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Pyramid of Care: Pediatric Edition

By Matthew S. Pavlichko, MS, RRT, RRT-NPS

As our healthcare landscape changes, reimbursement difficulties, cost containment, readmission penalties, and the role and scope of the future respiratory therapist is up for debate. Identifying and providing value to the patient and the organization is imperative for any respiratory care department, large or small. Our value is never more evident than during a respiratory emergency, most importantly, of a pediatric patient. This article will review the historical need for winter pediatric preparations in respiratory care as well as the treatment theory called the "Respiratory Pyramid of Care: Pediatric Edition."

Panel Discussion: NIV and HFNC for Neonates and Pediatric Patients

Moderator: Kathleen Deakins, RRT-NPS FAARC

Panelists: Rob DiBlasi, RRT-NPS
Lee Williford, RRT-NPS, RCP
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Several methods are used in pediatric and infant populations to ensure adequate breathing and sufficient levels of blood oxygen. These methods are placed along a continuum or pyramid of utility. Two of the most popular methods are: High-Flow nasal cannula (HFNC) which adds heat and humidity to the air flow to create a level of comfort that other oxygen devices are lacking, and continuous positive pressure airway pressure (CPAP) devices, which is a noninvasive method of delivering air to the lungs under mild pressure. In this panel discussion, three experts discuss the pros and cons of HFNC as well as CPAP, and when and how they should be used.

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Pyramid of Care: Pediatric Edition

By Matthew S. Pavlichko, MS, RRT, RRT-NPS

As our healthcare landscape changes, reimbursement difficulties, cost containment, readmission penalties, and the role and scope of the future respiratory therapist is up for debate. Identifying and providing value to the patient and the organization is imperative for any respiratory care department, large or small. Our value is never more evident than during a respiratory emergency, most importantly, of a pediatric patient. This article will review the historical need for winter pediatric preparations in respiratory care as well as the treatment theory called the "Respiratory Pyramid of Care: Pediatric Edition."

The Emergency Medicine Network has recorded that there are 5,273 EDs in the US.[1] However, of those 5,273 emergency departments, only 220 reside in a children's hospital (CHA).[2] These statistics lead to the assumption that most pediatric ED visits are performed outside the walls of a children's hospital. Chamberlain and colleagues described the scope of this phenomenon in 2013,[3] when they reported that up to 90% of all pediatric emergency cases did not receive care at a pediatric specialty hospital. In addition, according to the Agency for Healthcare Research and Quality (AHRQ),[4] only 5% of pediatric ED visits result in admission to the same hospital. The AHRQ also reported that in 2015, the most common reason for pediatric patients to visit the ED was for respiratory disorders, especially during winter months.[4]

The ED is not the only location that deals with respiratory emergencies. Many inpatient pediatric units and neonatal intensive care nurseries across the country reside outside the wall of a children's hospital. This phenomenon places enormous pressure to deliver high quality care in a low-volume, high-risk patient population in settings where the least amount of experience, knowledge, and resources are available. Is pediatric respiratory emergency truly "low-volume"? This module will describe the Respiratory Pyramid of Care within the scope of pediatrics. Its purpose, is to provide comprehensive insight into the respiratory treatment strategy of the sick child and to better prepare clinicians for the child who will inevitably arrive.

What is the Pyramid of Care?

The Council for Advances in Respiratory Therapy developed the theory of "Navigating the Respiratory Pyramid of Care" in 2010. Led by David Vines, PhD, RRT, FAARC, the council (comprised of expert respiratory care thought leaders from across the country) developed an extensive, peer-reviewed educational curriculum to create a comprehensive understanding of oxygen therapy and ventilatory support.[5] This curriculum describes the treatment selection strategy for adult patients with respiratory compromise, as well as how to navigate the severity of their illness, from worsening progression to weaning. Although, initially created to care for the adult patient, the "Pyramid of Care" translates well to the pediatric patient population.(Figure 1)

The pyramid's shape is the most important concept. The foundation of the pyramid serves the largest population and has the least complexity; i.e., patients on room air. As one moves up the pyramid, one shifts in treatments that are higher cost and complexity but are necessary for a smaller number of patients. When patients' conditions worsen, they advance up the pyramid, but when they improve, they are weaned down the pyramid. Each treatment meets the patient's needs, but each has nuances that can serve as a conduit or a barrier to care. Each is described in more in depth below.

Treatments that Resolve Hypoxemia/Hypoxia

When the body's partial pressure of arterial oxygen (PaO_2) falls below normal levels, hypoxemia is present. Hypoxemia can be caused by hypoventilation, shunting, diffusion defects, abnormal hemoglobin, anemia, and/or poor perfusion. Signs and symptoms include increased work of breathing (WOB), tachypnea, shortness of breath, tachycardia, poor perfusion, and potential neurological deficit.[5] Hypoxemia can occur during severe trauma, shock, cyanide and carbon monoxide poisoning, cardiac arrest, and perioperative emergencies.

In 2016, The World Health Organization (WHO) created the Oxygen Therapy

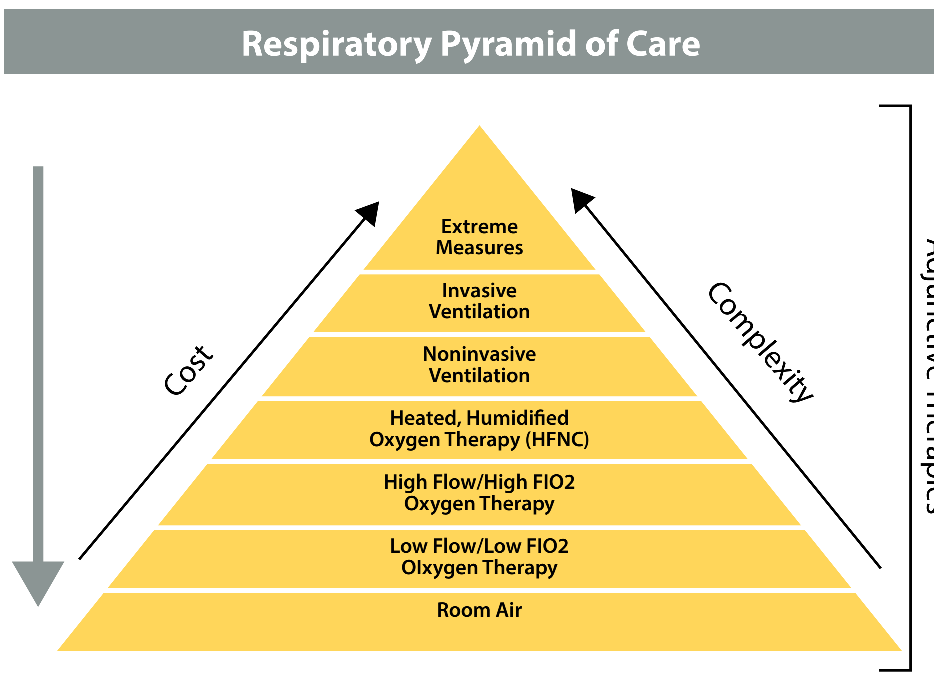

Figure 1.

for Children Guide, which describes, in detail, assessment and identification, treatment strategies, and monitoring of children on oxygen therapy.[6] PaO2 can be considered as a diagnosis of hypoxemia, but the measure of PaO_2 requires an invasive arterial blood gas (ABG) test. The WHO identified a target oxygen saturation (SpO_2), which is a non-invasive measure of tissue oxygenation, to adequately reflect hypoxemia and the response to therapy that is appropriate for children. This target goal is defined as a SpO_2 of 90-94%[6] via pulse oximeter. Treatment should target that goal.

High-flow Nasal Canuala

Room Air

Although not addressed by Vines and colleagues, room air is the best option for most pediatric patients, even those who present with respiratory illness. Oxygen is a prescribed therapeutic intervention that has benefits but also side effects. If a patient is adequately oxygenating, oxygen is contraindicated. Hyperoxia leads to oxygen toxicity, alveolar damage, absorption atelectasis, etc.[7] In addition, oxygen therapy devices are difficult to manage with pediatric patients due to lack of patient understanding. Oxygen therapy is only effective when the application is consistent. Comfort can overcome reason, but when room air is adequate, it is always the best option.

Low-Flow – Variable FiO_2 Devices

When oxygen is needed, the first step of the Pyramid of Care is low-flow oxygen. A low-flow oxygen device is described by Egan as an oxygen device that delivers a flow rate less than the inspiratory flow rate of the patient, thus creating variable FiO_2 due to respiratory rate and tidal volume.[8] Examples of low-flow devices are a standard nasal cannula, simple mask, air entrainment mask, and a large-volume aerosol mask. All these devices deliver FiO_2 to the patient less than that which is set on the flowmeter. Three of four use a mask as an interface. As pediatric patients come in all shapes and sizes, so do masks. As discussed in the previous section, effectiveness requires consistency of therapy, so comfort is very important. Have you ever put a mask on a 2-year old? For reasons of comfort and compliance, the nasal cannula is the standard low-flow delivery device for pediatrics.

The nasal cannula is the most comfortable option, comparatively speaking. They come in many sizes, can be humidified using a bubble humidifier, and now are made of very soft material to maximise comfort. Patients can talk and eat while fitted with a nasal cannula. The initial application may be difficult depending on the patient, but the standard nasal cannula should be the first option for oxygen therapy.

High-Flow – Fixed FiO_2 Devices

When a higher level of FiO_2 is required, the low-flow device may be inadequate and a high-flow fixed FiO_2 may be needed. In contrast to low-flow, a high-flow device is one that meets or exceeds the patient's inspiratory demand thus providing a stable or fixed FiO_2. The FiO_2 at the blender flowmeter is what is delivered to the patient with minimal air entrainment. These include non-rebreather masks, dual large-volume aerosol masks, and high-flow/high FiO_2 air entrainment masks. Once again, masks are difficult options for pediatric patients, which creates a challenge to the delivery of high oxygen volumes to children.

Air-Oxygen Blenders

The use of low-flow and high-flow oxygen devices creates a potential problem for respiratory therapists. Flow and FiO_2 that are dependent on each other does not cause a major problem for adults but does present a barrier to the treatment of children. FiO_2 is the treatment needed to meet the therapeutic SpO_2 goal of 90-94%, but FiO_2 is flow dependent. Or is it?

As described above, hyperoxia should always be avoided. In 2010, the AHA and AAP changed the NRP algorithm to reflect a strategy to reduce the detrimental effects of hyperoxia. The algorithm includes the recommendation to resuscitate infants using < 100% FiO_2 to meet target saturations over time.[9,10] Air-oxygen blenders, found routinely in the delivery room, are becoming popular for delivering oxygen therapy to all children. The use of blenders allows the clinician to deliver flow and FiO_2 independent of one another. FiO_2 can be adjusted to meet SpO_2 targets, and flow can be adjusted to meet work of breathing targets. What if an oxygen delivery device could give precise/prescribed FiO_2 while using flow as a therapy and be comfortable for pediatric patients?

Heated Humidified HFNC

The next step of the pyramid is the high-flow nasal cannula (HFNC). This very popular respiratory modality has applications in both adults and pediatrics,[11,12] but its name is misleading. HFNC only describes part of the therapy. The key difference between this and a standard nasal cannula is not the flow rate, but rather the addition of heat and humidity. The addition of heat and humidity, which creates a level of comfort that other oxygen devices are lacking. Add a blender and you have a heated, humidified high-flow nasal cannula with customizable FiO_2. It meets the major challenges in pediatric oxygen therapy, comfort, with consistent application of therapy, with FiO_2 and flow autonomously delivered.

Heat and humidity at or near body temperature and pressure saturated (BTPS), delivering flow via nasal interface provides comfort because it does not impede the work of the nose. Heated humidification prevents airway cooling, discomfort, and intolerance of high-flows. It also prevents water loss, the cause of thickened nasal secretions, and inflammation, the cause of increased airway resistance. Heat and humidity can make any nasal cannula an HFNC, even those at low-flow rates. Just as with a standard low-flow nasal cannula, the interface provides for consistent therapy due to its comfort and convenience.

Just like high-flow, fixed FiO_2 devices, an HFNC can meet or exceed the patient's inspiratory flow rate, thus delivering exact FiO_2 to help prevent hyperoxia. Using a high-flow/blender system, the clinician may deliver precise flows and FiO_2 to meet the patient's needs.[5] For example, a nasal cannula delivering heated humidity at a flow rate of 20 L/min at 30% FiO_2 is possible using this system. FiO_2 independent of flow is key to delivering specific oxygen therapy to children.

One cannot discuss HFNC without discussing airway pressure created by flow or PEEP. There is an enormous amount of literature on this subject; does it provide benefit or detriment because the pressure created is not fixed? HFNC does create PEEP, but it varies based on nares size, cannula size, and respiratory pattern.[13] In 2004, Bamford & Lain stated that high-flow delivered through a non-occluding nasal cannula does create a small, but consistent, increase in oropharyngeal pressure.[14] In their model, 36 L/min created 3 cm H_2O pressure to the oropharynx. The most important part of their statement is "through a non-occluding" cannula[14]. The purpose of HFNC therapy is to provide flow; PEEP is inadvertent. HFNC therapy is not (CPAP) therapy; thus its own category on the pyramid below CPAP.

Initial settings for HFNC are debated as well. Recent studies have stated that 1.5 to 2 L/min/kg is safe and effective for pediatric patients.[15,16] Safe is a relative term, based on the resources available (i.e. proximity and pediatric intensive care). Signs of clinical improvement, oxygenation, and WOB should guide your care. Close and careful monitoring is required.

Non-Invasive Ventilation - CPAP

With some pediatric patients, flow does not provide enough therapeutic value; pressure is required to improve hypoxia. The next escalation of the pyramid is CPAP therapy. The patient care goals remain the same: improve oxygenation and WOB. The challenge with CPAP therapy is its application: few optimal patient interfaces are available which is especially challenging with children. To create pressure, minimal or no leak is required (in contrast to HFNC). The mask or interface can be tight fitting, feel "suffocating", and potentially cause skin breakdown[17] (picture of patient on CPAP). The American Academy of Respiratory Medicine Clinical Practice Guidelines suggest active humidification is an option to improve adherence and provide some relief during use of this therapy, but this also has its challenges.[18] Patients must also be able to protect their own airway due to risk of aspiration. Limited comfort with this therapy also may require sedation, which may challenge efforts to avoid aspiration. This modality is considered advanced; proper resources and experienced personnel should be available.

Treatments for Hypoxemia/ Hypoventilation

The next steps of the Respiratory Pyramid of Care represent a higher complexity of care that requires overcoming a new challenge: hypercarbia. Patients whose disease state leads to hypoventilation require reestablishment of ventilation to ensure survival. Hypoventilation is an abnormally high partial pressure of arterial carbon dioxide ($PaCO_2$) or hypercarbia. Hypercarbia that leads to acidosis or pH < 7.30 is respiratory failure. These patients require oxygen therapy and assistance with ventilation.[5]

Non-Invasive Ventilation - BiPAP

Just as with CPAP, bilevel positive airway pressure, or BPAP, delivers pressure to the lungs to improve oxygen exchange at the alveolar level. BPAP also provides pressure on inspiration, called IPAP. The difference in the two levels of pressure is pressure support (PS), or the pressure created to inflate the lungs to remove CO_2. BPAP provides oxygenation and ventilation where as CPAP only provides oxygenation. Ventilation is delivered non-invasively, thus not incurring the complications of invasive conventional mechanical ventilation (CMV).[16] The therapy goals of SpO_2 remain the same, with the added goal of improving ventilation, normalizeing $PaCO_2$ and increasing pH to > 7.35.[5] Initial settings are debated, but as in all therapies, aim to meet patient needs without excess. Initial IPAP settings of 8-10 cm H_2O and PEEP of 3-5 cm H_2O appear to be safe. To meet the patient's oxygenation needs, FiO_2 and PEEP may be adjusted (PEEP of 1-2 cm H_2O). To wean or adjust to meet $PaCO_2$ and pH goals, the level of PS should be adjusted. This is completed by increasing or decreasing the IPAP by 1-2 cm H_2O.

CPAP and BPAP share the same challenges. Non-invasive ventilation is not indicated for every child, even if the therapy is required. Comfort and application issues remain barriers, and some pediatric patients are unable to generate enough flow to trigger the IPAP. This may cause an increase in WOB as the patient is "locked out".[17] BPAP therapy is also considered an advanced practice.

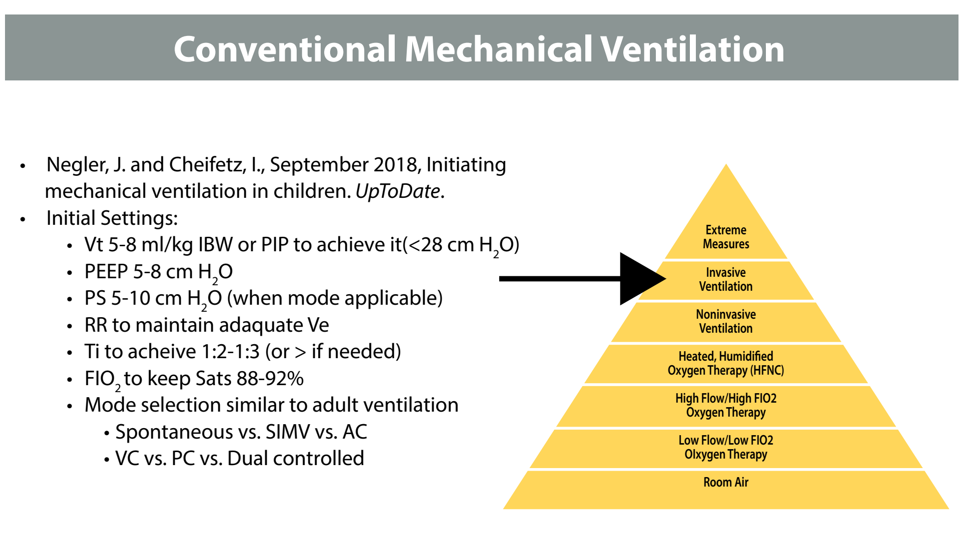

Figure 2.

Conventional Mechanical Ventilation

The last step of the pyramid that will be reviewed is conventional mechanical ventilation, or CMV. Although, intubation and ventilation are life-saving measures, this step incurs many inherent risks. The main characteristic of invasive ventilation compared with non-invasive ventilation (NIV), is the endo-tracheal tube (ETT). ETT intubation of a child is a high-risk, low-volume procedure that should be performed by the most capable and available clinician.[9] Risks are present during the act of intubation such as bleeding, aspiration, trauma, and cardiac compromise. Lee, J. stated that "Number of intubation attempts was associated with desaturations and increased occurrence of intubation associated events in critically ill children with acute respiratory failure. Thoughtful attention to initial provider as well as optimal setting/ preparation is important to maximize the chance for first attempt success and to avoid desaturation."[19] Risk is also present when attaching the patient to the ventilator such as asynchrony, pneumothorax, and ventilator-associated pneumonia. All risks should be considered prior to intubation, and ventilation to ensure optimal safety and benefit.

The goals of CMV are similar to NIV and the rest of the pyramid of care: maintain adequate oxygenation, ventilation, and airway protection. Initial settings for CMV should consider disease process (healthy vs unhealthy lungs) and should always keep lung protection in mind. Comfort considerations include sedation, paralytics, and active or passive humidification. Consulting with an expert is also recommended.[20] Although initial settings are not standardized, Neglar and Cheifetz (2018) published an UpToDate article on safe starting settings (Figure 2).

The authors also offered insight on monitoring, stabilization, and weaning of the ventilated pediatric patient that includes serial blood gases, cardiac monitoring, pulse oximetry, and capnography.[20] Keeping respiratory therapists competent and current with evidence-based practice will ensure the best possible outcomes.

Extreme measures are the top of the respiratory pyramid of care and are exclusive to tertiary children's hospitals. These measures may include advanced ventilation modes, high frequency ventilators, and extra corporeal membrane oxygenation. The availability and proximity of these options should be considered when creating a pediatric emergency plan.

Pediatric Emergency Plan: Stabilization and Transfer

Stabilization and transport is a key step to any pediatric emergency plan. Transporting a critically ill child has its risks, so careful and calculated actions are required prior to the physical transport. Communication with all clinicians involved is vital. Key elements of patient transport include decision to transfer, stabilization and preparation, mode of transport, personnel needed, equipment, drugs, monitoring, documentation, and handoff.[21]

Proactive preparations are crucial to successfully caring for the pediatric patient. Often, communication between facilities and key opinion leaders are forgotten, which jeopardizes the quality of continuing care. Whether a rural community hospital or a large referring children's hospital, the communication and preparation between the care networks is essential. Children's hospitals should be discussing plans with community hospitals; providing support, education, and resources. Community hospitals should not hesitate to ask for this assistance. Potential topics include resource management, standards of care, referral communication, and potential extenuating circumstances (distance, weather, emergency management, etc.).

Conclusion

Sick children will arrive, the question is when? Start preparing by conducting a labor and non-labor needs assessment and address the gaps found during that assessment. Use resources that are available, including training programs, clinical practice guidelines, and treatment methodologies like the Pyramid of Care. Most of all, collaborate and communicate with your health-care team members to ensure the best possible outcomes for this vulnerable patient population.

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Panel Discussion

NIV/HFNC for Neonates and Pediatric Patients

Moderator: **Kathleen Deakins,** RRT NPS FAARC

Panelists: **Rob DiBlasi,** RRT NPS

Lee Williford ,RRT-NPS RCP

Keith Hirst, MS, RRT-ACCS, RRT-NPS, AE-C

Can you clarify the terminology used for heated high-flow nasal cannula (HFNC)? Are there limitations or advantages when using these systems in the pediatric vs the neonatal population?

Hirst: A high-flow device is anything that meets or exceeds the patient's inspiratory demands. Because of this, clinicians can deliver a more precise level of FiO_2 to the patient. Proper implementation of a high-flow system is meant to minimize the amount of air that is entrained, which would lower the FiO_2. The general rule of thumb in neonates is that the flow has to be equal to or greater than the patient's current weight to deliver precise FiO_2.[1] However, FiO_2 also varies with changes in the patient's breathing, which are factors beyond our control. While a stable oxygen delivery is desirable, combinations of flow and concentration that maximize stability over time need to be studied. In the neonates, if that flow is below their current weight, then you are only delivering high humidity to the patient. For example, a 2.5 kg infant should have their flows set to ≥ 3 L/min if the team wants the patient to be in true high-flow. Otherwise, it is just considered a high humidity nasal cannula.

In pediatrics, flows > 6 L/min that are typically considered high-flow.[2] HFNC use continues to increase as the system is easily set up and is well tolerated by patients. The use of a nasal cannula adapted to the infant's nares size to deliver heated and humidified gas at high-flow rates has been associated with improvements in washout of nasopharyngeal dead space, lung mucociliary clearance, and oxygen delivery, compared with other oxygen delivery systems. HFNC may also create positive pharyngeal pressure to reduce the work of breathing (WOB) which positions the device midway between classical oxygen delivery systems, like the high-concentration face mask, and continuous positive airway pressure (CPAP). The basic limitation is the cannula size, the patient, and the flow that it can accommodate. Different manufacturers have different size cannulas and different flow limitations. The cannula should not occlude any more than 50% of the nares. Most of the single limb circuits can accommodate the flows needed. There is an additional advantage that most patients will tolerate a high-flow nasal cannula when compared to a nasal interface for CPAP.

> HFNC is capable of providing humidification at higher flows than standard oxygen therapy…
>
> *- DiBlasi -*

DiBlasi: HFNC provides humidification and oxygen to spontaneously breathing patients. The level of support provided by HFNC is based on the patient size, respiratory pattern, flow setting, cannula size, oral and/or nasal leak, and the HFNC system being used. Oxygen therapy, using anhydrous gas, is usually titrated to a maximum value of 2 and 6 L/min for neonates and adults, respectively. HFNC is capable of providing humidification at higher flows than standard oxygen therapy, so there is less risk associated with administering dry gas.

Technical definitions for HFNC are lacking, especially when the range of patient diseases and sizes that are supported by this therapy are considered. Some sources define HFNC as flows that exceed peak inspiratory flow or minute ventilation.[3] Unlike CPAP, the HFNC prongs are intended to occlude 50% of the nasal airway opening. Increasing flows will provide increased FiO_2 and pressure delivery. Studies in vitro[4] and in vivo[5,6] have shown that increasing flow will provide pressure in the lungs that is similar to CPAP in infants. The feature that sets HFNC apart from CPAP is the unique ability to improve effective minute ventilation by eliminating re-breathing of exhaled carbon dioxide from the nasopharyngeal deadspace.[4,7] This effect is notable even at lower flows (~2 L/min) in premature and term newborn models. Based on over a decade of research with HFNC, there is an improved understanding about the complex physiologic effects in what appears to be a relatively simple noninvasive system. However, based on recent findings, it is unclear whether HFNC is more like CPAP or noninvasive ventilation (NIV), such as noninvasive intermittent positive pressure ventilation (NIPPV).

Williford: As noted by my colleagues, HFNC is the use of flows greater than a supplemental nasal cannula can provide (1, 3, and 6 L/min in neonate, pediatric, and adult patients, respectively). The term, "high-flow" also implies that the flow meets or exceeds the patient's inspiratory demand. These high-flows provide flushing of extrathoracic dead space with fresh gas which results in a more efficient oxygen delivery and clearance of carbon dioxide.[3,8,9] In addition, there is evidence that positive pressure equivalent to CPAP is generated by HFNC, allowing for airway stenting and alveolar recruitment.[4] These benefits associated with HFNC provide offloading of respiratory work at flows up to 6 – 8 L/min in neonates[10] and between 1.5 and 2 L/min/kg in pediatric patients < 8 kg.[11] The effect is less dramatic in patients > 8 kg. The flow rate/kg needed to achieve optimal support in larger patients appears to decrease based on a L/min/kg dosing. One possible cause for this reduction in flow/kg in larger patients is the amount of extrathoracic dead space: in infants, 3 mL/kg of anatomic dead space is appreciated, which reduces with age to approximately 0.8 mL/kg at age 6. The fact that HFNC provides comparative support to nCPAP (nCPAP) and has a simple, skin-friendly application makes this mode of respiratory support desirable. The limitation of one level of support that is based on set flow can limit its application when respiratory distress progresses.

> These high-flows provide flushing of extrathoracic dead space with fresh gas which results in a more efficient oxygen delivery and clearance of carbon dioxide.
>
> *- Williford-*

Respiratory therapists are on a quest to do the right thing. Can you provide evidence supporting noninvasive respiratory support devices to be used after a delivery?

Hirst: There have been several recent clinical trials that have looked at this question. The first one was the HIPSTER trial.[14] HIPSTER showed that HFNC was inferior for newborns with respiratory distress syndrome (RDS) and had a higher failure rate when compared with nCPAP. Since then, some additional trials have come out which, depending on which one you read, may support the use of HFNC or nCPAP in the newborn. Recently a meta-analysis looked at all the trials published and reviewed the quality of the evidence, which they graded as moderate quality.[15] They concluded that HFNC is inferior to nCPAP when it comes to newborns with RDS.[13] A recent analysis showed that using CPAP was more cost-effective than using HFNC with CPAP as rescue.[16] Based on this and other reviews, I would suggest continuing nCPAP when it comes to providing respiratory support for newborns right after delivery.

DiBlasi: A major limitation with CPAP and NIV in pediatric patients is that most interfaces require a complicated fixation. This requires highly skilled individuals to ensure patient comfort, minimize leaks, and avoid pressure injuries. HFNC may overcome many of these limitations and may be preferable after a delivery or post-extubation. The added benefit of carbon dioxide from the dead-space, coupled with similar pressures as CPAP, make HFNC an attractive option. However, there is a lack of research, standardized clinical protocols, and disease-specific guidelines for HFNC in newborns, which make it difficult to determine timing for therapy, maximum settings, and weaning approaches in patients. A review of clinical data related to outcomes in newborn infants is reviewed later in this interview.

Williford: Noninvasive modes of respiratory support, such as HFNC, CPAP, and (NIPPV), are common methods to obtain respiratory stability in the patients with increasing respiratory distress. High-flow nasal cannula provides heated humidified gas that provides positive end-expiratory pressure (PEEP) levels similar to CPAP.[17,18] CPAP has been established as the support mechanism in preterm infants that can prevent intubation.[15] HFNC and CPAP have been shown to reduce extubation failure.[16] Nasal trauma is the most common complication associated with CPAP. In a recent Cochrane review in which CPAP was compared to NIPPV, NIPPV was superior to CPAP in reducing respiratory failure and need for intubation.[21] There are no data that suggest chronic lung disease is lower with NIPPV, CPAP or HFNC.

When providing support to newborns, the mechanism of action specific to HFNC and CPAP are similar. Each improves respiratory efficiency due to a flushing of anatomic dead space, reduction of inspiratory resistance, and stenting of the airway through distending pressure.[11,18] The choice between CPAP and HFNC may be associated with availability, personal practice preference, and comfort with a given device. Along with preference, nasal deformities are associated with CPAP. This may provide superiority to HFNC when compared to CPAP.

NIPPV provides inspiratory support above a baseline pressure. This inspiratory support decreases thoracoabdominal asynchrony, decreases the need for intubation, and has been shown to decrease extubation failure.[24] When initiating this type of unsynchronized respiratory support, the rate should be set to provide support for > 50% of the patients' intrinsic respiratory rate. When at least 60% synchrony is seen, patients' WOB is reduced when compared to HFNC.[25] Given that data suggest that NIPPV is superior to nCPAP, an initial therapy of NIPPV can be recommended to prevent respiratory failure post-delivery.

Do protocols and guidelines support clinical practice? What flow rates are recommended and how are they determined for neonates and pediatric patients?

Hirst: Hospital-based protocols and guidelines should be supported by current evidence. The use of HFNC in both the neonatal and pediatric population is an evolving area. Guidelines and protocol need to include indications as well as contraindication, flow ranges, failure criteria, etc. It is important to look at not only the body but the level of evidence. For neonates, a consensus conference was held in 2015, and based on the literature and evidence then, they recommended flows from 2 -8 L/min.[26] Many will use HFNC in recently extubated infants or for patients who may have failed trials off CPAP. There is a growing body of literature that is suggesting that use of HFNC in infants may prolong oxygen requirements and delay discharge. Many also feel that switching to HFNC may be a way to safely orally feed infants. However, current literature and research does not support this.[22]

For pediatrics, there are a multitude of studies, but none really support any level of flow. Most flow is titrated to meet the patients demands/needs. This is supported by a recent survey, which showed a lack of consensus regarding where to set flow and how to titrate.[23] This is still a work in progress as how you treat the pediatric population. It is going to vary because of the different disease states that one sees in the pediatric population.

Many will use HFNC for use in recently extubated infants or for patients who may have failed trials off CPAP.

- Hirst -

DiBlasi: There are very few available evidence-based guidelines and protocols to support clinical practice in pediatric patients. Many HFNC strategies have been derived from study protocols or are based on expert opinion or both.[24] In the neonatal intensive care unit (NICU), many centers use HFNC at 2-8 L/min, since these settings have been shown to result in ~2-8 cm H_2O CPAP in the lungs of infants.[5,6] It is not uncommon for some institutions to report using 1.5-3.0 L/min/kg outside of the neonatal setting. This would equate to HFNC settings ~ 20-60 L/min in a 20 kg child. In a 3D-printed closed-mouth, anatomic nasopharyngeal and lung model, reported end-expiratory pressures of 15-22 cm H_2O at 30 L/min have been reported using two different HFNC systems.[4] Owing to the lack of definitive data, determining appropriate HFNC settings in children represents a major challenge and area for new research. As such, many clinicians choose to take an individualized strategy or transition to CPAP or NIV once HFNC reaches a predefined maximum setting. HFNC protocols and guidelines are needed using the highest level of evidence. In toddlers and small children, there is a lack of appropriately sized CPAP and NIV masks. HFNC therapy has been a wonderful option over traditional CPAP and NIV for this niche patient population.

Williford: Utilization of these respiratory support modes should be done in a stepwise manner. Failure associated with these devices must be recognized. During initiation of HFNC an expected reduction in oxygen requirement and overall WOB should be noted within one hour.[33] If either of these requirements are not met, an increase in support or change in mode may be indicated.

In pediatric respiratory distress patients, flow should be initiated at 1.5 L/min/kg in patients <8 kg.[11] The flow/kg of body weight appears to decrease with age, which suggests, in patients > 8 kg, a flow of 1 L/min/kg may be a good starting point. Flow via HFNC can be increased to a maximum of 2 L/min/kg based on patient respiratory assessment. If 2 L/min/kg is utilized and a decrease in WOB and oxygen need is not seen, positive pressure via noninvasive or invasive support may be indicated.

In neonatal patients, flow setting should be set based on patient weight as well. Flows of 4-6 L/min in preterm infants <1599 grams and 6-8 L/min for patients >1599 g.[21] These flows are based on the potential CPAP achieved.

Compare and contrast HFNC and CPAP for pediatric patients. Can similar outcomes be achieved from using either device?

Hirst: With HFNC, there is clearly a better comfort level that can be achieved, compared with CPAP in the pediatric population. There is less risk of skin breakdown with HFNC as well. There does seem to be some clinical evidence that use of HFNC may reduce the risk or incident of intubation in the pediatric ICU (PICU).[26,27] While there does not appear to be any direct head-to-head study looking at HFNC and CPAP in the pediatric population, based on the current studies, I do believe that you could get similar outcomes if you used either device.

DiBlasi: A growing body of evidence supports HFNC as an alternative to other noninvasive support techniques for term and preterm infants following extubation. A meta-analysis from six randomized control trials (n = 934 subjects) comparing outcomes between HFNC and CPAP post-extubation in term and preterm newborns showed no differences in death or chronic lung disease or rate of treatment failure or reintubation.[10] While these findings were not consistent across all trials, subgroup analysis of infants 28-32 weeks of age shows less treatment failure with HFNC than CPAP. Also, infants randomized to HFNC had lower nasal trauma, and pneumothorax and trend toward lower necrotizing enterocolitis compared with other forms of noninvasive therapy. It is important to note that very few extremely low birth weight infants were included in these studies. Another study comparing HFNC to CPAP in subjects from a cardiac ICU showed that subjects initially extubated to CPAP experienced greater resource utilization: longer time to low-flow nasal cannula, longer time to room air, and longer post-surgical hospital length of stay.[28]

While research supports HFNC as an effective alternative to CPAP post-extubation, clinicians are increasingly considering HFNC as an initial form of support in premature infants. In a recent meta-analysis (4 studies, 439 premature infants), when used as primary respiratory support after birth, there were no differences in death or chronic lung disease between HFNC and CPAP.[10] HFNC resulted in longer duration of respiratory support, but there were no differences in other secondary outcomes. The HIPSTER study is one of the only randomized controlled trials that has compared outcomes in premature infants prior to surfactant administration between HFNC (6-8 L/min) and CPAP (6-8 cm H_2O).[12] There was greater combined treatment failure in the HFNC group. Failure criteria were based on $FiO_2 > 0.4$, hypercarbia, and/or severe apnea. No differences were noted for individual failure outcomes between the two groups. There were no differences in in intubation rates within 72 hr but, infants randomized to CPAP had more nasal pressure injuries, a higher frequency of pneumothorax or other air leak, and were more likely to require emergent intubation than infants supported with HFNC. Two clinical trials have shown that HFNC may be as effective as NIV in preventing endotracheal ventilation in the primary treatment of RDS in premature infants.[40, 41] More studies are needed in preterm infants to determine whether HFNC is as effective as an initial form of noninvasive support.

> In larger infants and children (<18 years), HFNC at 8 L/min was shown to result in similar effort of breathing as CPAP in a PICU setting.
>
> *- DiBlasi -*

Outside of the NICU setting, most research has focused on short-term outcomes in patients with bronchiolitis, and very few include subjects outside of infancy. In infants, WOB has been shown to be similar on HFNC, NIMV, and nCPAP after extubation.[42] In larger infants and children (>18 years), HFNC at 8 L/min was shown to result in similar WOB as CPAP in a PICU setting.[8]

Few data exist to support safety and effectiveness for HFNC in large pediatric patients.[31] As mentioned previously, the most widely-studied HFNC group outside of NICU includes infants with bronchiolitis, but data remain inconclusive as to whether HFNC improves outcomes when compared with other forms of noninvasive support. HFNC has been shown to result in less need for care escalation than a 'low-flow' oxygen cannula in bronchiolitis patients. Also, fewer infants with bronchiolitis experience treatment failure on HFNC than with standard oxygen cannula but length of O_2 therapy is not different.[32] As such, HFNC might be better as a rescue therapy.

Williford: In pediatric patients, < 6 months of age, the reduction in WOB when comparing HFNC and CPAP, is negligible. When comparing HFNC, CPAP, and NIPPV with respect to percent of assisted breaths to total respiratory rate, NIPPV plays a role in the reduction of work. When patients have a high level of synchrony, NIPPV is superior to CPAP and HFNC.[20] In a randomized control trial, Milesi et al reviewed CPAP vs HFNC in bronchiolitis and suggested that CPAP may be more efficient in treating moderate-to-severe bronchiolitis, but they note that both CPAP and HFNC are safe.[33] CPAP data are limited with respect to use in pediatric patients with acute illness except for bronchiolitis. CPAP and NIPPV provides challenges associated with appropriately sized mask and prongs, especially in small pediatric patients. Usage of HFNC for asthma, bronchiolitis, pneumonia, and congenital heart disease have all been described in the literature with success.[34] The patient population with the highest rate of failure was pneumonia. Indications of failure are: worsening respiratory rate, PCO_2, or need for increased oxygen after initiation.[2] Due to the aforementioned challenges with appropriate masks and prongs, the level of support provided, and ease of application, HFNC is a superior in the setting of acute onset respiratory distress.

How do you determine when to use which non-invasive modality? (CPAP or HFNC)

Hirst: All of our patients who require initial respiratory support for RDS will get a trial of CPAP unless there is a direct contraindication for CPAP, at which point the patient will get intubated. Our preferred mode of support for post-extubation is CPAP, usually Bubble. To minimize nares and skin breakdown we alternate between a nasal mask and prongs. There are some instances where we will extubate to either a low-flow nasal cannula or room air. In our NICU, HFNC is used primarily when a patient has failed room air or low-flow nasal cannula trial off nCPAP at least twice. Our clinicians believe that patients should be removed from a CPAP and not supported by HFNC. This method, called the CICADA (CeasIng Cpap At standarD criteriA) method was trialed and validated in Australia through a series of studies and RCT.[37] We will also use HFNC for patients with apnea of prematurity when a low-flow nasal cannula is not stimulating them enough.

For pediatric patients, the issue arises regarding the amount of support and how much lung is collapsed as well as the level of respiratory acidosis. For patients who have minimal lung collapse or the lung appears over-distended, I would recommend HFNC, titrating to the effect that the team wants. This includes patients with bronchiolitis, asthma, and pneumonia. However, if there is collapse or the team's main goal is to recruit the lung, then I would recommend the use of CPAP for the main reason that the level of end expiratory pressure on HFNC can be variable, and if the patient needs lung recruitment, it is better to deliver the pressure that is needed. For patients who are in the early stages of respiratory failure, HFNC may be suitable to prevent intubation. However, for those patients who are starting to fail, CPAP would be a more appropriate.

DiBlasi: In the NICU setting, patients who do not tolerate ≤ 8 L/min may require a different form of NIV as an alternative to intubation. In some infants with floppy airways, flows of ~10 L/min may be necessary to stent the airways open. In larger infants and small children, it is common to use flows 10-20 L/min. It is unclear whether this can be tolerated, so clinicians need to use caution in this age group, as pressures have not been measured at those flows, so air-leak could be a risk; whereas CPAP or NIV may not pose a similar risk. Institutions that use HFNC must develop protocols using specific HFNC systems in order to determine the appropriate timing and location to initiate HFNC or switch to a different form of noninvasive support.

Williford: Based on the available evidence in the neonatal setting, CPAP and HFNC are interchangeable. Consideration may be given to CPAP in patients with upper airway obstruction. If HFNC failure is noted, transition to NIPPV is the next clinical step for respiratory support. NIPPV usage with an initial rate of ≥ 50% of the patient's intrinsic rate and an initial peak inspiratory pressure (PIP) of 2 above the settings at extubation, or 16 cm H_2O and a PEEP of 5 is commonly described.[19] Once the patient is weaned to a minimum fraction of inspired oxygen and a mean airway, pressure that can be duplicated via HFNC, the patient can be transitioned to a high-flow nasal cannula setup. Failure of both modes is associated with tachypnea and increasing oxygen requirement.

Based on the available evidence in the neonatal setting, CPAP and HFNC are interchangeable.

- Williford -

Within the pediatric population, HFNC is the first-line treatment for mild-to-moderate distress. Evidence suggest that HFNC flows of 1.5–2 L/min/kg provides a similar reduction in WOB when compared with CPAP and NIPPV when used in smaller pediatric patients.[13] CPAP and NIPPV can be used interchangeably for patients < 6 months of age for increasing respiratory distress as an alternative to HFNC. In larger pediatric patients, there are limited data associated with HFNC. A reasonable approach in the pediatric population > 10 kg may be the use of a lower prescribed dose, starting at a flow setting of 1 L/min/kg. This approach may be prudent given the reduced overall extrathoracic dead space and the lack of data in this patient population. In these patients who require increasing support, a bilevel support mode of NIV may be indicated.

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Bios

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Learning Objectives

Upon completion of this activity, the participant will be able to:

1. Identify the signs and symptoms of impending respiratory failure in children.
2. Describe "Pyramid of Care" theory and its relation to neonatal/pediatric respiratory care.
3. Discuss safe and effective initial settings for this population based on evidence-based guidelines
4. Identify the clinical practice applications of HFNC and NIV in pediatric and neonatal patients.

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