In addition to establishing and maintaining the artificial airway, the clinician must demonstrate a working knowledge of the multiple supportive pulmonary care skills that are essential for optimal care of the intubated and ventilated neonate. This chapter presents the principles and guidelines required for the safe intubation and successful pulmonary care of these critically ill infants. Some of the guidelines addressed will reflect significant changes in cardiopulmonary resuscitation (CPR) of the newborn presented in the revised Neonatal Resuscitation Program (NRP) (see Chapter 4). With the “explosion” of new information available regarding the care of the neonate who requires assisted ventilation, we attempt to focus the discussion in this chapter on pulmonary care. The reader will be referred to other chapters of the book for a more in-depth presentation of specific topics.

All caretakers involved in the management of these babies need to be aware of the safety issues with regard to the transmission of pathogenic organisms by bodily fluids and closely follow the Occupational Safety and Health Administration (OSHA) standards outlined in Appendix 30.

**Indications for Intubation**

**Resuscitation at Delivery**

The neonatal resuscitation guidelines published jointly by the American Academy of Pediatrics (AAP) and the American Heart Association provide a comprehensive step-wise algorithm for the assessment and resuscitation of the newborn infant at delivery. Ongoing reassessment of the infant’s response as resuscitation proceeds is a major feature of this algorithm. Endotracheal intubation may be warranted at any of several points during resuscitation, and the timing of intubation may be influenced by the skill and experience of the operator as well as the clinical circumstances. Indications for endotracheal intubation during delivery room resuscitation include (1) tracheal suctioning for prevention of meconium aspiration; (2) need for prolonged positive-pressure ventilation; (3) administration of prophylactic surfactant; (4) presence of obstructive upper airway lesions requiring an artificial airway; and (5) cases in which air distention of the gastrointestinal (GI) tract is undesirable, such as with congenital diaphragmatic hernia.

Aspiration of meconium before or during delivery can lead to an aspiration pneumonia, and plugging of airways with particulate meconium may cause air trapping and subsequent pneumothorax. Early uncontrolled trials suggested that immediate endotracheal intubation and tracheal suctioning was warranted for all babies born through meconium-stained amniotic fluid in order to prevent meconium aspiration and its consequences. However, more recent multicenter prospective trials have shown that this approach offers no benefit to infants who are vigorous at birth. A vigorous infant is defined as one who has good respiratory effort, good muscle tone, and a heart rate (HR) of less than 100. Current guidelines suggest that an infant born through meconium-containing amniotic fluid requires immediate endotracheal intubation and suctioning only when the infant is not vigorous at birth. If the infant is intubated to suction meconium from the trachea, a meconium aspirator should be attached to the endotracheal tube to provide appropriate suctioning. If meconium is recovered, intubation and suctioning can be repeated if the infant is not bradycardic; if the infant is bradycardic, positive-pressure ventilation should be provided without further attempts at tracheal suctioning.

Positive-pressure ventilation should be initiated during neonatal resuscitation when the infant is bradycardic (HR less than 100) or apneic despite stimulation or when there is persistent cyanosis despite supplemental oxygen administration. Under these circumstances, positive-pressure ventilation should be initially provided with a resuscitation bag and mask. Intubation for positive-pressure ventilation should be considered if bag and mask ventilation is ineffective or if the need for positive-pressure ventilation continues beyond a few minutes.

Intratracheal surfactant replacement therapy, administered via the endotracheal tube, has been an essential component of the prevention and treatment of respiratory distress syndrome (RDS) in premature infants since the early 1990s (also see Chapter 22). Multiple trials have compared prophylactic surfactant administration, usually given within the first 10 minutes of life in the delivery
room, with later rescue treatment of established RDS in infants at substantial risk for the development of RDS. A meta-analysis of these trials demonstrated that prophylactic surfactant administration leads to significant reductions in the risk of air leak complications and death. These benefits are most pronounced in those infants born at less than 30 weeks of gestation who have not been exposed to antenatal steroids. Current recommendations from the AAP Committee on the Fetus and Newborn suggest that prophylactic surfactant be considered for those premature infants at highest risk for RDS. However, use of prophylactic surfactant is quite variable in neonatal units across the country. One reason for this variation in practice is widespread interest in early application of nasal continuous positive airway pressure (CPAP), rather than prophylactic intubation and surfactant treatment, for the prevention and early treatment of RDS (see Chapter 8). Early nasal CPAP may have the potential to reduce the incidence of bronchopulmonary dysplasia without an increase in other morbidities. However, a recently concluded randomized, controlled trial demonstrated that early nasal CPAP, as compared with early intubation, did not significantly reduce the rate of death or bronchopulmonary dysplasia.

Certain anatomic lesions may cause obstruction at the level of the nasopharynx, larynx, and upper trachea and may necessitate endotracheal intubation of affected neonates during initial resuscitation. Beginning at the nasal level, these lesions include bilateral or severe unilateral choanal atresia or stenosis; pharyngeal hypoponita; and micrognathia, such as may be seen in the Robin sequence (which may include cleft palate and glossoptosis). At the level of the larynx, obstructive problems may include laryngomalacia (or laryngotracheomalacia), laryngeal web, bilateral vocal cord paralysis, and congenital subglottic obstruction. In addition, critical airway obstruction may be secondary to other lesions that may compress the airway and impair normal respiration. These may include cystic hygroma, goiter, or hemangioma. Many of these lesions, particularly those causing significant fixed obstruction at the level of the larynx or below, may render endotracheal intubation extremely difficult and may require emergency tracheostomy (see Chapter 25).

Infants born with congenital diaphragmatic hernia frequently require positive-pressure ventilation at delivery because of respiratory distress with cyanosis. Provision of positive-pressure ventilation with bag and mask will drive large amounts of air into the upper GI tract, causing distention of bowel that has herniated into the chest. Such bowel distention will cause further lung compression and compromise respiratory function. For this reason, infants with diaphragmatic hernia should be promptly intubated in the delivery room if resuscitation is required. Some clinicians also advise that these infants should be paralyzed with a muscle relaxant to prevent spontaneous breathing from causing bowel distension. An orogastric tube should also be placed to evacuate any air that does enter the stomach. The diagnosis of diaphragmatic hernia is often confirmed by antenatal ultrasound studies and should be suspected in any infant with a scaphoid abdomen, unilaterally diminished breath sounds, and persistent respiratory distress.

Postnatal Respiratory Failure

Infants in the neonatal intensive care unit may require endotracheal intubation and positive-pressure ventilation because of respiratory failure related to a variety of causes. Two common scenarios that merit particular consideration include preterm infants with worsening respiratory distress syndrome and infants with postextubation respiratory failure.

A variety of competing factors will influence the decision to intubate an infant who has worsening respiratory distress syndrome. The symptoms of untreated RDS will tend to worsen during the first 48 to 72 hours of life, until the infant begins to make significant amounts of endogenous surfactant. Therefore, an infant with moderately severe respiratory insufficiency and distress during the first 24 hours of life may merit intubation and ventilation in anticipation of worsening disease, whereas an infant with comparable disease severity at 3 or 4 days of life may avoid intubation in anticipation of spontaneous improvement.

Surfactant treatment of established RDS has been shown to decrease the incidence of air leak complications and death.

Although the optimal timing of surfactant administration for treatment of RDS is controversial, the available data suggest that early treatment is more effective, and this observation may thus lead to earlier intubation. On the other hand, positive-pressure ventilation delivered through an endotracheal tube is well known to cause lung injury, particularly if large tidal volumes are used. Some centers that make extensive use of nasal CPAP to avoid intubation and mechanical ventilation have reported very low rates of chronic lung disease. However, this finding was not duplicated in a recent randomized controlled trial. Different practitioners will weigh these competing factors differently, and the indications for intubation of an infant with RDS will vary depending on the clinical circumstances and local practices.

Postextubation respiratory failure is a common occurrence in preterm infants, occurring in as many as one third of infants. Causes of respiratory failure in these infants include central or obstructive apnea, respiratory insufficiency leading to progressive atelectasis, and early chronic lung disease. Early application of nasal CPAP following extubation has been shown to reduce the need for additional ventilatory support, but it may fail in 25% to 40% of infants. Some evidence suggests that nasopharyngeal positive-pressure ventilation may be more effective in preventing postextubation respiratory failure, but this modality is also not universally effective. Other techniques to avoid re-intubation include the use of methylxanthines, use of ventilation through nasal prongs, and frequent postextubation chest physiotherapy. Indications for re-intubation include progressive respiratory acidosis, significant oxygen requirement, or severe apnea.

Routes of Intubation

Intubation can be performed orally or nasally. The choice of route depends on the circumstances and the preference of the clinician. Both oral and nasal endotracheal
intubation have their unique complications and share a few as well.17-19 Oral intubation is easier, faster, and less traumatic to perform, and it may be preferable in an emergency. Available data have failed to demonstrate statistically significant differences between oral and nasal intubation with respect to tracheal injury, frequency of tube retaping, or tube replacement.20 However, a higher incidence of postextubation atelectasis has been noted in nasally intubated patients, especially in preterm infants with birth weight less than 1500 g; atelectasis was associated with a marked reduction in nasal airflow through the previously intubated nares and stenosis of the nasal vestibule.21,22 Midface hypoplasia has been reported to be associated with long-term intubation for bronchopulmonary dysplasia.23

On the other hand, proponents of nasal intubation believe that fixation of the tube to the infant's face is easier and more stable because it minimizes the chance for accidental dislodgment and decreases tube movement, which can result in subglottic stenosis. Prolonged oral intubation can result in palatal grooving24 and defective dentition.25 Furthermore, there is evidence that acquired subglottic stenosis is increased in patients who were orally intubated and whose birth weight was less than 1500 g. The same study and one other offer evidence that the nasotracheal tube is easier to stabilize than an oral tube and that extubation occurs less frequently than in oral intubation.19,26 Acquired subglottic stenosis secondary to oral intubation may be a sequela of tracheal mucosal damage from the endotracheal tube itself or from repeated intubations. Most significantly, severe damage can occur from the up-and-down movement of the endotracheal tube.20 Even with perfect fixation of the tube, up-and-down movement of 7 to 14 mm has been reported owing to the varying degrees of flexion of the neck. The caretaker team can minimize palatal grooving and defective dentition by rotating the fixation site from side to side during periodic retaping. Devices are available commercially that serve as palate protectors for prolonged intubation of very-low-birth-weight infants (Gesco Planate®, MedChem Products, Woburn, Mass). Continuing attention to the quality of fixation, together with stabilization of the infant's head position, minimizes tube shifting and accidental extubation with the oral approach. However, both the oral and nasal techniques will continue to have a place in the care of the ventilated neonate. Problems associated with oral and nasal endotracheal tube use are summarized in Box 6-1.

## Equipment

The equipment needed for intubation is listed in Box 6-2, and the guidelines for choosing the correct tube size and suction catheters are listed in Tables 6-1 and 6-2.1

The use of tubes of appropriate size minimizes trauma, airway resistance, and excessive leak around the tube. A standard kit containing all of the equipment, as listed in Box 6-2, can be prepared and stocked, but it must be checked regularly to ensure that all of the necessities are present. The infant should be placed under a radiant warmer for endotracheal intubation. A laryngoscope with a Miller no. 0 or no. 1 blade should be used to visualize the vallecula, epiglottis, and glottis. The no. 0 blade is used for almost all newborns. The no. 1 blade is used for infants who are several months old or newborns whose birth weight is greater than 4 to 5 kg.1,27 A Miller “00” blade has been touted for use in extremely low-birth-weight infants because its smaller blade is more easily accommodated in

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**Box 6-1** PROBLEMS IN NEWBORN INFANTS WITH ORAL AND NASAL ENDOTRACHEAL TUBES

<table>
<thead>
<tr>
<th>Common Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Postextubation atelectasis—more common with nasal endotracheal tubes</td>
</tr>
<tr>
<td>- Pneumonia/sepsis</td>
</tr>
<tr>
<td>- Accidental extubation</td>
</tr>
<tr>
<td>- Intubation of mainstem bronchus</td>
</tr>
<tr>
<td>- Occlusion of tube from thickened secretions</td>
</tr>
<tr>
<td>- Tracheal erosion</td>
</tr>
<tr>
<td>- Pharyngeal, esophageal, tracheal perforation</td>
</tr>
<tr>
<td>- Subglottic stenosis</td>
</tr>
</tbody>
</table>

**Problems Unique to Nasal Endotracheal Tubes**

- Nasal septal erosion
- Stricture of the nasal vestibule

**Problems Unique to Oral Endotracheal Tubes**

- Palatal grooving
- Interference with subsequent primary dentition


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**Box 6-2** EQUIPMENT NEEDED FOR INTUBATION

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laryngoscope with premature (Miller no. 0) and infant blades (Miller no. 1); Miller no. 00 optional for extremely premature infant</td>
</tr>
<tr>
<td>Batteries and extra bulbs</td>
</tr>
<tr>
<td>Endotracheal tubes, sizes 2.5, 3.0, 3.5, and 4.0 mm ID</td>
</tr>
<tr>
<td>Stylet</td>
</tr>
<tr>
<td>Suction apparatus (wall)</td>
</tr>
<tr>
<td>Suction catheters: 5.0, 6.0, 8.0, and 10.0 French</td>
</tr>
<tr>
<td>Meconium aspirator</td>
</tr>
<tr>
<td>Oral airway</td>
</tr>
<tr>
<td>Stethoscope</td>
</tr>
<tr>
<td>Non–self-inflating bag (0.5 L), manometer, and tubing; self-inflating bag with reservoir, manometer optional for self-inflating bag</td>
</tr>
<tr>
<td>Newborn and premature mask</td>
</tr>
<tr>
<td>Source of compressed air/O₂ with capability for blending</td>
</tr>
<tr>
<td>Humidification and warming apparatus for air/O₂</td>
</tr>
<tr>
<td>Tape: ½-inch pink (Hytape)</td>
</tr>
<tr>
<td>Scissors</td>
</tr>
<tr>
<td>Magill neonatal forceps</td>
</tr>
<tr>
<td>Elastoplast (elastic bandages)</td>
</tr>
<tr>
<td>Cardiorespiratory monitor</td>
</tr>
<tr>
<td>Carbon dioxide monitor or detector</td>
</tr>
<tr>
<td>Pulse oximeter (SpO₂)</td>
</tr>
</tbody>
</table>
that extends around the circumference. The alternative is the rigid but anatomically shaped Rendell-Baker/Soucek mask, which may have less dead space but has been demonstrated to be more difficult to use, often resulting in ineffective ventilation.\textsuperscript{28}

Two different types of resuscitation bags or manual resuscitators are available to provide assisted ventilation via mask or endotracheal tube: the self-inflating bag and the non–self-inflating or “anesthesia” bag.\textsuperscript{1} The non–self-inflating bag is also commonly referred to as a flow-inflating bag.\textsuperscript{1} Both come in a wide variety of configurations, but all configurations share some basic attributes, including an oxygen inlet, patient outlet, flow-control valve, and pressure manometer attachment site. The self-inflating bag, as the name implies, reinflates after squeezing and does not require the flow of oxygen to reinflate. However, this bag with an oxygen source can deliver only about 40% oxygen because as the bag reinflates, room air is drawn into the bag and mixes with 100% oxygen from the oxygen source. A reservoir will not allow room air to come into the bag; therefore, the self-inflating bag attached to an oxygen source with a reservoir is able to deliver 90% to 100% oxygen to the baby.

Two other important characteristics of most self-inflating bags are a “popoff valve,” which is “set” at 30 to 40 mm Hg, and a non-rebreathing valve, which is built into the bag and prevents the reliable delivery of free-flow oxygen.\textsuperscript{29} In order to deliver free-flow oxygen, the operator needs to disconnect the oxygen tubing from the bag and hold the oxygen tubing close to the nose of the baby. In contrast, the non–self-inflating bag is an excellent source of free-flow oxygen, especially with the use of the appropriate-sized mask attached to the bag. Finally, both of these bags require a pressure manometer in order to provide safe and effective ventilation to the newborn.\textsuperscript{29} Table 6-3 compares the two ventilation bags (or manual resuscitators).

<table>
<thead>
<tr>
<th>TABLE 6-3</th>
<th>Neonatal Manual Resuscitators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Self-Inflating Bag</strong></td>
<td><strong>Non–Self-Inflating Bag</strong></td>
</tr>
<tr>
<td><strong>Types</strong></td>
<td>“Anesthesia bag” with spring-loaded or variable-orifice bleed port</td>
</tr>
<tr>
<td><strong>Operator</strong></td>
<td>Requires both experience and knowledge of bag characteristics for adjustment of flow and bleed</td>
</tr>
<tr>
<td><strong>Oxygen-air source positive ( F_iO_2 ) delivery</strong></td>
<td>Requires compressed gas</td>
</tr>
<tr>
<td><strong>Pressure delivery</strong></td>
<td>Delivers ( F_iO_2 ) of gas source unambiguously</td>
</tr>
<tr>
<td><strong>Comments</strong></td>
<td>Oxygen delivery same on spontaneous breaths as it is on mandatory breaths</td>
</tr>
</tbody>
</table>

Table 6-3 compares the two ventilation bags (or manual resuscitators).

Types of Tubes

The endotracheal tube should be made of a nontoxic, thermomabile, nonkinking material that molds to the airway. The tube should meet the standards of the American Society for Testing and Materials F1242-89 and be radiopaque or have a radiopaque line. Cuffed endotracheal tubes are not routinely used in neonates because the bulk of the cuff may prevent the practitioner from inserting as large a diameter tube as would otherwise be possible. There is always a serious concern that the inflated cuff may damage the very sensitive airway mucosa of the small baby. If sealing the space around the tube becomes a priority, cuffed tubes are now available (Sheridan, Inc., Argyle, NY, USA).

The type of endotracheal tube used most commonly is the Murphy endotracheal tube (Fig. 6-1). The Murphy tube is preferred for long-term ventilation. Most often, Murphy tubes have centimeter markers to show the overall depth of the tube, as well as vocal cord guide markers near the tip. These markers, under laryngoscopic visualization, show the clinician the depth within the trachea. Standard default markers should be used with caution because of the range of anatomic variation. In one review of the length of the black area at the tip of endotracheal tubes produced by four major manufacturers, the marker length varied by 10 mm in 2.5-mm internal-diameter tubes.

A Murphy tube has a tip bevel that allows smooth passage through the nares and a side hole whose purpose is to allow ventilation even if the tip is partially obstructed or is placed in the right mainstem bronchus. Some clinicians avoid using side-hole (“Murphy eye”) tubes for prolonged ventilation because of anecdotal evidence that these tubes can abrade the trachea and cause scarring. Exclusive use of these endotracheal tubes in one institution was associated with an increased incidence of subglottic stenosis that ended when use of the tubes was discontinued. It can be adequately maintained in the correct position if the lip marker is placed on the tube at the lip level and it is fixed to the face. After proper placement is determined, the marker can be used as a reference to ensure that the tube’s position remains constant. The Murphy tube is pliable (and becomes even less firm when it is allowed to remain under a radiant warmer while preparations are made for resuscitation). Many clinicians prefer to use an obturator or stylet to facilitate insertion. The stylet should not extend beyond the distal tip of the tube to avoid tracheal damage from the insertion process.

The vicious cycle of asphyxia is frequently in progress in the critically ill neonate who requires emergent tracheal intubation. The process of intubation in such an infant can exacerbate the difficulties that he or she is already experiencing. Intubation is associated with severe bradycardia, hypoxia, and elevation of arterial blood pressure and intracranial pressure.

Techniques

There are a number of methods for performing endotracheal intubation in newborns, but the technique outlined in the NRP textbook should be considered the technique of choice and “a common sense approach.” The steps are as follows, with other acceptable techniques included in parentheses:

- Stabilize the baby’s head in the “sniffing position.” A shoulder roll placed under the shoulders can help maintain the baby’s head in the correct position.
- Deliver free-flow oxygen during the procedure and suction the mouth and pharynx before sliding the blade into the mouth.
- Slide the laryngoscope over the right side of the tongue, pushing the tongue to the left side of the mouth, and advance the blade until the tip lies just beyond the base of the tongue.
- Lift the blade up slightly; raise the entire blade, not just the tip. The blade should be placed in the vallecula and, as the blade is raised, the epiglottis and the glottis with the vocal cords should be visualized. (Some clinicians slide the blade and raise the epiglottis to visualize the vocal cords.)
- Look for anatomic landmarks; suction as necessary for visualization.
- If the vocal cords are closed, wait for them to open. Insert the tip of the tube from the right side of the mouth until the vocal cord guide is at the level of the vocal cords. Avoid placing the tube into the blade groove during the insertion because that will block the vision of the glottis and vocal cords.
- Hold the tube firmly against the baby’s hard palate while removing the laryngoscope once the tube has been placed. Hold the tube while removing the stylet as well.
The NRP textbook states that the procedure should be completed in 20 seconds, but timed video recording of trained teams have shown the procedure may take 30 to 40 seconds even with skilled practitioners. This time allotment does not include setting up all of the equipment and getting the team together to help with the resuscitation. Heart rate and pulse oximetry should be monitored during the intubation procedure and the infant ventilated with bag and mask prior to starting and between attempts. Recovery should be allowed between intubation attempts as indicated by improving vital signs and pulse oximetry. The practitioner can improve O₂ tension during intubation by taping a suction catheter connected to a low-flow O₂ source along the laryngoscope blade. Other investigators have maintained a flow of O₂ (3 to 5 L/min) through the endotracheal tube during intubation in an attempt to prevent drastic changes in oxygenation. At least two laryngoscopes have been designed with an O₂ port alongside the blade.

There is a developing consensus that premedications should be used with nonemergent intubations to minimize pain, reduce bradycardia, and prevent increases in intracranial pressure. Medications such as atropine, succinylcholine, pancuronium bromide, and analgesics have been recommended although there is no standard formula. In some respects, atropine could be helpful in decreasing the volume of secretions and blocking a bradycardia secondary to a vagal response, a muscle relaxant might be helpful in decreasing movement of the baby, and analgesics can be safely used to reduce the discomfort of the procedure.

**Nasotracheal Intubation**

Nasotracheal intubation may be more time consuming and technically more difficult than orotracheal intubation for the less experienced practitioner. A nasotracheal tube is inserted into one of the nares and guided into the posterior pharynx along the floor of the nose. A laryngoscope is placed into the mouth and the glottis is visualized. A Magill forceps is held in the right hand and introduced into the mouth along the right side of the laryngoscope blade. The nasotracheal tube is grasped a short distance from its tip with the forceps. The tip of the tube is elevated until it is at the level of the glottis and is advanced between the vocal cords and into the trachea. An assistant may be needed to grasp the exterior (or distal) end of the endotracheal tube and assist with its advancement. Care should be exercised in using the Magill forceps so that the soft tissues of the oropharynx are not damaged. Experienced operators may successfully accomplish nasotracheal intubation without the Magill forceps. In addition, cooling a Murphy tube with a predetermined bend prior to intubation may facilitate the procedure.

**Digital Intubation**

Direct digital intubation of the trachea is considered to be an alternative method, which is performed using the index finger as a guide and using no laryngoscope or visualization. The technique is well described by Hancock and Peterson and is summarized as follows (Fig. 6-2):

- The operator may stand on either side or at the foot of the child; gloves are recommended.
- Moisten the tube and the gloved finger with sterile water to facilitate the procedure; (a slight crook in the end of the tube may be helpful; use of a stylet may also be helpful, at least until the operator becomes familiar with the procedure).
- The index finger of the nondominant hand slides along the tongue until the finger tip passes the epiglottis and identifies the aryepiglottic folds at the opening of the trachea.
- Slight cricoid pressure may be applied using the thumb of this hand.
- The endotracheal tube is then advanced with the thumb and index finger of the dominant hand holding the tube like a pencil and using the index finger of the dominant hand as a guide.
- The endotracheal tube is passed into the trachea and advanced the appropriate distance; a slight tightening about the tube is felt and placement is confirmed by feeling the secure position and by palpation of the trachea and tube.
- The tube is then secured if intended to be left in place.

**Depth of Tube Insertion**

In addition to direct visualization of the tube as it passes through the glottis, there are a number of different suggested “rules of thumb” for initial estimation of proper depth of tracheal tube placement. These rules use the centimeter markings on the side of a standard Murphy tube to gauge the depth of placement. The most common rule uses birth weight and a simple formula, the rule of 7-8-9. An endotracheal tube is advanced 7 cm to the lip for a 1-kg infant, 8 cm for a 2-kg infant, and 9 cm for a 3-kg infant. The rule of 7-8-9 is not appropriate for infants.
with hypoplastic mandibles (e.g., those with Pierre Robin syndrome) or short necks (e.g., those with Turner syndrome). Similarly, nasotracheal tube insertion can be governed by adding 1 cm to the 7-8-9 rule.

**Determination of Placement**

Placement of the endotracheal tube after intubation is determined first clinically and then by chest radiograph. Clinical determination includes the following:

- Improvement or maintenance of heart rate in the normal range
- Good color, pulses, and perfusion after the intubation
- Good bilateral chest wall movement with each breath
- Equal breath sounds heard over both lung fields
- Breath sounds heard much louder over the lung fields than are heard over the stomach
- No gastric distention with ventilation
- Presence of vapor in the tube during exhalation
- Direct visualization by laryngoscope of the tube passing between the vocal cords
- Presence of exhaled CO₂ as determined by a CO₂ detector and/or an end-tidal CO₂ monitor or capnography
- Tip to lip measurement: Add 6 to the newborn’s weight in kilograms (rule of “7-8-9”)

The chest radiograph should be performed to demonstrate that the tube is in the mid trachea. Tube position can change during the x-ray procedure if the infant’s neck is in a flexed or extended position. Endotracheal tube position can be confirmed on x-ray by following both of the main-stem bronchi back to the carina and cephalad to the tip of the tube. Occasionally a lateral radiograph is necessary to confirm placement in the trachea.

**Tube Fixation**

Secure fixation of the endotracheal tube is important, not only to prevent accidental extubation but also to minimize tube movement during ventilation and other interventions such as suctioning or chest physiotherapy (CPT). Accidental extubation and repeated intubations have been demonstrated to be associated with the development of subglottic stenosis, as well as increased mortality. The likelihood of accidental extubation also has been found to be associated with younger gestational age, higher level of consciousness, higher volume of secretions, and slippage of the tube. It also is clear that there is no consensus as to which tube fixation method is most effective. The technique shown in Figure 6-3 represents a modification of the method originally described by Gregory and is similar to what is used at the authors’ institutions. The exception is that tincture of benzoin is no longer used, especially in “micropreemies.” Also, some of these techniques can be used to secure nasotracheal tubes (Fig. 6-4) without the use of tincture of benzoin. Several devices for fixation of neonatal endotracheal tubes are available from various manufacturers. (See also discussion in Chapter 7.)

**Acquisition and Maintenance of Intubation Skills**

Intubation of the trachea is a complex psychomotor skill taught to a variety of health care professionals. Although
individuals be proficient at intubation yet may be unable to provide opportunities to maintain proficiency. The challenge is that, without regular practice, individual intubation skill level decreases over time and the complications from an unskilled intubation may be severe.

Initial training in intubation often occurs in a Clinical Skills Lab using plastic manikins made specifically for the purpose of intubation. This is typically the first exposure to the skill of intubation for medical students as well as for other disciplines. Courses such as the Neonatal Resuscitation Program and the Pediatric Advanced Life Support course include intubation education, practice, and testing on a manikin. The fact that students are “tested” on their ability to intubate a plastic manikin airway model may lead some to think that they are now “proficient.” It is important to emphasize that such courses provide only limited exposure to the intubation skill and that the ability to intubate a plastic manikin does not immediately translate to the bedside. However, recent improvements in the manikin, especially the anatomy and “feel” of the airway, make this simulation experience more readily transferrable to actual clinical situations.

Studies have shown that, over time, cognitive knowledge remains but the actual hands-on skill level declines and that ongoing review and proctored skills practice is needed to maintain a level of proficiency. A 10-year study of neonatal intubations performed by pediatric residents at one institution showed that median success rates varied from 33% for PL 1 residents to 40% for PL 2 and PL 3 residents. Success rates for residents with greater than 20 intubation attempts was 49%, whereas those residents with less than 20 attempts had a 37% success rate. These same pediatric residents may go on to take positions where they are expected to and need to have intubation proficiency, yet the study showed that they did not have the opportunity during their training to achieve a high level of success at the procedure. Another study found that, although pediatric residents stated that they felt confident with neonatal intubation skills, objective findings showed that they did not meet the study-specified definition of technical competence.

Neonatal and Pediatric Transport Teams typically use a combination of registered nurses, respiratory therapists, paramedics, and physicians, and there are many teams that run primarily as nurse-therapist or nurse-paramedic. Because team members are expected to perform advanced level skills, team training generally includes skills such as intubation, umbilical line, and needle aspiration/chest tube insertion. In addition to a didactic and skills practice orientation, transport team members should attend regular update and competency sessions. In the book Risk Management Techniques in Perinatal and Neonatal Practice, the authors state that team members need an adequate number of transports to maintain skills and, if the number of transports is low, there must be other mechanisms to simulate transport team function.

Over the last 25 years there have been many changes related to the indications for intubation of the neonate. Historically, all newly born infants with meconium staining of the amniotic fluid require intubation and suctioning. The latest Neonatal Resuscitation Program recommendations call for intubating only those infants

![Figure 6-4](image-url)
with meconium staining who are not vigorous. Newer oxygen delivery methods, such as high-flow nasal cannula and nasal CPAP, allow more infants to be cared for without the need for intubation. Ready availability of High-Risk Perinatal Units and Neonatal Intensive Care Units ensures that more critically ill neonates are born at a center with high-level skills. All of these advances are good for the neonate, but they have resulted in a decreased number of intubations available for pediatric residents and other practitioners. When a neonate (or any other patient) needs an airway emergently, competence is important.

Health care educators need to be creative in providing the initial intubation education and also in monitoring and facilitating the continuing education of those individuals expected to respond to a neonatal emergency. A blended learning approach can integrate online learning with supervised manikin practice. Although expensive, animal intubations (usually cats) can provide an excellent practice model, but must be done adhering to the NIH Office of Animal Care and Use (OACU) guidelines. The airline industry has long been using simulators for initial training and for continuing education and competency evaluation. The simulator manikin set-up is expensive but provides an excellent learning model that functions in real time. Patient simulations are generally enjoyed by students (generic and professional) and are perceived by the students to be of benefit. The newest neonatal simulator manikins, although expensive, provide an excellent resource for this training.

Looking to the future, educators should consider the use of virtual reality simulation. Virtual reality simulators are available to teach trauma assessment and skills and also diagnostic bronchoscopy. In one study the virtual reality bronchoscopy simulator was used to train new students in doing a diagnostic bronchoscopy. With minimal time practicing on the simulator, the new students were able to attain a level of proficiency similar to that of more experienced bronchoscopists. Virtual reality simulation can be used for initial education and practice and at regular intervals to reinforce skills.

**Alternatives to Endotracheal Intubation: Use of the Laryngeal Mask Airway**

The laryngeal mask airway (LMA) has been available for a number of years as an alternative to endotracheal intubation in babies, infants, children, and adults. It is mentioned but not recommended for routine use in the new NRP textbook, and a variety of papers discuss its use in various clinical scenarios, including the following:

- In neonatal resuscitation of term and larger preterm infants (size 1 LMA) (see Fig. 4-9)
- In the difficult airway, such as in the Robin sequence, and other situations when micrognathia is profound
- As an aid to endotracheal intubation
- As an aid in flexible endoscopy
- In surgical cases in place of endotracheal intubation

The success rate of insertion of the LMA has been reported to be greater than 90% in a number of descriptive studies of small series of infants and children (see Chapter 4 for further discussion of LMA use).

**Humidified High-Flow Nasal Cannula**

Avoiding ventilator-induced lung injury is a common goal of neonatal intensive care and has led to considerable interest in less invasive means of providing effective respiratory support. Neonates who might require respiratory support short of intubation and mechanical ventilation include those with apnea of prematurity, mild to moderate respiratory distress syndrome, and atelectasis caused by respiratory insufficiency, as well as recently extubated infants at risk for postextubation respiratory failure. Nasal CPAP has traditionally been a widely used support modality in these infants. It has the advantage of being well studied and is known to improve pulmonary mechanics and to stabilize the upper airway. However, nasal CPAP devices are bulky, may cause nasal trauma, and can be difficult to properly maintain in position.

Recently, humidified high-flow nasal cannula (HHFNC) devices have come into widespread use in neonatal intensive care units. These devices differ from traditional nasal cannula therapy in that the gas flow to the patient is warmed and humidified up to the point of patient contact, allowing the use of higher gas flows without causing nasal drying, mucosal trauma, and patient cooling. Gas flow rates used in neonatal HHFNC therapy may range between 2 and 8 L/min. The higher gas flows that can be attained with HHFNC have led many to view this therapy as a viable alternative to nasal CPAP that is less bulky and easier to maintain.

The level and consistency of CPAP that can be attained with HHFNC has been examined in several small case series reports, with variable results. There is general agreement that HHFNC can produce a clinically significant level of CPAP, particularly at higher flow rates. However, several variables appear to play an important role in determining the level of CPAP attained, including patient size, cannula diameter, and whether the mouth is open or closed. In some instances, particularly when the nasal cannula completely occludes the nares, dangerously high levels of CPAP may be produced. It should be noted that unlike nasal CPAP devices, HHFNC devices at this time do not incorporate a safety popoff valve in their design, raising the possibility that very high pressures could be transmitted to the lungs. Until better safety and efficacy data are available, HHFNC should be used with caution and not be viewed as a substitute for nasal CPAP devices.

The indications for HHFNC use in neonates are not well defined at present, and the manufacturers of the devices used in HHFNC therapy do not make any specific recommendations about clinical applications. When used in newly extubated infants to prevent extubation failure, a single-center study using historical controls found that HHFNC was as effective as nasal CPAP. A small randomized crossover trial found that HHFNC was more effective than “standard” high-flow cannula therapy in preventing extubation failure. When used as a primary mode of respiratory support, HHFNC has been shown in a retrospective study to be more effective than nasal CPAP in preventing intubation for respiratory failure. In all of these studies, HHFNC appeared to be well tolerated.
However, the variability of the patient populations in these studies, the small numbers of patients studied, and the absence of any large-scale, randomized, controlled trials do not allow delineation of a clear role for HHFNC at this time.

Safety concerns related to HHFNC use mainly relate to the level of CPAP generated and the potential for barotrauma, as discussed above, and to infectious risks. Reports of infections caused by *Ralstonia* sp., associated with the Vapotherm® HHFNC device led to the recall of that device from the marketplace in January 2006. That device has since been returned to the marketplace, with new instructions for its use designed to minimize the possibility of infection. However, this incident highlights the potential for waterborne infections originating in the humidification apparatus of HHFNC devices, and close surveillance of infection rates associated with these devices seems prudent until more data is available.

### Monitoring During Conventional and High-Frequency Ventilation

Electrocardiography, respiratory impedance tracings, and serial arterial and/or capillary blood gases have been the traditional mainstays of bedside monitoring of the newborn, and they still have an important role. In general, the emphasis on noninvasive monitoring has resulted in the development and availability of new technologies that allow close monitoring without invasive procedures. The following is a list of those instruments:

- Transcutaneous monitoring of \( P_{O_2} \) and \( P_{CO_2} \)
- Pulse oximetry to provide continuous measurement of hemoglobin saturation with \( O_2 \)
- End-tidal \( CO_2 \) monitoring

See Chapters 7 and 17 for a more in-depth discussion of these noninvasive monitoring techniques.

For infants on high-frequency ventilation (HFV), pulmonary care involves new technology and keen observation. These critically ill babies require a definite team approach, including an experienced respiratory therapist and nurse, and the traditional tools, including cardiorespiratory monitoring, intermittent arterial blood gases (from an arterial line), and “wiggle” assessment. A sample of a protocol used in the Infant Special Care Unit at our institution includes the following:

**Assessments every 1 hour:**
- Vital signs from monitors, including heart rate, arterial blood pressure, body temperature
- Vibration (or wiggle) assessment (scale +1 to +3)
- Capillary refill
- Comfort level

**Assessments every 4 hours—“Hands-on assessment”:**
- Auscultation of breath sounds on oscillator
- Palpation of pulses
- Nasogastric tube placement can be assessed without having to take the baby off of the ventilator

**Assessments every 8 hours—Ventilator is turned off but patient remains on the circuit or back-up rate (high-frequency jet ventilation [HFJV]):**
- Heart rate, position of point of maximum intensity (PMI) of heart, presence or absence of a heart murmur
- Bowel sounds
- Other assessments:
  - Arterial blood gases after initiation of HFV: hourly for 6 hours, every 2 hours for 6 hours, every 4 hours and as needed thereafter
  - Chest radiograph schedule: just prior to being placed on HFV, within 1 hour after initiation of HFV, every 12 hours twice, then daily and as needed
  - Continuous monitoring of oxygen saturation using the pulse oximeter

### Airway Management After Artificial Airway Placement

The keys to optimal management of the airway after placement of an endotracheal tube include knowledge of the potential problems, close monitoring of clinical parameters, thoughtful use of the technology listed previously, and intervention if problems arise. This level of care is the responsibility of all members of the team caring for each baby.

### Humidification and Warming

The endotracheal tube bypasses the normal humidifying, filtering, and warming systems of the upper airway; therefore, heat and humidity must be provided to prevent hypothermia, inspissation of airway secretions, and necrosis of airway mucosa. Filtration of dry gases before humidification also is needed because of the contamination sometimes found in medical gas lines. A heated water humidifier is necessary to ensure that inspired gases are delivered at or near body temperature (37°C) and that they achieve near-total saturation with water vapor. A minimum dead space hygroscopic condenser (Hudson/RCI, Temecula, Calif, USA) should be considered for use during transport or short-term ventilation. In the past, nebulizers were used in some applications, particularly in oxygen administration by head hood after extubation. Use of this system has been discarded because of impairment in oxygenation and the possibility of water intoxication caused by excess delivery of particulate water droplets and the presence of excessive noise. Sterile distilled water rather than saline is used in continuous therapy.

It should be noted that water packaged “for irrigation” exceeds standards established for water packaged “for respiratory therapy” and costs less.

A modern servocontrolled heated humidifier, with its high and low temperature alarms and heated wires that prevent accumulation of condensation, should provide adequate humidification with proper operation. O’Hagan et al. observed wide variation in the delivery of relative humidity, even when the temperature was maintained above 34.7°C; this variation resulted in failure to meet the American National Standards Institute guidelines for humidifier performance. This may account for the findings of O’Hagan et al., who observed a significant increase in morbidity when temperatures below 36.5°C were maintained at the airway. These studies have led to the recommendation that relative humidity, as well as temperature, be monitored continuously. Miyao et al. suggest...
that even maintenance of the Institute's standards (70% humidity at 37° C) may be inadequate, particularly if heated wire circuits are used. Use of circuits with heated wires was adopted primarily because of the frequency with which condensation needed to be drained and because of infection control considerations. The heated wire circuits were intended to enable the clinician to heat the gas inside the circuit to a temperature above that at which it left the humidifier, ensuring adequate absolute humidity without condensation in the circuit. This feature, which results in delivery of a hot gas with a lower relative humidity, may have caused the problems noted earlier.68

The increased temperature of a gas shifts the isothermal boundary (the point at which the gas completes equilibrium to body temperature and humidity levels) to a point closer to the airway opening. At first glance, this seems beneficial because less mucosa is exposed to the humidity deficit of the gas. However, because the effect of a given humidity deficit is concentrated on a smaller area of the mucosa, there is the potential for a greater degree of damage. Moreover, use of higher airway temperatures means that, even with lower humidity, there is relatively less opportunity for humidified air from within the lung to recondense some of its humidity upon exhalation. The result is an increase in the humidity deficit (the difference in total water content of inspired gas and the water content it achieves within the lung). The potential for adverse effects with use of the heated wire circuit is exacerbated by inadequate monitoring of humidity levels. If the wire is so hot that the circuit is dry, it is not known whether the relative humidity is 70% (the nominally acceptable American National Standards Institute value) or less.68

Traditionally, probes for monitoring inspired gas have been placed as close as possible to the patient connection so that the effect of the trip down the inspiratory line on the inspired gas can be monitored. Unfortunately, in some neonatal circumstances, the probe is continuously in the presence of a heated field and may register the effect of this heat by radiation and/or convection, totally apart from the effect of the inspired gas. If this temperature is sensed by a servocontroller, the humidifier and the heated wires may automatically heat less because the temperature is actually being controlled by another heat source (Fig. 6-5). An extension adapter, which is provided by most manufacturers, allows the probe to be placed outside of the heating field, thus remedying this problem. This extension does not need to incorporate heated wires because the gas temperature is maintained by the heated field on entry.

Figure 6-5  A, Temperature probe located inside a heated field tends to indicate a heat representative of the heated field rather than of the inspiratory gas before entry into the field. The humidifier does not provide the heat that is being detected by the wire controller. The heat source is particularly difficult to assess because most heated wire circuits operate with humidifiers that do not provide a display of the temperature of the gas immediately after it leaves the humidifier. B, Proper placement of the probe. If the probe is only slightly outside a radiant warmer field, it may need to be shielded, particularly if phototherapy is in use. (From Chatburn RL: Principles and practice of neonatal and pediatric mechanical ventilation. Respir Care 36:560, 1991.)
An additional set of problems associated with heated wire circuits has been reported by the Emergency Care Research Institute (ECRI) and the US Food and Drug Administration (FDA; see Appendix 31). Generic circuits that are not always compatible with the humidifier and its power source have been manufactured, leading to melting or charring of circuit components. Use of such circuits must be preceded by careful compatibility testing. In addition, the ECRI emphasizes that the circuits must never be covered by bed linens or drapes and that they must never be activated in the absence of flow through the system; otherwise, melting or charring may result. If a nonheated wire system is used, the temperature must be monitored by a thermometer placed inline to ensure proper temperature ranges. Use of inline water traps is recommended for decreasing the resistance to flow caused by condensate and for ensuring stability of oxygen concentrations. Despite all of the hazards and limitations of the current generation of heated wire circuits, their use has become widespread in most neonatal intensive care units. The clinician should adopt the following precautions specified by the ECRI and the FDA (in addition to the previously mentioned standards):

1. Temperature monitoring must take place before gas enters the heated field.
2. Temperature must be maintained at 36° to 37°C.
3. At least some visible condensation must be present on the inspiratory limb, despite previous beliefs to the contrary.

**Bronchopulmonary Hygiene**

The clinician must keep the chest clear of secretions in the conducting airways, and he or she must keep the artificial airway patent by ensuring proper humidification and suctioning of the endotracheal tube. These procedures may be done as needed but normally are performed routinely on a schedule, followed by administration of aerosolized medications. The frequency of suctioning should depend on the patient’s need, because this and other methods of bronchopulmonary hygiene may have detrimental side effects, especially in the very-low-birth-weight infant.

CPT involving postural drainage in concert with percussion or vibration has been shown to be beneficial in removing secretions and preventing atelectasis in recently extubated neonates. It also has been shown to result in removal of more secretions from intubated neonates. Furthermore, oxygenation has been shown to be enhanced after completion of CPT. The benefit of this procedure may lie in the periodic redistribution of the gravity-dependent regions of the lung, rather than in the physical removal of secretions. On the other hand, CPT has not gained universal acceptance. Its use should be individualized in each baby because as noted earlier, use of these techniques has been associated with a variety of negative effects, especially in infants born weighing less than 1000 g. This group of extremely low-birth-weight infants frequently is on a minimal stimulation plan of care for the first 3 to 5 days of extrauterine life, thus minimizing any pulmonary care interventions. The paucity of airway secretions in this group of infants during this time has led some clinicians to suction only on an “as needed” basis or not at all.

**Positioning of the Patient**

Postural drainage involves the use of various positions in which the different mainstem bronchi are positioned vertically so that drainage from the smaller bronchi moves into the larger bronchi (Figs. 6-6 to 6-13). The two forces at work during this procedure are gravity and airflow. Any area of the bronchial tree that is to be drained (with the exception of the medial basal segment) must be uppermost. These positions may not be practical for implementation in critically ill babies who have chest tubes or endotracheal tubes, who have undergone surgery, or who are at great risk for intraventricular hemorrhage. Optimal, the infant should be monitored during CPT; potential monitors include transcutaneous O2 or CO2, or pulse oximeter. Significant oxygen desaturation during the procedure should cause the caretaker to pause and initiate measures necessary to correct hypoxemia.

**Percussion and Vibration**

Two types of hand pressure can be applied to the neonatal chest to expedite adequate drainage: percussion and vibration. Percussion in the neonate can be performed with small plastic cups with padded rims or with soft circular masks with their adapters plugged so that the air pockets are maintained. The chest is percussed over the area to be drained for 1 to 2 minutes. Percussion may be reserved for infants who weigh more than 1500 g and are older than 2 weeks of age because of the potential risk for intraventricular hemorrhage.

The traditional view of vibration is that it is effective only during exhalation because it causes secretions to move from the periphery of the lungs with the outflow of air. This technique requires careful observation of chest movements. For vibration, the wrist is extended and the arm muscles are contracted in a manner similar to that used for isometric exercises. The result can be described as a controlled quiver. The placement of fingers flat against chest walls of infants suffices. A light touch with rapidly vibrating fingers has been considered effective in mobilizing secretions in neonates. Because few practitioners feel comfortable with this technique, vibrations can be done with a padded electric toothbrush, a small hand vibrator, or a commercially available pulmonary vibrator.

Vibration is tolerated by a greater number of patients than is percussion. The duration of vibration therapy is subject to the infant’s tolerance and can be monitored on the basis of the parameters discussed previously.

**Optimization of Drug Delivery**

The common practice of administering aerosolized medications before bronchopulmonary hygiene and suctioning is based on custom more than scientifically verified practice. The pharmacology of drug action is discussed in Chapter 21.

Although delivery of aerosolized medication has a number of advantages over systemic dosing, recent
Figure 6-6  Drainage of the posterior segments of the upper lobe. The infant is leaned over at a 30-degree angle from the sitting position. The clinician claps and vibrates over the upper back on both sides.

Figure 6-7  Drainage of the anterior segments of the upper lobe. While the infant is lying flat on his or her back, the clinician claps and vibrates between the nipples and the clavicle on both sides.

Figure 6-8  Drainage of the apical segment of the upper lobe. The infant is leaned backward about 30-degrees from the sitting position, and the clinician claps or vibrates above the clavicle on both sides.

Figure 6-9  For drainage of the right middle lobe, the caregiver elevates the hips to about 5 inches above the head. He or she rolls the infant backward one-quarter turn and then claps and vibrates over the right nipple. For drainage of the lingular segments of the left upper lobe, the caregiver places the infant in the same position but with the left side lifted upward; he or she then claps and vibrates over the left nipple.

Figure 6-10  Drainage of the lateral basal segments of the lower lobes. The caregiver places the infant on the left side with the hips elevated to a level about 8 inches above that of the head. The caregiver rolls the infant forward one-quarter turn and then claps or vibrates over the lower ribs. Note that the position shown is for draining the right side. For draining the left side, the same procedure is followed, except that the infant is placed on his or her right side.

Figure 6-11  Drainage of the superior segments of the lower lobe. The clinician places the infant flat on the stomach and then claps or vibrates at top of the scapula on the back side of the spine.

Figure 6-12  Drainage of the posterior basal segments of the lower lobe. The clinician places the infant on the stomach with the hips at a level 8 inches above that of the head. He or she then claps and vibrates over the lower ribs close to the spine on both sides.

Figure 6-13  Drainage of the anterior basal segment of the lower lobes. The caregiver places the infant on the left side with the hips at a level about 8 inches above that of the head. He or she then claps and vibrates just beneath the axilla. Note that for drainage of the opposite anterior basal segment, the infant is turned on the right side.
information has helped in the design of a few reliable aerosol delivery systems (Boxes 6-3 and 6-4 and Table 6-4). The basic fundamental characteristics of factors that influence neonatal aerosol delivery and deposition are listed in Box 6-3. These factors can be divided into two groups: host-related factors and aerosol system–related factors. Box 6-4 lists the characteristics of “the ideal aerosol delivery system.” Table 6-4 compares the advantages and disadvantages of the three most frequently used aerosol delivery systems: the pressurized metered-dose inhaler and the jet and ultrasonic nebulizers. However, even with the progress being made in the design of aerosolized medication delivery systems, the clinician may need to test a variety of delivery devices and decide which system is most efficacious for each individual patient. The same may have to be done with the type and dose of aerosol medication in order to establish a bronchodilator dose, that is, measuring a patient’s response to a specific drug and dose using bedside pulmonary function methods detailed in Chapter 18 rather than using predetermined dose tables. In addition, it is important to understand the variables unique to the aerosol route that can affect the drug delivery device. The small internal diameter and high resistance of the neonatal endotracheal tube impair aerosol delivery in the intubated patient compared with the non-intubated patient. In studies with animals, humans, and bench models, from 0.19% to 2.14% of the total drug amount in the nebulizer cup was administered to the lung or lung model when conventional jet nebulizers were used compared with 10% of the total dose that was shown to be deposited in the lungs of nonintubated patients.

With currently available methods, the placement and operation of a nebulizer are important for maximizing drug delivery to the lung. The nebulizer should be placed

<table>
<thead>
<tr>
<th>Box 6-3</th>
<th>OVERVIEW OF FACTORS THAT INFLUENCE NEONATAL AEROSOL DELIVERY AND DEPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Host-Related Factors</strong></td>
<td></td>
</tr>
<tr>
<td>• Anatomic (nasal breathing, size of oropharynx, airways, lung development)</td>
<td></td>
</tr>
<tr>
<td>• Physiologic (breathing pattern, inspiratory flow rate, tidal volume, pulmonary mechanics)</td>
<td></td>
</tr>
<tr>
<td>• Pathophysiologic (inflammation, mucus, atelectasis, fibrosis)</td>
<td></td>
</tr>
<tr>
<td><strong>Aerosol System–Related Factors</strong></td>
<td></td>
</tr>
<tr>
<td>• Characteristics of the medication (particle size, shape, density, output)</td>
<td></td>
</tr>
<tr>
<td>• Generator [pressurized metered-dose inhaler (pMDI) or nebulizer]</td>
<td></td>
</tr>
<tr>
<td>• Delivery devices–patient interfaces (face mask or endotracheal tube)</td>
<td></td>
</tr>
<tr>
<td>• Conditions (ventilatory, environmental)</td>
<td></td>
</tr>
<tr>
<td>• Provider technique (optimum use of pMDI with spacer)</td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Box 6-4</th>
<th>THE IDEAL AEROSOL DELIVERY SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>• High efficiency in aerosol delivery</td>
<td></td>
</tr>
<tr>
<td>• Predictable and reproducible (in same patient and different patients)</td>
<td></td>
</tr>
<tr>
<td>• Easy to use and maintain</td>
<td></td>
</tr>
<tr>
<td>• Efficient to administer</td>
<td></td>
</tr>
<tr>
<td>• Convenient</td>
<td></td>
</tr>
<tr>
<td>• Cost-effective</td>
<td></td>
</tr>
<tr>
<td>• Environmentally safe</td>
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<tr>
<th>TABLE 6-4</th>
<th>Advantages and Disadvantages of Aerosol Generators in Neonates</th>
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</thead>
<tbody>
<tr>
<td><strong>Aerosol Generator</strong></td>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Pressurized metered-dose inhaler (pMDI)</td>
<td>• More consistent aerosol particle size and output</td>
</tr>
<tr>
<td></td>
<td>• Less time-consuming</td>
</tr>
<tr>
<td></td>
<td>• Less preparation time</td>
</tr>
<tr>
<td></td>
<td>• Less contamination</td>
</tr>
<tr>
<td></td>
<td>• Less expensive than single-use nebulizers</td>
</tr>
<tr>
<td></td>
<td>• Some HFA formulations have more optimal aerosol particle size</td>
</tr>
<tr>
<td>Jet nebulizer</td>
<td>• Tidal breathing</td>
</tr>
<tr>
<td></td>
<td>• Passive cooperation</td>
</tr>
<tr>
<td></td>
<td>• Can be used for long periods to deliver high doses</td>
</tr>
<tr>
<td></td>
<td>• Wide range of medications</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrasonic nebulizer</td>
<td>• Potentially more efficient than jet nebulizer and pMDI</td>
</tr>
<tr>
<td></td>
<td>• Tidal breathing</td>
</tr>
<tr>
<td></td>
<td>• Passive cooperation</td>
</tr>
<tr>
<td></td>
<td>• Can be used for long periods to deliver high doses</td>
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at least 5 inches upstream from the patient connection (not directly on the ventilator Y), and the humidifier should be bypassed for the duration of medication delivery.\(^7\) If the nebulizer itself can provide the necessary flow for operation of a time-cycled pressure-limited ventilator, source flow other than the nebulizer should be eliminated if dilution of medication is to be prevented; however, the nebulizer flow should not be permitted to back up into the ventilator.\(^8\) On the other hand, for more sophisticated ventilators in which this technique would trigger an alarm, nebulizers that prime the inspiratory tubing while running only in the expiratory phase are under development.\(^9\)

**Suctioning**

Standards for suctioning protocols vary among institutions and usually are not based on physiologic principles or the results of current research.\(^3\) The role of endotracheal suctioning is important, but the potential risks are many.\(^4,5\) Use of a closed “inline” suctioning system has been promoted to decrease respiratory contamination and pulmonary infections. Disadvantages of these systems include increased expense and potential increase in air leaks. Suctioning should be performed by experienced personnel because complications from the trauma of this procedure may lead to hypoxemia, cardiovascular embarrassment, barotrauma, and intraventricular hemorrhage. However, with care, patience, and appropriate anticipation, suctioning is a highly effective method of clearing the airway. The interval should be individualized and documented at the bedside; an example is illustrated in Figure 6-14. Following are a few suggestions on how to optimize benefits and prevent complications (see Table 6-5 and Figs. 6-13 and 6-15 for additional information):

- Anticipate when setting up for suctioning by having the proper equipment available.
- Be aware of ventilatory parameters and FiO₂.
- Perform noninvasive monitoring of oxygenation before, during, and after suctioning.
- Have two people available (two-person job).
- Have the proper suction catheter size (see Tables 6-1 and 6-2 and/or Figs. 6-14 and 6-15). Ensure the external diameter of the suction catheter is not more than two thirds the internal diameter of the endotracheal tube.
- Individualize suctioning interval, catheter size, and depth of instillation of suction catheter as outlined in Tables 6-1 and 6-2.
- Prepare settings for vacuum pressure, from 60 to 100 mm Hg.

<table>
<thead>
<tr>
<th>Table 6-5</th>
<th>Endotracheal Suctioning in Newborn Infants</th>
</tr>
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<tbody>
<tr>
<td><strong>Hodge</strong></td>
<td><strong>Hagedorn et al.</strong></td>
</tr>
<tr>
<td>Irrigation solutions</td>
<td>Saline, but not routinely</td>
</tr>
<tr>
<td>Amount for irrigation</td>
<td>0.1-0.2 mL/kg</td>
</tr>
<tr>
<td>Catheter size</td>
<td>0.5-0.66 of tube diameter</td>
</tr>
<tr>
<td>Depth of insertion</td>
<td>Length of tube only</td>
</tr>
<tr>
<td>Hyperinflation</td>
<td>PIP 10%-20% above baseline</td>
</tr>
<tr>
<td>Hyperventilation</td>
<td>Equal total respiratory rate</td>
</tr>
<tr>
<td>Oxygen enhancement</td>
<td>10%-20% above baseline</td>
</tr>
<tr>
<td>Suction pressure</td>
<td>50-80 cm H₂O</td>
</tr>
<tr>
<td>Duration</td>
<td>Not specified</td>
</tr>
<tr>
<td>Intermittent vs continuous</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Head turn</td>
<td>No</td>
</tr>
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</table>


PIP, Peak inspiratory pressure.
Surfactant Administration

This section addresses the technical aspects of surfactant administration, including dosage forms, amounts, and administration techniques. Other aspects of surfactant treatment are discussed in Chapter 22.

The surfactant pool size in lungs of healthy, full-term neonates is about 100 mg/kg. Infants with RDS have a surfactant pool size that is approximately 10% of that seen in the healthy, full-term lung. Surfactant doses for prevention or treatment of RDS are aimed at achieving a surfactant pool size comparable to that in the full-term lung while also allowing for some uneven distribution of exogenous surfactant and surfactant inactivation by protein exudates. Thus surfactant doses in the range of 50 to 200 mg/kg have been used in various clinical studies. Currently available commercial surfactant preparations contain varying amounts of phospholipids, but the recommended dosage amounts give 100 to 200 mg/kg of phospholipids per dose (Table 6-6). All currently available surfactant preparations are obtained by extraction from animal lungs and are available in a liquid form for intratracheal instillation, although a new, completely synthetic surfactant (lucinactant) may be available by the time this text is published. Differences in recommended dosage volume may lead the clinician to favor a particular surfactant preparation in certain clinical situations.

Recommended modes of surfactant administration are based on those used in research protocols, but there are limited human data comparing different techniques of sur-

<p>| Table 6-6 Surfactant Preparations |
|-----------------------------------|------------------|----------------|</p>
<table>
<thead>
<tr>
<th>Surfactant</th>
<th>Source</th>
<th>Phospholipid Content, mg/mL</th>
<th>RECOMMENDED DOSE (mL/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infasurf</td>
<td>Calf lung</td>
<td>35</td>
<td>Initial: 3, Repeat: 3</td>
</tr>
<tr>
<td>Survanta</td>
<td>Cow lung</td>
<td>25</td>
<td>Initial: 4, Repeat: 4</td>
</tr>
<tr>
<td>Curosurf</td>
<td>Pork lung</td>
<td>80</td>
<td>Initial: 2.5, Repeat: 1.25</td>
</tr>
</tbody>
</table>

Data from package inserts. See references 90, 99, 100.
factant administration. Surfactant is generally administered through a small-bore catheter inserted into the endotracheal tube, although the Infasurf package insert suggests instillation through a side-port adapter. Animal data suggest that administering surfactant by bolus or rapid intratracheal infusion results in more even distribution of surfactant than giving the surfactant by very slow continuous intratracheal infusion. Surfactant doses are typically divided into 2 or 4 aliquots. The infant is positioned before each aliquot so as to ensure even distribution of surfactant throughout both lungs, although there are limited data regarding the efficacy of this practice. Very limited data suggest that delivery of surfactant by nebulization might result in improved distribution of surfactant, but this approach requires further study.

Extubation

There is no single reliable physiologic parameter or pulmonary function test in neonates that determines readiness for extubation. The optimal time for extubation is determined by a variety of parameters, including mean airway pressure, oxygen requirement, ventilatory requirements (see Chapters 9 and 10 on modes of ventilation), estimation of negative inspiratory force, static compliance, and most importantly, the appearance of the baby. Gillespie et al. have suggested placing the infant on endotracheal CPAP for 10 minutes while monitoring the spontaneous minute ventilation. The ability of the infant to spontaneously generate at least 50% of the minute ventilation that was seen during assisted ventilation predicted readiness for extubation and shortened the time to successful extubation. The clinician may also use intermittent bagging of the infant to get a sense of the compliance of the lung. The baby’s primary problem and the clinical course and duration of assisted ventilation can provide helpful information regarding the appropriate timing for extubation. Some experts believe that a transition period from assist mode, pressure support, and/or extubation to nasal prong or nasopharyngeal continuous positive airway pressure (CPAP) is an excellent way to facilitate extubation. Sometimes a methylxanthine is used during the weaning process because its effects include “reminding the newborn to breathe” and increasing the efficiency of the diaphragm, especially in very-low-birth-weight infants. If the infant has been on assisted ventilation for several days and there is concern about edema and inflammation in the upper airway, one or two doses of dexamethasone, given 24 to 48 hours prior to extubation, may be helpful.

Extubation Technique

Many authors advise extubation with positive pressure to avoid atelectasis. Some clinicians, however, use negative pressure to suction the airway during the extubation process. To the best of our knowledge, no controlled clinical study has yet established the advantage of extubating with positive or negative pressure.

Postextubation Care

The extubated infant requires frequent clinical assessment during the postextubation period. Frequent observation of breathing patterns, auscultation of the chest, and monitoring of vital signs, pulse oximetry (continuous), transcutaneous CO₂ levels, and/or blood gases are all of value. Other interventions, including bronchopulmonary hygiene, can be started in an attempt to prevent or reverse atelectasis, most often seen in the right middle and upper lobes. Racemic epinephrine may help open up the airways by decreasing edema of the airway, although reviews of its efficacy have been negative. After extubation, if there is a clinical concern, a chest radiograph can be obtained. If the baby continues to deteriorate, other techniques to consider include initiation of CPAP using the nasopharyngeal technique (NPCPAP), intermittent manual bagging using the correct-sized mask and non-self-inflating bag, racemic epinephrine, and/or corticosteroids (inhalation or parenterally) if signs of upper airway obstruction are noted. The risk-benefit ratio for corticosteroids should always be considered before use.

If the baby is unable to maintain adequate ventilation despite interventions, then reintubation and suctioning should be accomplished. There are multiple reasons for extubation failure; Box 6-5 provides a comprehensive list. Extubation failure should prompt a search for a cause that can be corrected before the next extubation attempt.

<table>
<thead>
<tr>
<th>Box 6-5 Major Causes of Extubation Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Pulmonary</td>
</tr>
<tr>
<td>A. Primary disease not resolved</td>
</tr>
<tr>
<td>B. Postextubation atelectasis</td>
</tr>
<tr>
<td>C. Pulmonary insufficiency of prematurity</td>
</tr>
<tr>
<td>D. Bronchopulmonary dysplasia</td>
</tr>
<tr>
<td>E. Eventration or paralysis of diaphragm</td>
</tr>
<tr>
<td>II. Upper Airway</td>
</tr>
<tr>
<td>A. Edema and/or excess tracheal secretions</td>
</tr>
<tr>
<td>B. Subglottic stenosis</td>
</tr>
<tr>
<td>C. Laryngotracheomalacia</td>
</tr>
<tr>
<td>D. Congenital vascular ring</td>
</tr>
<tr>
<td>E. Necrotizing tracheobronchitis</td>
</tr>
<tr>
<td>III. Cardiovascular</td>
</tr>
<tr>
<td>A. Patent ductus arteriosus</td>
</tr>
<tr>
<td>B. Fluid overload</td>
</tr>
<tr>
<td>C. Congenital heart disease with increased pulmonary flow</td>
</tr>
<tr>
<td>IV. Central Nervous System</td>
</tr>
<tr>
<td>A. Apnea (extreme immaturity)</td>
</tr>
<tr>
<td>B. Intraventricular hemorrhage</td>
</tr>
<tr>
<td>C. Hypoxic ischemic brain damage/seizures</td>
</tr>
<tr>
<td>D. Drugs (phenobarbital)</td>
</tr>
<tr>
<td>V. Miscellaneous</td>
</tr>
<tr>
<td>A. Unrecognized diagnosis (e.g., nerve palsy, myasthenia gravis)</td>
</tr>
<tr>
<td>B. Sepsis</td>
</tr>
<tr>
<td>C. Metabolic abnormality</td>
</tr>
</tbody>
</table>
References


86. Unpublished observations.