctioning or a resuscitation that used oropharyngeal suctioning with a DeLee catheter but no intratracheal suctioning. There was no mortality in either group. There was no respiratory morbidity in the group that received oropharyngeal suctioning; however, there were six cases of respiratory compromise (2%) in the group that had routine intratracheal suctioning. These finding were confirmed in a large (n>2000) multi-center international collaborative trial [65]. Vigorous infants were randomized to receive intratracheal suctioning or expectant management. There were no significant differences between groups in the occurrence of MAS or other respiratory disorders. Of 1098 infants who were intubated successfully, 42 (3.8%) had a total of 51 complications of the procedure. In all cases, the complications were mild and transient in nature. A 2001 Cochrane Database evidence-based review of the need for intratracheal suctioning of vigorous, meconium-stained newborns concluded that “routine endotracheal intubation at birth in vigorous term meconium-stained babies has not been shown to be superior to routine resus-
citation including oro-pharyngeal suction. This procedure cannot be recommended for vigorous infants until more research is available” [74].

Additional controversy exists over the need to intubate and suction routinely infants who have thin or watery-stained fluid. Although the risk of MAS is greater with thick staining of the amniotic fluid [75–80], infants who have thinly-stained fluid can develop MAS and severe respiratory failure. Approximately 5% of the cases of MAS develop in infants who have only thin staining of the amniotic fluid [76,78,81,82], although the associated respiratory disease usually is mild [78,82].

The NRP course consistently has recommended combined obstetric and neonatal suctioning for selected infants who are born with meconium-stained amniotic fluid. The NRP course has evolved, however, as related to the need to suction vigorous infants and infants who have thin or watery staining of the amniotic fluid. Gradually, the course has evolved toward suctioning more infants who have thin staining of the amniotic fluid and toward suctioning fewer infants who are vigorous at birth. The first edition of NRP in 1987 believed that “special management of infants [with thin, watery amniotic fluid] is not necessary.” There was no differentiation of vigorous infants from non-vigorous or depressed infants; all infants who have thick stained fluid were to be intubated and suctioned [3]. In 1990, the technique of the second edition of NRP was moving toward intubation of some babies who have thin meconium staining and away from intubating vigorous babies [4]. The second edition of NRP stated “special management of these infants [with thin or watery meconium-stained fluid] is probably not necessary.” And “if an infant has passed thick meconium, yet is very active and crying vigorously, a judgment must be made whether the difficulty of intubating a vigorous infant outweighs the advantages of full meconium removal.” The third edition of NRP in 1994 recommended no tracheal suctioning if the meconium was thin, as long as that infant was vigorous at birth [5]. Intratracheal suctioning was recommended for infants who have cardiorespiratory or muscle tone depression who had thin meconium and for all cases of infants who were born with thick, meconium-stained amniotic fluid. It was acknowledged that “controversy exists whether a vigorous baby with meconium-stained fluid requires tracheal suctioning.” The current, fourth edition of NRP that was published in 2000 makes no differentiation between thick or thin meconium [6]. The technique recommends no intratracheal suctioning for any infant who is vigorous, regardless of the consistency of the meconium-stained amniotic fluid. Endotracheal suctioning is recommended for any infant who has depressed respirations, depressed muscle tone, and/or a heart rate less than 100 beats per minute and who is born after meconium staining of the amniotic fluid—thick or thin.

Despite the current guidelines for oropharyngeal and intratracheal suctioning, cases of MAS continue to occur [72,83], albeit with less mortality and less morbidity than 30 years ago. Many investigators attribute the cases of MAS today to intrauterine meconium aspiration that is unpreventable with suctioning at birth. Reed [84] first reported in utero meconium aspiration in 1918. Since then, many other investigators have documented evidence of intrauterine meconium aspiration [85–90]. Brown and Gleicher [88] reviewed 200 consecutive autopsies
of stillborn infants. Twenty-five cases demonstrated histologically evident amniotic fluid aspiration and eight had intra-alveolar meconium. Some of the histologic changes were determined to have taken several days to occur.

Another explanation for some of the residual cases of MAS today is the failure to follow the established recommendations for obstetric and neonatal suctioning. Singhal et al [91] reviewed the quality of more than 5000 newborn resuscitations. Of 110 resuscitations that required intubation and suctioning for meconium, 28 (25%) were not managed according to NRP standards. Wiswell and Henley [69] reported 36 infants who had MAS; 12 (33%) were not intubated. Four were not intubated because they were considered to be “vigorous” at birth; eight were not intubated because no meconium was found in the hypopharynx or upon inspection of the vocal cords. The outcome of the 12 nonintubated, nonsuctioned neonates was poor. Four of the 12 died or required extracorporeal membrane oxygenation (ECMO) and their ventilator requirements were significantly greater compared with the infants who had MAS who were intubated and suctioned. It is unknown how many of these 12 cases of severe MAS would have been of lesser severity or prevented altogether if intratracheal suctioning had taken place, although if the NRP technique had been followed, at least 8 of the 12 would have received the benefits of endotracheal intubation and suctioning.

Although some investigators advocate intubation and trachea suctioning only if meconium was visualized in the hypopharynx or at the vocal cords [92], the NRP never has made this recommendation because of the possibility of meconium in the trachea, even when not visualized on the vocal cords [3–6]. Hageman and colleagues [93] reviewed 464 consecutive newborns who were born after meconium staining of the amniotic fluid. Patients who had meconium present on the vocal cords had meconium below the cords 76% of the time. If no meconium was observed on the vocal cords, meconium still was present below the cords 7% of the time.

In summary, a combined obstetric and pediatric suctioning approach will lessen the incidence of MAS, the severity of MAS, and the mortality of MAS. The current standard of care requires endotracheal suctioning and intubation of any nonvigorous infant, regardless of whether the meconium is thick or thin. It is not adequate merely to inspect the hypopharynx and vocal cords in these infants—intubation is mandated. Following the standards that are established by the NRP will not eliminate MAS totally, but will reduce the morbidity and mortality of MAS substantially and will reduce the resuscitator’s potential for professional or legal criticism if a bad outcome follows.

**Problems with postresuscitation stabilization efforts**

**Hypoglycemia**

Hypoglycemia is a common complication during the stabilization period after birth asphyxia. Traditionally, it has been believed that a fetus who is stressed
by hypoxia or asphyxia may deplete the glycogen stores which results in hypoglycemia soon after birth [6]. Many other asphyxiated babies are born with conditions that are associated with hyperinsulinemia as an apparent cause of significant hypoglycemia [94–97]. This is especially true for asphyxiated infants of diabetic mothers [97].

Although asphyxia and ischemia are known to be causes of neonatal brain injury, the neonate is at an even greater risk of brain injury if the asphyxia or ischemia is combined with hypoglycemia [98]. Laboratory evidence that demonstrates the increased risk that is attributable to hypoglycemia was derived from hypoxic newborn rats [99], asphyxiated newborn dogs [100], postasphyxial newborn lambs [101], and ischemic newborn dogs [102]. Data from newborn humans who have hypoplastic left heart syndrome also revealed an increased risk of ischemic brain lesions associated with a concomitant exposure to hypoglycemia [103].

Salhab and colleagues [104] recently reviewed the charts of 185 term infants who were admitted to a newborn ICU because of severe acidemia (arterial pH less than 7.0). Those who were admitted who had coincident hypoglycemia (blood sugar less than 40 mg/dL) had significantly worse outcomes than those who had severe acidemia without hypoglycemia. Twenty-seven infants had severe acidemia and hypoglycemia; 15 (56%) of these infants had an abnormal neurologic outcome. One hundred and fifty-eight infants had severe acidemia without hypoglycemia; only 26 (16%) of these infants had an adverse neurologic outcome. Collectively, the clinical and laboratory data suggest that the combination of hypoglycemia with hypoxia, ischemia, or asphyxia may result in brain injury, even when any one of these conditions alone might not have resulted in damage [98]. The increased risk of hypoglycemia seems to be related to a combination of decreased brain energy reserves, impaired autoregulation of cerebral blood flow, and the increased risk of damage from postasphyxial seizure activity [98].

It is important to anticipate and treat hypoglycemia in the stabilization period following a neonatal resuscitation. Although NRP recommends monitoring blood sugars closely after resuscitation, no specific recommendations for monitoring or intervention are offered [6]. Although many authorities recommend keeping the blood glucose greater than 40 mg/dL during the stabilization period [105], Volpe [98] recommends maintaining the blood glucose between approximately 75 mg/dL and 100 mg/dL after resuscitation. These increased glucose levels may be difficult to achieve if the infant also is under fluid restriction during the stabilization period. Care also must be taken to avoid hyperglycemia because this can result in hyperosmolality and associated vascular brain injury [106].

**Hypocarbia**

There may be a role for modest hyperventilation and hypocarbia to reduce cerebral edema and intracranial pressure in the postresuscitation stabilization period [107]. Additionally, modest hyperventilation is used commonly for pulmonary artery vasodilatation to treat persistent pulmonary hypertension of the new-
born [108]; however, care must be taken to avoid excessive hypocarbia. Cerebral blood flow in the newborn is highly dependant upon the PCO$_2$. Studies in newborn lambs demonstrated abrupt decreases in cerebral blood flow with the onset of hypocarbia [109]. Every decrease of the PCO$_2$ by 1 mm Hg caused an approximate 3% decrease in cerebral blood flow—an effect that could exacerbate the cerebral ischemia of birth asphyxia. The decreased cerebral blood flow that was associated with hypocarbia became less prominent over time [109]; however, after the hypocarbia was terminated there was a sudden increase in cerebral blood flow to greater than baseline levels. If this occurred in the human newborn, it could result in cerebral hyperemia with cerebral hemorrhage and reperfusion injury.

Hypocarbia has been associated with adverse neurologic outcomes in the laboratory and clinical settings. Vannucci et al’s [110] studies in 7-day-old rats found that modest hypocarbia (PCO$_2$ of 26 mm Hg) following hypoxia-ischemia resulted in worse neurologic damage than observed in hypoxic-ischemic rats that had normocarbia (PCO$_2$ of 39 mm Hg). Mildly hypercarbic rats (PCO$_2$ of 54 mm Hg) had the most favorable outcomes.

Studies of newborns who had persistent pulmonary hypertension demonstrated worse outcomes in those who had longer periods of hyperventilation and hypocarbia [111,112]. The infants who had the longest periods of hyperventilation and hypocarbia, however, probably had the most severe pulmonary hypertension, and correspondingly, the most severe hypoxia. Therefore, the adverse outcomes that are associated with hypocarbia may have been the result of the severe persistent pulmonary hypertension or the hypocarbia.

There is no consensus of the level or duration of hypocarbia that presents a risk to the asphyxiated newborn. The benefits of hyperventilation to manage cerebral edema and increased intracranial hemorrhage are probably small, however [98]. Modest hyperventilation may be useful in the treatment of persistent pulmonary hypertension, but should be limited to the minimal amount necessary to achieve acceptable oxygenation. There are no data to indicate that hyperventilation is beneficial in the prevention of persistent pulmonary hypertension in the asphyxiated newborn; this practice should be discouraged. For asphyxiated newborns who do not have persistent pulmonary hypertension, normocarbia or even mild hypercarbia is preferred to hypocarbia.

**Hypotension**

Healthy babies have the ability to autoregulate cerebral blood flow across a range of blood pressures; however, asphyxiated infants lose this ability to autoregulate and cerebral blood flow becomes pressure passive [113,114]. Thus, any degree of hypotension in the postasphyxial stabilization period has the potential to contribute to the newborn’s cerebral ischemia and brain injury. Hypotension is a common complication that is seen in the immediate stabilization period. A major cause of hypotension is asphyxial cardiomyopathy. Up to 80% of asphyxiated newborns experience asphyxial cardiomyopathy that is
sufficient to require transfusion therapy or vasopressors in the immediate stabilization period [115]. Other asphyxiated infants demonstrate hypotension as a result of acute blood loss from conditions, such as fetal–maternal transfusion, twin-to-twin transfusion, placental abruption, placenta previa, and cord accidents. Regardless of the cause of the hypotension, aggressive management with transfusion therapy and vasopressors may be necessary to treat the hypotension and maintain adequate cerebral blood flow.

Box 1. Ten recommendations to avoid the common pitfalls of newborn resuscitations

1. Strictly follow the guidelines of the NRP. There should be few, if any, departures from the guidelines.
2. Develop a plan to ensure that at least one skilled resuscitator is immediately available for every birth. This does not have to be a pediatrician.
3. Any provider of newborn resuscitation must be trained in the techniques of the NRP. This includes obstetricians and anesthesiologists.
4. Mock codes with manikins should be used to maintain resuscitation skills.
5. Limit the number of individuals who serve as the team leader of newborn resuscitations. Hospitals should consider using neonatologists, hospitalists, nurse practitioners, respiratory therapists, or nurses to serve as the skilled team leader.
6. Follow NRP recommendations in selecting the proper sized endotracheal tube and placing the tube at the correct depth.
7. Capnography and colorimetric CO₂ monitors should be used to document that the endotracheal tube is in the trachea.
8. If an infant is meconium-stained and has cardiorespiratory or neurologic depression at birth, thorough suctioning of the airway must take place before giving positive pressure ventilation. It is not acceptable to visualize the hypopharynx and vocal cords; intubation and intratracheal suctioning is mandated.
9. Avoid hypoglycemia during the postresuscitation stabilization period.
10. Avoid hypotension and unnecessary hypocarbia during the stabilization period. Modest hypocarbia may be beneficial in the treatment of persistent pulmonary hypertension, but has not been shown to be of use in the prevention of the condition.
Summary

Ten percent of all newborns require resuscitative efforts at birth. By adhering to the techniques of the NRP and following the 10 recommendations in Box 1, neonatal resuscitators will have the best chance of avoiding the common pitfalls of neonatal resuscitation and achieving the best possible long-term neuro-developmental outcome.

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