Managing Common Neonatal Respiratory Conditions During Transport

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ABSTRACT
As neonatal care in the tertiary setting advances, neonatal transport teams are challenged with incorporating these innovations into their work environment. One of the largest areas of advancement over the last decade involves respiratory support and management. Many major respiratory treatments and the equipment required have been adapted for transport, whereas others are not yet feasible. This article reviews the history of respiratory management during neonatal transport and discusses current methodologies and innovations in transport respiratory management.
Key Words: high-frequency jet ventilation, infant transport, inhaled nitric oxide, neonatal transport, rapid sequence intubation, RSI

Neonatal transport medicine is a specialized field that involves complex coordination and skilled clinicians in a resource-limited environment. Although many transported infants require pediatric specialty consultations, the most common reason for a transport request is respiratory distress. This article discusses neonatal respiratory problems and their management needs during transport.

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Very low-birth-weight (VLBW) infants who are at the highest risk for respiratory distress have better outcomes when born in a hospital with a neonatal intensive care unit (NICU).[1] About 30% of these infants are delivered outside a tertiary perinatal center.[2] According to the American Academy of Pediatrics, having specialized and regionalized intensive care services for infants and children improves outcomes.[3] Specifically, having a transport team trained in neonatal respiratory stabilization and management is essential to decrease infant mortality and morbidity rates when they are born in nontertiary settings.

HISTORY OF TRANSPORT

Historically, neonatal transports to a hospital began in the early 1920s with the creation of premature ambulance services and the invention of the first transport isolettes in Chicago, Illinois.[4,5] The premature ambulance service consisted of a nurse and a driver pair who specialized in bringing premature infants from home to hospital.[4] Home births during this era were common. During this time, even mildly distressed infants had a very high mortality rate because of the unsanitary birth conditions.

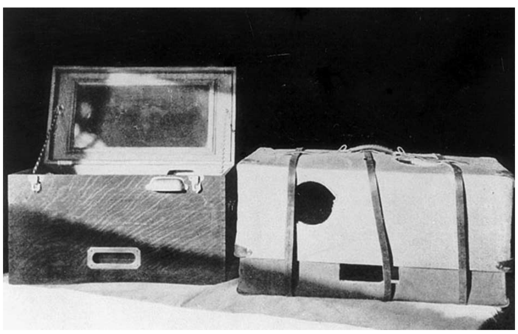
The primitive isolettes developed by Dr Julius Hess were made of a leather and steel case (Figures 1 and 2), hand-carried, and electronically charged during the automobile or train transport from home to hospital.[4,5] Many of the transported infants were premature and the newly created isolette used hot coals or heated water bottles between the 2 walls to ensure a warm environment. Because transport isolettes allowed premature infants to stay warm, mortality rate likely decreased. In addition, the top of these isolettes contained clear glass allowing constant visualization to assess the infant's color and breathing.

Early isolettes were later modified to carry a small oxygen tank (Figures 2 and 3), to allow oxygen to be initiated during the transport for respiratory support.[4,5] Transport isolettes advanced further around 1970 after the introduction of NICU monitors and the first neonatal ventilator called the Babybird. Dr Forrest Bird (Percussionaire Corporation, Sagle, Idaho) was a World War II pilot who was sent to medical school by the military after expressing his ideas of optimizing pilot breathing during high-altitude flights.[6] Dr Bird's ideas led him to create the first ventilator in 1955 and the Babybird in 1969. According to a televised interview with Dr Bird in 2007, he was most proud of the Babybird ventilator as it helped his neighbor's 2 infant sons survive to later grow into adults.[7] At the time, the Babybird ventilator was felt to have decreased the infant mortality rate from approximately 70% to 10%.[6]

In addition to the advances in transport, infant mortality rate was further decreased by the introduction of perinatology as a medical specialty. The safety of a hospital delivery was recognized and many births gradually transitioned from home to hospital. Pediatrician-led teams began to attend deliveries of high-risk infants and NICUs became more advanced to address the needs of smaller premature infants, especially after invention of the Babybid ventilator. Transport medicine also advanced with the availability of an automated heat source, oxygen, monitor, and ventilator. Transport isolettes transitioned from primitive heat sources to advanced, portable systems capable of safely transporting sick infants from the birth hospital to the tertiary center.

Today, neonatal teams have expanded their equipment to include more technologically complex isolettes with advanced modes of respiratory management. Transport teams typically include specially trained nurses and respiratory therapists (RTs) as team members.[3,8] Although NICU advances in respiratory care led to advanced neonatal transport technology, the often-challenging transport environment

FIGURE 1.



Early, hand-held transport isolette. From Neonatology on the Web. http://www.neonatology.org/pinups/earlytransport.html.

FIGURE 2.

Early transport isolette with oxygen. From Neonatology on the Web. http://www.neonatology.org/pinups/earlytransport.html.

FIGURE 3.

Early premature ambulance service. From Neonatology on the Web. http://www.neonatology.org/pinups/earlytransport.html.

continues to limit novel respiratory therapies and the empirical evidence to support neonatal transport medicine is still minimal.

AIRWAY AND RESPIRATORY DISTRESS CONSIDERATIONS FOR TRANSPORT

Management of common airway and respiratory conditions during transport requires knowledge of the condition, treatments needed, and ongoing assessment of treatment effectiveness during transport. Common respiratory conditions encountered during transport, the needed therapies to treat them, and the ability to provide the treatment on transport are included in Table. To ensure that the infant is successfully cared for before and during transport, good communication between the referral and accepting hospital is essential. From the initial call to completion of the transport, assessment of the infant's condition including work of breathing, vital signs, inspired oxygen requirements, pulse oximeter readings, arterial blood gas results, and the respiratory illness trajectory including birth history is necessary. Depending on the referring hospital's level of expertise and available resources, the accepting physician gives guidance to the referring physician about advancing respiratory care before the transport team's arrival. Finally, the accepting physician provides the transport team with the information needed about the infant's severity of illness and anticipated care needs.

The infant's anticipated condition and severity of illness, supplies and equipment needed by the team to treat the infant, current weather conditions, and current availability of various transport modalities need to be evaluated in concert to determine the best mode of transport. If the infant is severely ill, advanced equipment and more supplies are often needed; this can impact the mode of travel. Also, if the referral hospital is unable to manage the infant, the team may suggest a faster mode of transport. Before mode of travel is established, the team must first anticipate the needed equipment on the basis of the expected respiratory problem with the flexibility of addressing unanticipated issues that may arise. Airway supplies, including laryngeal mask airways (LMAs), the isolette equipped with the appropriate ventilator including either conventional or high-frequency jet ventilator (HFJV), as well as inhaled nitric oxide (iNO) may be required dependent on the anticipated respiratory condition. Newer transport isolettes are available with HFJV and nitric oxide delivery systems in addition to a reserve conventional ventilator.

TABLE. Common Neonatal Respiratory Conditions

Respiratory Condition	Incidence	Signs and Symptoms	Therapies Needed	Treatment Frequency on Transport
RDS[9,10,11]	1% 1 per 100	Accessory muscle use Grunting Nasal flaring	Oxygen NCPAP Conventional ventilation Surfactant	Frequently Occasionally Frequently Occasionally
PPHN[12]	1.9 per 1000[13]	Accessory muscle use Grunting Nasal flaring Desaturations/cyanosis	Oxygen[12,13] Conventional ventilation[12,13] HFJV[12,13,14] iNO[12]	Frequently Frequently Occasionally Occasionally
Pneumothorax[15]	1% to 2% of live births	Asymptomatic Shifted PMI Accessory muscle use Grunting Nasal flaring Abrupt desaturation/ change in condition	Observation Oxygen Needle aspiration Chest tube placement[16] Conventional ventilation HFJV	Frequently Frequently Occasionally Rarely Rarely Rarely
PIE[15]	<1% to 2% of live births	Accessory muscle use Desaturations/cyanosis	Position affected side down Conventional ventilation HFJV	Frequently Frequently Occasionally

Abbreviations: HFJV, high-frequency jet ventilator; iNO, inhaled nitric oxide; NCPAP, nasal continuous positive airway pressure; PIE, pulmonary interstitial emphysema; PMI, point of maximum impulse; PPHN, persistent pulmonary hypertension; RDS, respiratory distress syndrome.

Next, the mode of travel by air or ambulance is determined. Air transport includes helicopter travel, commonly referred to as rotor, and fixed wing aircraft. In most instances, rotor is the fastest mode and helpful for infants in severe distress located fairly far from the tertiary center. However, factors such as the current weather conditions, distance of itinerary, rotor availability, and size or weight of neonatal equipment may prevent a team from using rotor transport. Occasionally conditions of the infant such as pneumothorax or other air leaks may prevent rotor transport because of further expansion of the extrapleural air that may occur in unpressurized environments. In consultation with the accepting attending physician, the neonatal teams often elect to fly these infants by rotor at lower altitudes and preferably with the extrapleural air evacuated before transport.

Transport via fixed wing aircraft may be used for any infant and is not typically constrained by weather. Fixed wing aircraft can also complete longer transports than either rotor or ambulance transports. However, in many areas, fixed wing airplanes are not readily available and must be contracted for use, which causes a long delay in transport. Ambulance transport is probably the most common method used for neonatal transports and dedicated neonatal teams typically stock their ambulances with neonatal resuscitation supplies. Occasionally extreme weather conditions such as snow, ice, or floods may inhibit ambulance travel. Traveling during rush hour traffic can also severely delay the transport. When traveling to the referral hospital, the team may choose to use emergency lights and sirens if the infant is requiring resuscitation and the referral hospital personnel lacks adequate equipment and expertise to manage the infant's decompensation.

Regardless of the infant's severity of illness, the accepting physician and transport team can guide the referral hospital with steps for managing common respiratory conditions while the team is in route often using the Neonatal Resuscitation Provider (NRP) program for resuscitation and initial management.[16] Occasionally the infant with mild respiratory distress can be placed on a nasal cannula, oxyhood, or nasal continuous positive airway pressure before the transport team's arrival. For moderate to severe respiratory distress, intubation and later surfactant administration by the team may be required. When the transport team arrives and an infant resuscitation is in progress, the team can assess if assistance is needed or start resuscitation as necessary while assessing other needs of the infant.

AIRWAY DETERMINATION AND PLACEMENT

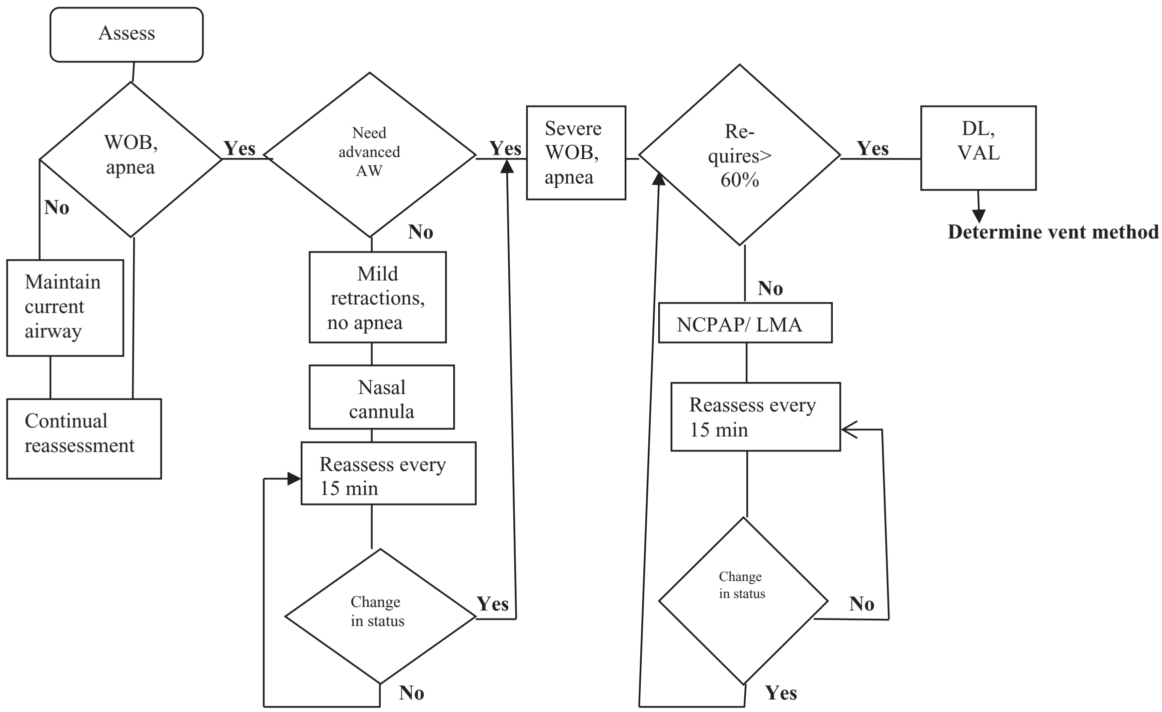
Neonatal specialty teams have several options for airway stabilization including conventional direct laryngoscopy, video laryngoscopy, or LMA placement. First the team determines if obtaining a stable airway is emergent which requires immediate intubation, often using direct laryngoscopy (Figure 4). Second, if not emergent, the team determines in consultation with their attending physician the infant's need for rapid sequence intubation). Rapid sequence intubation is a protocol that involves the use of a vasolytic medication such as atropine, a rapid-acting analgesic such as fentanyl, and a short duration muscle relaxant such as rocuronium[17] and reduces intubation-associated pain and discomfort.[17,18] Rapid sequence intubation also reduces the physiological responses of bradycardia, systemic hypertension, intracranial hypertension, and hypoxia related to intubation.[17,19,20]

The size of the endotracheal tube needed is determined on the basis of the weight of the infant or the gestational age according to NRP guidelines.[16] If emergent intubation is not required, endotracheal tube size can be discussed among the team members while the rapid sequence intubation medications are being infused. In addition, during this time the team discusses whether direct laryngoscopy or video-assisted intubation will be used considering the skill level of the team members.[21] Because video-assisted laryngoscopy is a new method of intubation on transport, not all team members are skilled and comfortable with this method.

Video-assisted intubation or video laryngoscopy typically includes a light and camera at the end of a plastic blade that projects an enlarged image of the posterior pharynx and airway onto a screen. This allows multiple clinicians to view the anatomy and intubation procedure and enables recording of the procedure for later study. Use of this method is often based on the intubator's preference and experience with video laryngoscopy. Several studies with anesthesiologists[22,23] have shown little or no differences with the first attempt success obtaining an airway using video laryngoscopy or the direct laryngoscope, but there are some advantages in using video laryngoscopy instead direct laryndoscope.[24] With video laryngoscopy, there is improved glottic visualization, particularly in patients with difficult airways and decreased time for successful intubation was also noted.[24] Disadvantages of this method are the extra minutes necessary to assemble the equipment and larger size compared with direct laryngoscopy equipment.

For late preterm and older infants, insertion of the LMA should be considered for transport to the accepting hospital if the needed intubation is unsuccessful.[16,25] An LMA is inserted into the esophagus with a cuff inflated so that air enters the trachea rather than the esophagus and stomach. Infants with micrognathia, choanal atresia, and other airway anomalies are excellent candidates for LMA to prevent worsened respiratory distress or when

FIGURE 4.



Determination of airway placement on transport algorithm. Abbreviations; AW, airway; DL, direct laryngoscopy; LMA, laryngeal mask airway; NCPAP, nasal continuous positive airway pressure; VAL, video-assisted laryngoscopy; WOB, work of breathing.

resuscitation is needed.[25] Positive pressure ventilation can be also given via an LMA, but suctioning and medications cannot be provided. Laryngeal mask airway placement is commonly used in term infants, but their use in premature infants is limited.

Appropriate airway placement is confirmed with improvement or stabilization of the heart rate, auscultation of equal breath sounds, end-tidal carbon dioxide ($ETCO_2$) detection, absent epigastric sounds, and chest radiograph of the endotracheal tube. The airway must then be secured with tape or an endotracheal tube holder using a standardized method of depth insertion such as found in NRP. Documentation of the placement depth and the skin integrity are also recommended.

DETERMINATION OF VENTILATION METHOD

Once the infant's airway is stabilized and optimally positioned in the trachea, the neonatal team determines ventilation type, based on discussion with the attending physician and the equipment available. Transport ventilators typically include conventional ventilation with intermittent mandatory ventilation or synchronized intermittent mandatory ventilation with pressure or volume capabilities. Some transport teams have access to HFJV and the available systems are the Bunnell Life Pulse (Salt Lake City, Utah) or the Duotron (Sagle, Idaho). Use of high-frequency oscillatory ventilation on transport is not currently available. In addition, some transport teams may have iNO available for use, depending on suspected or confirmed PPHN (Figure 5). The most commonly used method for iNO is the Ikaria INOmax DS and INO blender (Hampton, New Jersey).

When an infant has RDS and the severity has progressed to intubation, the team will often place the infant on conventional ventilation, especially if the infant is 28 weeks to term gestation. The use of synchronized intermittent mandatory ventilation in this population is optimal to prevent asynchronous breaths.[26] Rarely infants may be placed on volume ventilation during transport, but this is an area that needs more study to recommend use on transport.

If the infant is less than 28 weeks, has an air leak, or has PPHN, the team may elect to place an infant on HFJV. For extremely premature infants with stiff, noncompliant lungs, HFJV is preferred to prevent overdistention of the alveoli, barotrauma, and PIE. For infants with air leak, HFJV is used to minimize overdistention and further air leak on susceptible

FIGURE 5.

Example of a neonatal transport isolette with high-frequency jet ventilator and inhaled nitric oxide. Photo compliments of Timmy Snow, RN, MSN, NNP, Winston-Salem, North Carolina.

alveoli. For infants with PPHN, HFJV may be used prophylactically to prevent air leaks and when other forms of ventilation have failed.[27]

Infants requiring high ventilator support, such as with PPHN, may require conventional ventilation and iNO or more commonly iNO and HFJV if the required transport isolette is available. Most infants who require these advanced forms of ventilation and nitric oxide are either term or late preterm (34weeks' gestation or greater). The use of HFJV, along with nitric oxide in infants with PPHN, results in pulmonary vasodilation, reversal of intrapulmonary shunting, and improved oxygenation.[12,28] Infants are usually started on iNO at 20 ppm, a dose that has been found very effective to achieve positive results. Higher doses of nitric oxide can lead to methemoglobinemia caused by toxic levels of oxides of nitrogen in the blood and the formation of methemoglobin. Methemoglobin has a higher affinity for oxygen than hemoglobin and will consequently cause a shift to the left in oxyhemoglobin dissociation curve, further impairing oxygenation because of impaired release of oxygen to the tissues. Patients become visibly cyanotic when levels of methemoglobin are greater than 10% and at 35%, and weakness and dyspnea can occur and can be fatal if methemoglobin levels exceed 70%.[29] Although premature infants may require stabilization and transport on the HFJV to prevent further damage, iNO is not usually advised in premature infants.

ADDITIONAL RESPIRATORY SUPPORT

After ventilation is established, the team assesses the need for surfactant in consultation with the attending physician and reports on arterial blood gas results and other findings. The decision to administer surfactant is usually based on the infant's condition including amount of oxygen required to keep saturations in a targeted range, arterial oxygen level, and chest radiograph results. If the decision is made to administer surfactant, the RT usually delivers this through the endotracheal tube after placement has been verified by chest radiograph. In addition, a subsequent arterial blood gas sampling is obtained to establish response to surfactant and to determine additional changes in ventilator settings.

If the infant is noted to have an air leak such as pneumothorax, the neonatal team will likely choose to evacuate this before transport.[30] Larger pneumothoraces under tension are most commonly needle aspirated initially and occasionally a chest tube may be placed to prevent reaccumulation. A flutter or Heimlich valve may be connected to the chest tube to maintain suction during transport.[31] These valves are small and make transport with a chest tube more efficient and are less likely to cause accidental dislodgement during the transport. Rarely an infant may have such a severe air leak that a water seal setup is needed. Infants transported by helicopter who have medium to large pneumothoraces always have them evacuated or drained before transport to prevent expansion in case the helicopter needs to elevate quickly, known as autorotation, to miss obstacles or to avoid unexpected weather conditions.[30]

After the team leaves the referral hospital, the infant is continually assessed for changes in condition. Respiratory status is assessed by observing work of breathing, oxygen saturations, and, if needed, arterial blood gas sampling. If abrupt changes occur, the neonatal team consults with the attending physician. Ventilator changes are made as needed. Occasionally additional sedation may be required after discussion with the attending physician.

CONCLUSION

Neonatal transport teams can often offer the same advanced respiratory management techniques that are currently used in the NICU. Transport respiratory management is accomplished by having a team of clinicians with advanced neonatal resuscitation skills, including registered nurses and RTs, with level III to IV NICU experience. Obstacles to respiratory management are size and feasibility of equipment, method of transport, team composition, and lack of research and evidence to support transport practice. To overcome these obstacles, teams are advised to encourage equipment manufacturers to develop portable ventilator systems feasible for neonatal transport. Teams should also regularly participate in flight training and provide input into medical helicopter and fixed wing aircraft modifications. Because many neonates are transported for respiratory conditions, it is optimal for tertiary centers to have RTs on their team. To promote transport medicine, teams should also regularly participate in research and disseminate their findings to add to the body of knowledge.

Future endeavors for neonatal transport teams may include other forms of respiratory management currently being used in some NICUs. Neotech's RAM cannula (Valencia, California) is a softer form of nasal continuous positive airway pressure that allows the infant to move more freely and to lie prone if needed. T-pieced resuscitators are commonly used in delivery rooms and some NICUs, but the equipment currently available is not feasible for many transport teams. Other modalities not available to neonatal transport include neurally adjusted ventilatory assist and pressure and volume limited ventilation. Neurally adjusted ventilatory assist uses electrical signals from the infant's diaphragm to allow the infant to control ventilation. Pressure limited ventilators limit the amount of pressure that can be delivered during inspiration and support synchronized ventilation. As early as 2011, volume ventilation began replacing pressure limited ventilation because it provides a controlled, consistent tidal volume with lower PIP to reduce lung damage.[27] Neonatal transport teams are encouraged to extend these modes of respiratory support into the transport environment to prevent infant morbidity.

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