According to estimates, worldwide 15 million infants are born preterm every year.1-3 Among these preterm infants, approximately 10% are born at 28 to less than 32 weeks’ gestation, and 5% are born at less than 28 weeks’ gestation.1,4 Prematurity is the leading cause of death in the neonatal period and the second leading cause of death in children less than 5 years old.3 Annually, 1.1 million infants die of direct complications of preterm birth.5 The incidence, morbidity, and mortality of preterm infants continue to challenge health care providers even though the emergence of neonatal intensive care units (NICUs) and advanced technology has improved the infants’ survival.3

Most preterm infants require minimal respiratory support in the delivery suite; however, some may need invasive mechanical ventilation to initiate and sustain breathing.4 A few infants may require mechanical ventilation for a prolonged period. Prolonged ventilation is a concept that lacks consistency in definition: the duration considered prolonged can vary from more than 2 hours6 to more than 21 days.6 NICU nurses are in a pivotal position to influence the outcome of extremely preterm infants. In this article, I focus on preterm infants who require mechanical ventilation for a prolonged period and on nurses’ role in management so that potential complications can be avoided.

Mechanical Ventilation in Preterm Infants

The World Health Organization1 categorizes infants born alive before 37 completed weeks of gestation into 3 categories: late and moderate preterm, which is 32 to less than 37 weeks (83% of all preterm births); very preterm, which is 28 to less than 32 weeks (10% of all preterm births); and extremely
preterm, which is less than 28 weeks (5% of all preterm births). About 90% of extremely preterm infants born in high-income countries with access to full intensive care survive, whereas only 10% born in low-income settings with limited physical and human resources survive.1 The high survival rate in preterm infants can be attributed to the emergence of NICUs with sophisticated technology and excellent nursing care.1 About 10% of all infants born in the United States need some assistance in the delivery suite.2 Of these, 1% may need extensive resuscitation that includes intubation and mechanical ventilation.7 Around 50% of preterm infants with a gestational age of 24 to 28 weeks may require intubation and mechanical ventilation to maintain extrauterine life.2,8 Administration of surfactant, a natural lipoprotein, into the alveoli may relieve an infant’s respiratory distress.9 Although this treatment improves pulmonary function, a lack of alveolar growth reduces the surface area for gas exchange.9 The goals of mechanical ventilation include preventing atelectasis, maintaining adequate pulmonary gas exchange, reducing the work of breathing, and minimizing ventilator-induced lung injury.9

Approaches to mechanical ventilation are highly variable and may be determined by the severity of an infant’s condition, available resources, and the experience of the care team.8 In addition, no standardized terminology for various modes of ventilation exists. Synchronized, patient-triggered, pressure-limited and volume-targeted, and high-frequency ventilation are the usual broad categories.8 Nitric oxide may be used to enhance vasodilatation and lung perfusion.8 Regardless of the type of ventilation used, the approach for each infant is individualized. When conventional mechanical ventilation is insufficient to maintain optimum gas exchanges, high-frequency ventilation with low-compliance tubing and connectors (jet ventilation or oscillatory ventilation) may be the treatment of choice.8 In these modes of mechanical ventilation, the fraction of inspired oxygen must be carefully adjusted to ensure optimum oxygen saturation. Hypoxemia is usually due to ventilation-perfusion mismatch or to left-to-right shunting, and the underlying physiological condition may determine the mode and settings of ventilation.8 Each mode of mechanical ventilation and the individual settings have specific advantages and disadvantages (Table 1).

Most NICUs have specific protocols and algorithms that provide guidelines for beginning or changing the ventilator settings. The decision on how to alter the settings is influenced by a constant interplay of factors, such as the infant’s hemodynamic status, progression and regression of the infant’s condition, lung pathological conditions, response to ventilator changes, and results of blood gas analysis. Despite efforts to wean an infant from mechanical ventilation, some infants require prolonged ventilation to allow the lungs to heal.

Ongoing observation and monitoring help in achieving well-timed extubation and in preventing complications. Reliance on proper criteria for extubation, such as the spontaneous breathing test, in addition to clinical judgment, may obviate reintubation.8 Vigilant observation, continuous monitoring, and regular clinical assessments are essential to recognize early warning signs of complications of mechanical ventilation, including ventilator-associated pneumonia, lung injury, chronic lung disease, infections, air leak syndrome, retinopathy of prematurity, malformations of the nasal and oral cavities, and skin complications.10 Appropriate synergy between the infant’s effort to breathe and the technology used can minimize volutrauma (volume-induced trauma to the lung) and barotrauma (pressure-induced trauma to the lung).8

Challenges for Nurses

Nurses caring for an infant receiving mechanical ventilation face many challenges. Expertise and extreme care are important aspects in providing safe and effective care. Cardinal aspects of care include thermoregulation, optimal positioning, airway clearance, stable hemodynamic status, and adequate nutrition for maintenance of growth and development. In addition, prolonged mechanical ventilation is associated with acute

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complications such as infection and accidental extubations and long-term complications such as chronic lung disease, subglottic stenosis, and neurodevelopmental problems. A summary of these challenges and possible courses of action are given in Table 2.

Table 1  Some types of mechanical ventilation and pathophysiological characteristics in infants

<table>
<thead>
<tr>
<th>Mode of ventilation</th>
<th>Indications/description</th>
<th>Physiological characteristics</th>
<th>Complication/nurse vigilance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous positive airway pressure (CPAP)</td>
<td>Presence of spontaneous breathing effort, but need for support to maintain oxygenation</td>
<td>Most newborns are obligate nose breathers, Constant distending pressure thereby prevents alveolar collapse, Mouth can act as pressure valve if pressure is too high</td>
<td>Nasal septal erosion/necrosis from bigger nasal prongs, Pneumothorax from excess positive pressure, Abdominal distention from swallowed air, gastric decompression, Nasal obstruction; ensure proper placement and clear airways</td>
</tr>
<tr>
<td>Neonatal nasal intermittent noninvasive positive pressure ventilation (NIPPV)</td>
<td>Provides noninvasive respiratory support; more support than CPAP with a set frequency of breathing</td>
<td>Improve respiratory drive, increase pharyngeal dilatation, Increase tidal volume and minute volume, Increase functional residual capacity</td>
<td>Abdominal distention from swallowed air, gastric decompression, Monitor for pulmonary graphics and ventilation loops</td>
</tr>
<tr>
<td>Synchronized NIPPV</td>
<td>Provides noninvasive respiratory support; more support than CPAP with a set frequency of breathing</td>
<td>Synchronize breathing with detection of abdominal wall movement by using a capsule, Infant has greater control of the breathing</td>
<td>Abdominal distention from swallowed air, gastric decompression, Monitor for pulmonary graphics and ventilation loops</td>
</tr>
<tr>
<td>Intermittent mandatory ventilation (IMV)</td>
<td>Failure of noninvasive modes of ventilation, Intubation is necessary</td>
<td>Pressure or volume is set to be delivered into the lungs, In support ventilation, every spontaneous inspiratory breathing effort is supported to culminate in mechanical breath, Predetermined rate</td>
<td>Monitor for pulmonary graphics and ventilation loops, Pneumothorax from excess positive pressure, Dislodgement of endotracheal tube, Inadvertent extubation, Ventilator-associated pneumonia (VAP); monitor for and initiate VAP bundle for prevention</td>
</tr>
<tr>
<td>Volume-targeted ventilation</td>
<td>Failure of noninvasive modes of ventilation, Intubation is necessary</td>
<td>Targets tidal volume and is controlled by flow sensor, Adjusts peak inspiratory pressure from breath to breath, Predetermined rate</td>
<td>Leaks around the tube, Dislodgement of endotracheal tube, Inadvertent extubation, VAP; monitor for and initiate VAP bundle for prevention</td>
</tr>
<tr>
<td>High-frequency ventilation</td>
<td>Failure of conventional mechanical ventilation, Air leak syndrome, Reduce barotrauma when conventional ventilator settings are high</td>
<td>Smaller dead space, Allows higher mean airway pressure, Prevent atelectasis and optimizes lung volume, Active expiratory phase</td>
<td>Monitor for pulmonary graphics and ventilation loops, Pneumothorax from excess positive pressure, Dislodgement of endotracheal tube, Inadvertent extubation, VAP; monitor for and initiate VAP bundle for prevention</td>
</tr>
<tr>
<td>Neurally adjusted ventilator-assist ventilation (NAVA)</td>
<td>Electrical activity of the diaphragm triggers mechanical ventilation, Higher patient synchronization</td>
<td>Insufficient data to support regular use</td>
<td>Insufficient data to support regular use</td>
</tr>
</tbody>
</table>

Thermoregulation

Thermoregulation is a vital determinant of morbidity, mortality, and optimum health outcome in infants, particularly premature infants. Invasive procedures requiring prolonged access to an infant, such as umbilical
catheterization, intravenous access, and radiographic procedures, may jeopardize thermal stability. The risk for heat loss and resulting hypothermia is more profound in preterm infants than in term infants because of the preterm infants’ limited brown fat and immature heat-preserving mechanisms. Hypothermia has been

catheterization, intravenous access, and radiographic procedures, may jeopardize thermal stability. The risk for heat loss and resulting hypothermia is more profound in preterm infants than in term infants because of the preterm infants’ limited brown fat and immature heat-preserving mechanisms. Hypothermia has been
independently associated with increased energy consumption, neonatal cold injury (as evidenced by lethargy and oliguria), poor weight gain, and susceptibility to infection that may jeopardize the condition of a neonate. Therefore, routine neonatal critical care includes measures to reduce heat loss by evaporation, conduction, convection, and radiation and use of methods to maintain normothermia. Judicious limited access into the incubators by care providers or infants’ family members may help prevent heat loss. Use of humidity, plastic wraps, and other accessory heating or warming equipment such as water-circulating heating pads help with transfer of heat. Positioning devices such as “snugglies” (devices with a cloth boundary for infants to brace their feet and straps to contain their arms) help conserve heat and can influence thermoregulation. Some challenges to neonatal thermoregulation are the infant’s size and gestational age and the care team’s need for access during procedures and assessments. The temperature of the humidifier in the ventilator circuit and buildup of condensation in the tubing also must be monitored to ensure the temperature of the inspired gases, which in turn affects thermoregulation.

Positioning and Maintaining a Patent Airway

Positioning an infant who is receiving mechanical ventilation can be a challenging task. Although a comfortable position is essential for rest, an infant’s position can affect chest expansion, patency of the endotracheal tube, and circulation. Benign routine care activities have been linked to changes in cerebral blood flow patterns, possibly contributing to intraventricular hemorrhages. Positioning devices and adequate boundaries help provide a stable position for an intubated infant. After reviewing literature and consulting experts in neurophysiology, Malusky and Donze recommended midline head positioning for preterm infants to prevent intraventricular hemorrhage but did not reach any conclusion about the duration of midline positioning. Maintaining an infant in the midline position while keeping the endotracheal tube secure in an optimum position in the short, narrow trachea is critical to ensure a stable hemodynamic status. Nurses prefer to position infants prone, because this position is better than the supine position for good oxygenation in preterm infants receiving mechanical ventilation. Compared with the supine position, skin-to-skin (kangaroo) care and the prone position were not factors for any variability in hemodynamic status in preterm infants.

Endotracheal suctioning is needed to maintain airway patency. The pressure, depth, and duration of suctioning are factors that can affect ventilation and oxygenation. Suctioning or position changes must be performed with extreme care because these procedures may increase cerebral perfusion and intracranial pressure. Such changes in perfusion and pressure can increase the risk for intraventricular hemorrhage and long-term sequelae such as cerebral palsy in extremely preterm infants. Head sonography is routinely performed on days 4 and 30 of life for extremely preterm infants for early detection of any intraventricular hemorrhage. Sonography sometimes requires that infants be repositioned, a situation that may cause stress, leading to bradycardia and desaturations. Warming up the gel used for the procedure may prevent cold stress in infants undergoing head sonography.

Maintaining a Stable Hemodynamic Status

Continuous cardiorespiratory and oxygen saturation monitoring is the standard of care in every NICU. In addition, infants receiving mechanical ventilation may have continuous arterial pressure monitoring and preductal and postductal pulse oximetry. The vital signs can change rapidly. A slight movement of the head may dislocate the endotracheal tube, triggering a vagal reflex and resulting in bradycardia, desaturations, or other inadvertent hemodynamic changes. An abrupt movement of the head may kink the endotracheal tube and generate the same effect. Highly sensitive equipment is helpful for monitoring. Alarm limits (upper and lower) for heart rate, respiration, blood pressure, and oxygen saturation are set on the basis of current evidence and the NICU’s specific standard of care. The American Academy of Pediatrics recommends that oxygen saturation measured by pulse oximetry be maintained at 90% to 95% for low-birth-weight and preterm infants and at 95% or higher for term infants. Although vigilant monitoring is essential for making changes in treatment, interventions, and validation of clinical progress, some infants become dependent on the mechanical ventilator for several weeks or months. As an
infant matures and become more active, maintaining the endotracheal tube in place can be difficult.

**Nutrition and Feeding**

A preterm baby may have abnormalities in fluid and electrolyte imbalance because of inadequate intake, frequent collections of blood specimens for laboratory tests, and evaporative losses. Feeding intolerance is a common complication of preterm birth. Enteral feeding is ideal for optimum growth and development and prevention of infection in a preterm infant. Practitioners vary in their process of initiating and advancing the feedings in preterm infants. Early initiation of trophic feeding is beneficial to all infants, particularly extremely preterm infants. The volume of feeding may be advanced carefully and as tolerated on the basis of institution-specific protocols. Stable hemodynamic status and existing pathological changes and anomalies may determine the process used. Nonetheless, Eicher et al reported that hypoxemia and poor mesenteric perfusion leading to necrotizing enterocolitis can be primarily related to prematurity. Necrotizing enterocolitis may delay feeding attempts and necessitate surgical intervention, including bowel resection, ileostomy or colostomy, leading to prolonged hospitalizations. Therefore, total parental nutrition is routinely used for these infants regardless of gestational age to meet nutritional needs until the infants can tolerate full-volume feedings. Practitioners must adjust the micronutrients daily; prolonged use of total parental nutrition can lead to complications such as cholestasis, infections, and longer hospitalizations. Intravenous access adds to the risk for infection in extremely premature infants. Prolonged intubation necessitates tube feedings for extended periods. This duration of tube feeding in addition to lack of oral motor stimulation can result in nipple aversion. Nipple aversion can result in slow progress in oral feeding, thereby delaying discharge to home.

**Communication With Infants’ Family Members**

In response to the fluctuating status of premature infants and unexpected outcomes, the infants’ family members may become emotional and concerned. Open, honest communication with the family is necessary for reducing their anxiety. Stress in parents of NICU infants has been studied, and nurses are front-line advocates and counselors for these families in crisis. Regular and ongoing support by social workers, personnel in pastoral care, developmental specialists, and nurses to educate the families on care-related topics is essential to sustain the families’ involvement through prolonged critical times in the NICU. The psychological and social needs of the parents must be considered. Cultural sensitivity and language barriers must be considered and addressed by providing qualified interpreters to communicate medical information.

**Complications**

**Prevention of Infection**

Extremely preterm infants are highly vulnerable to infection. Intrauterine infection can be a cause of premature birth. Risk for infection is higher in extremely preterm infants because artificial airways bypass the normal filtering of inspired air, thereby fostering microbial growth. The infants are also at risk for necrotizing enterocolitis, sepsis, respiratory infection, and fungal infections. Infants with sepsis can become critically ill, and a higher rate of cerebral palsy has been reported in infants with sepsis. In addition, surgeries such as ligation of a patent ductus arteriosus may increase the risk for infection.

All personnel in the NICU must adhere to the infection control policies to provide a safe environment for the infants in the unit. Hand washing, isolation, surveillance, seasonal screening of visitors for potential infection, and validating the immunization status of the sibling visitors may be challenging. Nurses must advocate for premature infants to ensure patient safety and prevent infection that can lead to long-term sequelae.

**Prevention of Unplanned Extubation**

Maintaining an artificial airway for a prolonged duration is essential. Sudden and unexpected movement of an infant’s head can dislodge the endotracheal tube from the trachea. Unplanned extubation can also happen during routine care or transfer of infants to parents for skin-to-skin care. Nurses may encounter challenges such as short tracheas, which can lead to quick extubation, and small endotracheal tubes (internal diameter 2 mm) that are easily blocked. In addition, nonadherence of the securing device (to secure the endotracheal tube) to the skin because of secretions, poor skin integrity, and a small
face on which to place the securing device pose additional challenges. Smaller airways make reintubation difficult. Vigilance by nurses is absolutely essential to maintain a patent airway and prevent inadvertent extubation.

Chronic Lung Disease, Subglottic Stenosis, Retinopathy of Prematurity

The potential long-term effects of mechanical ventilation and oxygen administration include volutrauma, barotrauma, and retinopathy of prematurity.2,24,25 Preterm infants with prolonged duration of mechanical ventilation may become dependent on the ventilator.2 In addition, prolonged mechanical ventilation increases the risk for chronic lung disease.2 Steroids may be used to reduce the inflammation in chronic lung disease, although the role of these drugs has not been fully established.26,27 Infants at increased risk for airway edema and obstruction may benefit from steroids, thereby avoiding reintubation after a planned extubation.27 Infants intubated for prolonged periods are also at risk for subglottic stenosis, which can result in airway obstruction and may require laryngotracheal reconstructive surgery or a tracheostomy for maintaining an open airway.28 Infants who require such surgery may require careful coordination of care, including training of parents in tracheostomy care and subsequent home care. This need for training is an additional challenge to NICU nurses. The nurses must ensure that parents are competent in tracheostomy care before an infant with a tracheostomy is discharged home.

Poor Neurodevelopmental Outcome

The results of studies on neurodevelopmental outcome and rate of disability in preterm infants are conflicting.29,30 Neurodevelopmental disabilities in preterm infants may include cerebral palsy, mental retardation, and visual and hearing impairments.2 In a study of 50 extremely premature infants, Sereni et al29 found severe mental developmental delay (78%), severe cerebral palsy (12%), and blindness (8.2%). The proportion of moderate or severe disabilities increased with the decrease in gestational age; 60% at 22 weeks to 17% at 26 weeks ($P < .001$ for trend). Boys (31%) were more prone to disability than were girls (23%). In other studies,29,30 family-centered and developmental care and sociodemographic factors were associated with better neurodevelopmental outcomes.29,30 Neurodevelopmental outcomes did not vary with a higher level of NICU care.31 Extremely premature infants may experience other disorders of central nervous system functions, including language disorders, learning disabilities, attention deficit hyperactivity disorder, neuromotor dysfunction, and behavioral and social-emotional difficulties.2 These infants may experience more difficulties at school, resulting in poor academic achievement later in life. Low levels of education among parents and social disadvantages are also associated with neurodevelopmental outcome in preterm infants.29

Long-term developmental interventional programs may be essential to prevent or modify the outcome in infants born prematurely.32 Although some of the adverse outcomes are inevitable because of the immaturity of the organ systems, a marked difference in behavior and neurodevelopmental outcome can be achieved by early identification and cost-effective and timely interventions.32 Purposeful communication by nurses can alleviate or reduce stress in parents who are in crisis mode in the NICU and can increase patient and family satisfaction with the care provided, although the outcome remains unchanged.33

Economic and Financial Impact of Prolonged Mechanical Ventilation on Infants’ Families and Community

The long-term effect of prematurity requiring prolonged mechanical ventilation may include poor quality of life of the child and the child’s family members, poor neurodevelopmental outcome, and extended use of technological support for life sustenance, effects that can economically deplete a society.1 This economic need can become a societal, legal, and organizational challenge. The cost associated with preterm birth in the United States was $26.2 billion in 2005.2 In addition, the cost of community resources during birth, hospitalization, and continued support services through school years and beyond are substantial.1,2 Out-of-pocket expenses can destabilize a family’s finances as well. The cost of care of a premature infant increases as the gestational age decreases.2

Ethical Issues

Several medically fragile infants who have survived with severe sequelae have generated much debate
about the ethics of aggressive care. When treatment is offered to infants with a very low level of predictable survival, the decision making becomes hard on parents and health care providers. The Institute of Medicine reported that in instances in which health care providers recommended withholding treatment but parents refused to allow the withholding, the number of days an infant survived increased but the overall outcome was not affected. NICU nurses can feel dispirited when their efforts become futile and death happens after they have spent busy, emotionally charged hours caring for an infant. When such a scenario occurs often, caregivers can experience emotional exhaustion.

Newer Perspectives and Future Methods of Mechanical Ventilation

Invasive mechanical ventilation is the common method of establishing and maintaining ventilation in infants who are born extremely premature. However, the complications of mechanical ventilation can result in major and irreversible damage to the health and well-being of the child and the child’s caregivers. Older methods such as bubble continuous positive airway pressure, nasal continuous positive airway pressure, and nasal intermittent noninvasive positive pressure ventilation are increasingly being used now in NICUs globally. The optimal method that can lead to better outcomes is a matter of debate. For example, the outcome report from New York Presbyterian Hospital indicated that these noninvasive methods of ventilation produced significantly better results in preterm infants than did other methods. Laryngeal mask ventilation is also used by some practitioners for short-term mechanical ventilation or transport purposes. Newer methods of ventilation such as the neurally adjusted ventilator assist method, which can be used invasively or noninvasively, in which the ventilation is controlled by diaphragmatic electrical activity, may gain popularity in NICUs.

Practices such as use of a minimally invasive approach in the delivery suite and early administration of surfactant may help reduce the number of infants who undergo prolonged mechanical ventilation and its long-term complications. However, having staff who are sufficiently trained in the use of any mode of mechanical ventilation is essential for successful implementation and optimal outcomes.

Conclusion

Initiation of resuscitation may enhance the survival of preterm infants, and some of these infants may need prolonged mechanical ventilation. Nevertheless, attempts to reduce morbidity and long-term sequelae of prematurity have been unsuccessful. Prolonged mechanical ventilation in preterm infants presents many challenges. Providing quality care requires up-to-date evidence-based knowledge, emerging noninvasive technology, and competent staff. Evaluating and continuously improving the care processes, monitoring the quality indicators for progressive positive trends, and ongoing supervision of care may reduce morbidity and long-term sequelae. Early use of continuous positive airway pressure, early extubation, selective intubation, and use of spontaneous breathing tests for timely extubation may improve outcome in infants who are born prematurely.

Research on the methods of mechanical ventilation, the outcome in infants, and the economic impact may change trends in caring for preterm infants.

Acknowledgments

I thank Lauren Kibler, respiratory therapist at Christiana Care Health Systems, for verifying the respiratory interventions in the neonatal intensive care unit.

Financial Disclosures

None reported.

Letters

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To learn more about mechanical ventilation, read “Weaning From Mechanical Ventilation: A Scoping Review of Qualitative Studies” by Rose et al in the American Journal of Critical Care, September 2014; 23:e54-e70. Available at www.ajcconline.org.

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Rachel A. Joseph

Crit Care Nurse 2015;35 58-66 10.4037/ccn2015396
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