PEDIATRIC EMERGENCY MEDICINE REPORTS

Practical, Evidence-Based Reviews in Pediatric Emergency Care

September 2016 VOL. 21, NO. 9

AUTHORS

**Erin Tromble, MD,** University of Arizona, Department of Emergency Medicine and Pediatrics, Tucson

**Aaron N. Leetch, MD,** Assistant Professor of Emergency Medicine & Pediatrics, Assistant Residency Director, EM and EM/Peds Programs, Banner University Medical Center, Tucson, AZ

PEER REVIEWER

**Larry B. Mellick, MD, MS, FAAP, FACEP,** Professor of Emergency Medicine, Professor of Pediatrics, Augusta University, Augusta, GA

STATEMENT OF FINANCIAL DISCLOSURE

To reveal any potential bias in this publication, and in accordance with Accreditation Council for Continuing Medical Education guidelines, we disclose that Dr. Dietrich (editor), Dr. Skrainka (CME question reviewer), Ms. Wurster (nurse planner), Dr. Tromble (author), Dr. Leetch (author), Dr. Mellick (peer reviewer), Ms. Coplin (executive editor) and Ms. Mark (executive editor) report no relationships with companies related to the field of study covered by this CME activity.

AHC Media

# Noninvasive Ventilation and Acute Respiratory Failure

*For a long time, endotracheal intubation with invasive mechanical ventilation was the only tool available for children with acute respiratory failure. The decision used to be to intubate or not to intubate. The advent of new tools, such as noninvasive ventilation, has provided an incredible resource for avoiding intubation and its complications. Noninvasive ventilation allows patients to maintain their own airway clearance (decreasing ventilator-associated pneumonia rates) and often decreases the need for patient sedation. The authors review noninvasive ventilation indications, contraindications, and the growing body of literature that supports its use in a variety of clinical scenarios.*

*— Ann M. Dietrich, MD, FAAP, FACEP*

Acute respiratory failure, one of the most common medical emergencies encountered by pediatric providers, is defined as failure of adequate gas exchange demonstrated either by $PaO_2$ < 60 mmHg, $PaCO_2$ > 50 mmHg, or both.

Until recently, endotracheal intubation with invasive mechanical ventilation (IMV) has been nearly the only management tool available for acute respiratory failure. However, in recent years, noninvasive ventilation (NIV) has gained significant attention as an alternative to IMV.[1-4] Its utility in treating adult respiratory failure, particularly in the management of chronic obstructive pulmonary disease and cardiogenic pulmonary edema, is well established.[2,5-10] The evidence supporting NIV use in pediatric populations is less robust, but a growing body of literature supports its use in certain clinical settings.[11]

Considering risks and benefits, there are several theoretic advantages of NIV over IMV. In addition to avoiding the upper airway trauma associated with endotracheal intubation, NIV allows patients to maintain their own airway clearance (decreasing ventilator-associated pneumonia rates) and often decreases the need for patient sedation.[11,12] Additionally, NIV devices are easier to apply or remove and carry far fewer complications when accidentally displaced.

NIV is not without any risks, however. (*See Table 1.*) Like IMV, NIV can lead to barotrauma and possible pneumothorax.[13] It also leaves an unsecured airway and has an increased risk of aspiration compared to IMV if the patient's mental status does not allow for adequate airway clearance.[14] Difficulty fitting NIV devices to achieve an adequate seal is not uncommon, leading to tissue injuries when the fit is too tight and air leaks when the fit is too loose.[15,16] Further, like IMV, the positive intrathoracic pressure produced by NIV can lead to hypotension and hemodynamic instability due to decreased cardiac preload with hyper-expanded lungs

## EXECUTIVE SUMMARY

- In addition to avoiding upper airway trauma associated with endotracheal intubation, noninvasive ventilation (NIV) allows patients to maintain their own airway clearance and often decreases the need for patient sedation. NIV devices are easier to apply or remove and carry fewer complications when accidentally displaced.
- The positive intrathoracic pressure produced by NIV can lead to hypotension and hemodynamic instability due to decreased cardiac preload with hyper-expanded lungs and positive intrathoracic pressures, although these risks have been shown to be less severe with NIV when compared to invasive mechanical ventilation.
- Conditions in which improved oxygenation is the primary goal and in which the patient's degree of respiratory distress is less severe may respond well to continuous positive airway pressure (CPAP) alone.
- By convention, both CPAP and the expiratory positive airway pressure setting of bi-level positive airway pressure (which both provide positive end-expiratory pressure [PEEP]) generally are started at 5 cm $H_2O$. This is estimated to be the baseline PEEP in healthy lungs.
- Identifying patients who likely will deteriorate on noninvasive therapy is crucial to avoid delays to intubation. The available pediatric literature suggests several predictors of NIV failure: high severity of illness at presentation as indicated by the Pediatric Risk of Mortality score, individual physiologic markers including high $FiO_2$ requirements and high $PaCO_2$ on admission, inability to wean $FiO_2$ and absence of improvement after 1-2 hours of therapy, and underlying etiology of respiratory compromise (acute respiratory distress syndrome, sepsis, oncologic processes, and immune deficiencies).

and positive intrathoracic pressures, although these risks have been shown to be less severe with NIV when compared to IMV.[17]

## Mechanism

NIV provides support through several mechanisms. (*See Table 2.*) Positive pressure helps maintain airway patency and allows improved exhalation in patients with lower airway obstructive processes (e.g., asthma, bronchiolitis) and decreased work of breathing in patients with dynamic upper airway obstruction (e.g., laryngomalacia).[11,18-25] Additionally, NIV aids in alveolar recruitment through the addition of positive end-expiratory pressure (PEEP), thus assisting with oxygenation and decreasing V-Q mismatch.[11,25,26] Inspiratory positive pressure also decreases the force that respiratory muscles must generate during inhalation, decreasing total energy expenditure.[11,25,26] In short, in select pediatric patients, NIV has the potential to improve gas exchange and decrease work of breathing in respiratory failure, thus forestalling or even entirely preventing the deterioration into respiratory arrest.

**Table 1. Potential Complications of Noninvasive Venitilation**

- Aspiration
- Air leaks
- Tissue breakdown/irritation
- Hemodynamic instability
- Nasal dryness/irritation
- Eye irritation

Source: Author created.

**Table 2. Mechanisms of Respiratory Support Provided by Noninvasive Ventilation**

- Maintain airway patency (decreased work of breathing, eased exhalation)
- Assists alveolar recruitment (improved oxygenation, decreased V/Q mismatch)
- Reduce work of breathing (decreased oxygen demand, decreased energy expenditure)

Source: Author created.

## Mode

NIV can be employed through a variety of methods, which range from high flow nasal cannula (HFNC) to noninvasive positive pressure ventilation (NIPPV) controlled by a ventilator. All will provide the same overall mechanics but with varying degrees of control and efficacy.

### High Flow Nasal Cannula

HFNC has been investigated as an alternative to continuous positive airway pressure (CPAP). The exact definition of HFNC remains somewhat nebulous, but generally it is used to refer to flow rates at or above 1-2 L/minute of oxygen that is warmed, blended, and humidified. Heating and humidifying oxygen replaces some of the physiologic role of the upper airway and is believed to reduce energy expenditure. Studies in preterm infants and neonates have found that HFNC can deliver positive pressures in the range typically

**Table 3. Interface Advantages and Disadvantages**

| Interface Type | Advantages | Disadvantages |
|---|---|---|
| Nasal Prongs | • Small, less invasive<br>• Easy to apply<br>• Generally well-tolerated | • Risk of air leaks through mouth<br>• Risk of intranasal pressure injuries |
| Nasal Mask | • Generally well-tolerated<br>• Small and less invasive than full face mask | • Risk of air leaks through mouth<br>• Risk of facial tissue injury |
| Full-face Mask | • High degree of control<br>• Less risk of air leaks | • May cause agitation, often poorly tolerated<br>• Risk of facial tissue injury |
| Helmet | • Air leaks unlikely<br>• No direct skin contact | • Large, cumbersome<br>• Limited availability<br>• May lead to $CO_2$ rebreathing |

Source: Author created.

administered via CPAP and can have similar physiologic benefits to CPAP.[27,28]

Further advantages of HFNC include its relative ease of initiation, without requiring use of a ventilator. However, the exact pressure support delivered to the patient cannot be measured directly, offering less control over the level of respiratory support. Higher flow rates also convey a risk of mucosal damage, airway desiccation and bleeding, and excessive nasopharyngeal airway pressures. These risks can be somewhat minimized by ensuring an adequate air leak around the nasal cannula. Lastly, studies demonstrating its efficacy in older children are lacking.[27,28]

### Continuous Positive Airway Pressure

CPAP delivers a constant level of pressure support throughout the respiratory cycle via a ventilator. Consequently, CPAP offers the functional equivalent of PEEP, aiding in alveolar recruitment, oxygenation, and V-Q mismatch.[11,16,19]

### Bi-level Positive Airway Pressure

Alternatively, bi-level positive airway pressure (BiPAP) provides two different levels of pressure, which vary during different phases of respiration. The higher pressure is administered during inspiration and is called inspiratory positive airway pressure (IPAP). The lower pressure, delivered during exhalation, is called expiratory positive airway pressure (EPAP). By setting two pressure modes, BiPAP allows for respiratory support both by creating PEEP (through EPAP) and by assisting respiratory effort by creating a driving pressure (the difference between EPAP and IPAP) with each breath. BiPAP may be synchronized, with each driving pressure administered with the patient's own spontaneous effort, or unsynchronized, with a fixed back-up respiratory rate if the patient does not initiate a minimum number of spontaneous breaths per minute.[11,16,19]

Selection of CPAP vs. BiPAP should take into consideration the patient's full clinical picture, including the underlying condition, current respiratory status, and ability to tolerate the selected mode of ventilation. Conditions in which improved oxygenation is the primary goal and in which the patient's degree of respiratory distress is less severe may respond well to CPAP alone. Further, the lower continuous pressure provided by CPAP may be easier for some patients to tolerate. In contrast, some patients find the dual pressure of BiPAP easier to tolerate, as it more closely mimics a physiologic respiratory cycle despite its higher peak pressures. BiPAP also confers a greater degree of respiratory support than CPAP and may be more appropriate for those with more severe distress.

## Interface Choice

If the decision is made to initiate CPAP or BiPAP, the next step is selection of the interface. These devices can include nasal prong devices, nasal masks, full-face masks, and helmets. (*See Table 3.*)

### Nasal Prongs

Nasal prongs, which are most often used in infants, are small and relatively easy to place. The shorter pronged cannulas are similar to a typical nasal cannula but with a larger gauge to allow for more flow. They fit snugly into the anterior nares but often can leak if not held in place. Other HFNC have longer prongs that must be placed in the posterior nares similar to a nasal trumpet. Both types must be monitored closely to ensure they do not cause pressure

sores and erosion of the nares or septum. Additionally, if the patient opens his or her mouth, an air leak is created via the mouth, and the positive pressure delivery to the airways and lungs is lost. Pacifiers and chinstraps are sometimes used in infants to help with this problem.[16,29,30]

### Nasal Masks

Nasal masks, like nasal prongs, are less cumbersome and obtrusive than full-face masks and often are tolerated better. They avoid the risk of erosion to the internal nose and nares caused by nasal prongs but still can result in pressure sores to the face if not fitted and adjusted properly. Like nasal prongs, if patients open their mouths during speech or sleep, positive pressure ventilation is lost.[16,29,30]

### Full-face Masks

Full-face masks, which cover both the nose and mouth, provide more consistent control over the pressure delivered. They administer positive pressure ventilation regardless of the position of the patient's mouth and provide a complete seal to prevent leaks. However, many patients, especially younger children and infants, develop agitation with full-face masks, and some patients may experience a sensation of claustrophobia. Anxiolysis or mild sedation or dissociation may help the patient cooperate better.[16,29,30]

### Helmets

Helmets also deliver pressure support reliably, avoid the risk of pressure injuries, and tend to be well tolerated.[31] These devices are large and often cumbersome to use and may predispose to $CO_2$ rebreathing.[31] Additionally, they tend to have limited availability.

Ultimately, the device chosen requires consideration of the individual patient's needs as well as the availability at each institution. Most facilities carry a limited range of equipment types and sizes. Using an inappropriately fitted device should be avoided, as it can lead to increased complications such as pressure sores from over-tightening an ill-fitting mask and air leaks from poor fit and seal.

## Initial Settings

By convention, both CPAP and the EPAP setting of BiPAP (which both provide PEEP) generally are started at 5 cm $H_2O$.[16] This is estimated to be the baseline PEEP in healthy lungs. However, the underlying respiratory disorder and oxygenation status of the patient must be considered when choosing these settings.[16] Initial IPAP levels often range from 8-10 cm $H_2O$.[33]

Patient tolerance, hemodynamic status, oxygen status, tidal volumes, and mean airway pressures must be monitored immediately after initiation of NIPPV. Adjustments in pressure often are made in increments of 2 cm $H_2O$ at a time. When using BiPAP, IPAP should be titrated to a target tidal volume of 6 to 8 mL/kg. If the patient's $FiO_2$ level cannot be weaned to appropriate levels, EPAP or CPAP likely will need to be increased, and transition to IMV should be considered.[16,33] (*See Figure 1.*)

Initial settings up to EPAP/CPAP of 10 cm $H_2O$ are believed to be safe in pediatric populations, and IPAP settings of up to 20 cm $H_2O$ are generally accepted.[16,34] Inspiratory levels above this should be employed with caution, as nasal and facial masks may lose their seal, air leaks may form, and barotrauma is more likely. High pressures also can overcome lower esophageal sphincter tone, insufflating the stomach, and increasing the risk of aspiration.

## Acclimatization of Pediatric Patients to NIV

A unique challenge faced when initiating NIV in pediatric patients is acclimatizing the patient to the therapy. Many adults poorly tolerate positive pressure ventilation and the associated interfaces, which may be augmented further in younger patients. In general, adolescent and older pediatric patients tend to tolerate NIV better than younger patients, although many preterm and younger infants also do well. In patients old enough and alert enough to understand their circumstances, it is important to provide as much orientation and hands-on modeling to NIV as is feasible. It may be helpful to begin with low pressures and gradual increases so that patients can adjust to the sensation of breathing with positive pressure. When possible, providing a trial of different interfaces can increase tolerance based on patient preferences. Intermittent changes of the delivery interface also may help patients tolerate ongoing therapy.[16]

## Indications for Initiation of NIV

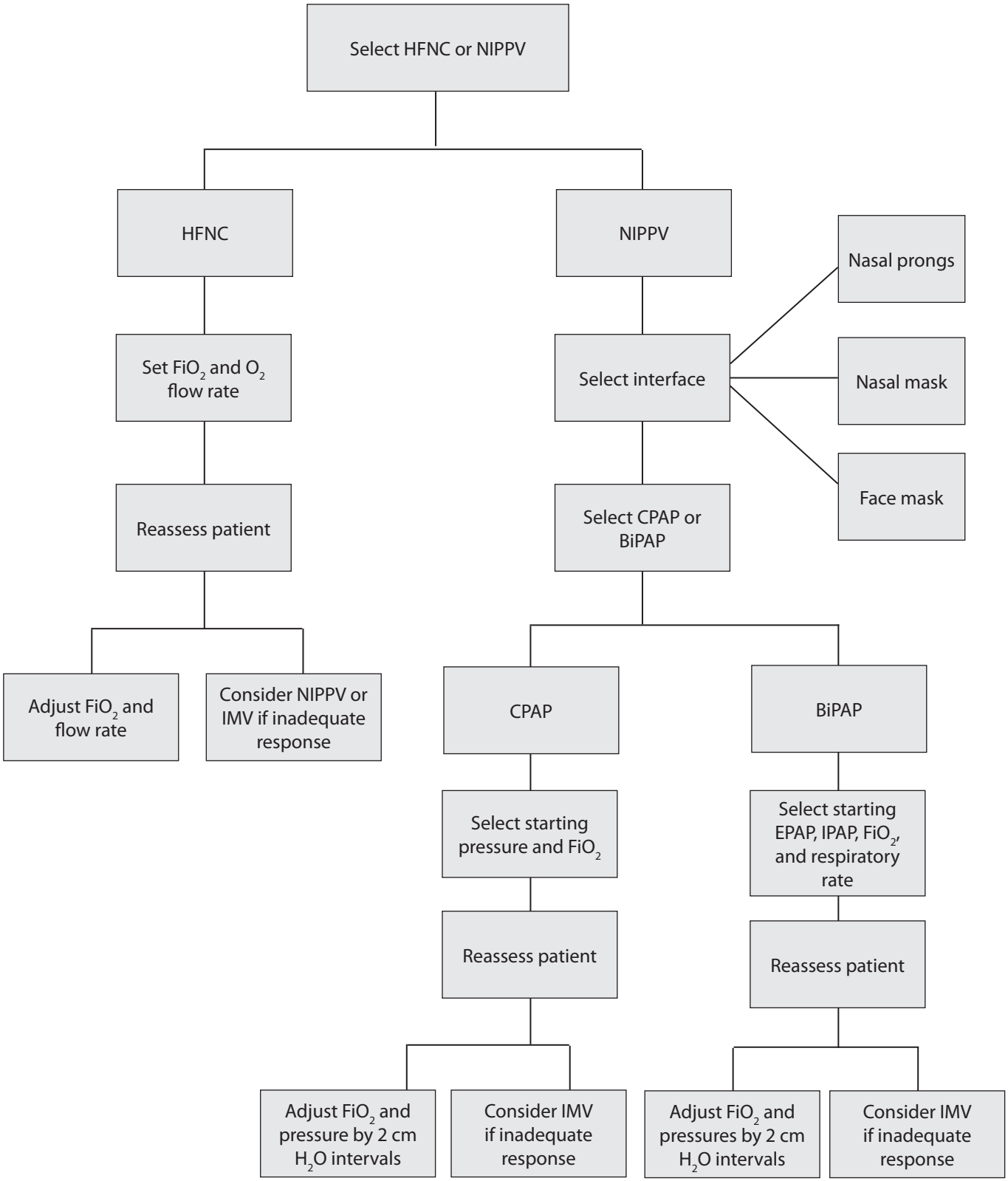
As previously discussed, although there is abundant evidence demonstrating the benefits of NIV use in adult patients, the literature is limited for pediatric populations. The majority of pediatric research involves case series with relatively few randomized, controlled trials. One notable prospective randomized, controlled trial, published by Yanez et al in 2008, found NIPPV used for treatment of acute respiratory failure reduced intubation rates and improved physiologic markers of respiratory distress.[23]

It is best to start NIV in patients who have underlying disease processes that are likely to reverse with its use. Existing evidence suggests that NIV can reduce intubation rates and improve respiratory status in cases of both hypoxemic and hypercapneic respiratory failure.[26] Table 4 provides a list of conditions and circumstances that current evidence suggests are responsive to NIV use.[19,21-24,35-55]

In the setting of lower airway obstruction, such as bronchiolitis and asthma, EPAP helps maintain lower airway patency, thus helping decrease lung hyperinflation and auto-PEEP. Additionally, IPAP provides respiratory muscle support and decreases work of breathing. Conversely, patients with dynamic upper airway obstruction, such as croup and laryngo/tracheomalacia, may benefit from upper airway stenting provided via CPAP or IPAP. In parenchymal lung disease, EPAP aids alveolar recruitment and, therefore, assists with oxygenation, while IPAP again appears to improve the work of breathing.[19]

Chronic neuromuscular disorders represent a common group of diseases among pediatric patients

## Figure 1. Steps to Initiation of Noninvasive Ventilation




BiPAP: bi-level positive airway pressure; CPAP: continuous positive airway pressure; EPAP: expiratory positive airway pressure; HFNC: high flow nasal cannula; IMV: invasive mechanical ventilation; IPAP: inspiratory positive airway pressure; NIPPV: noninvasive positive pressure ventilation.

Source: Author created.

in which NIV is applied routinely. In this population, muscular weakness of both the upper and lower respiratory muscles is the primary mechanism of respiratory failure. As such, positive pressure administered via IPAP serves to support the lower respiratory muscles, while EPAP or CPAP can help maintain patency of the upper airway in the setting of obstructive sleep apnea.[35]

In apnea of prematurity, NIV offers similar support to those conditions previously discussed via offloading the work of lower respiratory muscles, stenting upper and lower airways, and alveolar recruitment. In this condition, however, NIV is theorized also to stimulate an augmented inspiratory reflex (inspiratory effort triggered by inflation of the lung), which helps to establish a functional residual capacity and maintain alveolar patency. Such an effect is not seen in term infants or older patients. However, patients with apnea must be monitored closely after initiation of noninvasive respiratory support to ensure the apnea appropriately resolves. If these patients continue to have persistent apneic episodes, transition to IMV should be considered.[36]

Conversely, there is minimal research into the use of NIV in the setting of trauma. To date, the existing evidence in adult literature suggests that there may be some utility to NIV in the setting of blunt chest trauma (e.g., flail chest, pulmonary contusion). In these conditions, positive pressure is believed to minimize alveolar collapse and ease work of breathing. However, clinical judgment remains paramount in the context of trauma, and NIV should not be used in patients with altered mental status, aspiration risk, or facial trauma.[53-55]

Research also has found that the use of NIV following extubation may reduce rates of re-intubation in pediatric populations, and it also may be used to optimize respiratory and oxygenation status prior to intubation.[19,46,58]

## Contraindications

NIV requires patients to be able to cooperate with machine-delivered breaths and is contraindicated in patients with altered mental status. Additionally, NIV is not appropriate in patients for whom a secure airway is indicated or those who have a risk of airway loss (e.g., expanding neck hematoma; epiglottitis). Further contraindications to NIV use include hemodynamic instability, facial trauma (which may limit ability to fit masks), poor secretion clearance, vomiting, and upper GI bleeds.[56] (*See Table 5.*)

Patient selection also should take into account the availability of the necessary supplies and in the appropriate sizes, the ability of the patient to tolerate treatment, and the availability of appropriate support staff (nurses and respiratory therapists) with the capability to manage pediatric NIV.

**Table 4. Conditions with Possible Benefit from Noninvasive Ventilation**

- Apnea of prematurity
- Respiratory distress syndrome
- Asthma
- Bronchiolitis
- Dynamic upper airway obstruction
- Pneumonia
- Acute respiratory distress syndrome
- Cystic fibrosis
- Acute chest crisis
- Patients with underlying neuromuscular disorder
- Diaphragm paralysis
- Interstitial edema
- Blunt chest trauma
- Post-extubation failure

Source: Author created.

**Table 5. Absolute Contraindications to Noninvasive Ventilation**

- Impaired level of consciousness
- Impending airway loss
- Inability to tolerate/cooperate
- Hemodynamic instability
- Facial trauma, deformity, or surgery
- Vomiting
- Upper gastrointestinal bleeds

Source: Author created.

## Predictors of Failure

Identifying patients who likely will deteriorate on noninvasive therapy is crucial to avoid delays to intubation. The available pediatric literature suggests several predictors of NIV failure. (*See Table 6.*) One such predictor is

## Table 6. Predictors of Noninvasive Ventilation Failure

| | |
|---|---|
| Severe disease | • High Pediatric Risk of Mortality score<br>• High initial $FiO_2$ requirements<br>• High initial $PaCO_2$ |
| Poor initial response to therapy | • Inability to wean $FiO_2$<br>• Absence of clinical improvement after 1-2 hours of therapy |
| Underlying process | • Acute respiratory distress syndrome<br>• Sepsis<br>• Oncologic process<br>• Immune deficiencies |

Source: Author created.

## Table 7. Markers of Noninvasive Ventilation Failure

- Elevated $FiO_2$ requirements
- Failure of ability to wean $FiO_2$
- Elevated $PaCO_2$
- Tachypnea
- Respiratory distress
- Tachycardia
- Hypertension
- Agitation

Source: Author created.

high severity of illness at presentation as indicated by the Pediatric Risk of Mortality score.[19,43,57,58] Individual physiologic markers that have been found to be predictors of failure include high $FiO_2$ requirements and high $PaCO_2$ on admission.[19,43,50,58] Inability to wean $FiO_2$ and absence of improvement after 1-2 hours of therapy also may predict failure.[47,57,60,61] Lastly, the underlying etiology of respiratory compromise is an important factor. Patients with underlying acute respiratory distress syndrome, sepsis, oncologic processes, and immune deficiencies have been found to have high failure rates on NIV.[47,59]

## Signs of NIV Failure

After NIV has been initiated, the patient must be reassessed continually for evidence of improved respiratory status vs. signs of therapy failure. Each patient requires individualized evaluation of his or her own clinical circumstances and underlying pathology. As such, multiple variables should be considered when assessing the success or failure of NIV use. Signs of NIV failure may include persistent tachypnea or respiratory distress, inability to wean $FiO_2$ (with target < 0.6), or persistently elevated $FiO_2$ of > 60 mmHg. (*See Table 7.*) Other physiologic markers of NIV failure may include persistent tachycardia or hypertension. Additionally, clinical tolerance of NIV should be monitored. Patient agitation also suggests a need for escalation of therapy.[62,63]

## Conclusion

NIV increasingly is used by both adult and pediatric providers. Although the advantages of NIV in certain populations are clear, appropriate patient selection and understanding of the risks and benefits of noninvasive techniques are paramount to their successful implementation. Further investigation is needed to adequately delineate the appropriate use of NIV in pediatric populations. Nevertheless, NIV continues to develop as a valuable tool in the management of acute and pending respiratory failure in pediatric patients.

## References


1. Fanning JJ, Lee KJ, Bragg DS, Gedeit RG. U.S. attitudes and perceived practice for noninvasive ventilation in pediatric acute respiratory failure. *Pediatr Crit Care Med* 2011;12:e187-e194.
2. Liesching T, Kwok H, Hill NS. Acute applications of noninvasive positive pressure ventilation. *Chest* 2003;124:699-713.
3. Sinuff T, Cook DJ, Randall J, Allen CJ. Evaluation of a practice guideline for noninvasive positive-pressure ventilation for acute respiratory failure. *Chest* 2003;123:2062-2073.
4. Maheshwari V, Paioli D, Rothaar R, Hill NS. Utilization of noninvasive ventilation in acute care hospitals: A regional survey. *Chest* 2006;129:1226-1233.
5. Brochard L, Mancebo J, Wysocki M, et al. Noninvasive ventilation for acute exacerbations of chronic obstructive pulmonary disease. *N Engl J Med* 1995;333:817-822.
6. Keenan SP, Sinuff T, Cook DJ, Hill NS. Which patients with acute exacerbation of chronic obstructive pulmonary disease benefit from noninvasive positive-pressure ventilation? A systematic review of the literature. *Ann Intern Med* 2003;138:861-870.
7. Plant PK, Owen JL, Elliott MW. Early use of non-invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease on general respiratory wards: A multicentre randomised controlled trial. *Lancet* 2000;355:1931-1935.
8. Gray A, Goodacre S, Newby DE, et al. Noninvasive ventilation in acute cardiogenic pulmonary edema. *N Engl J Med* 2008;359:142-151.
9. Weng CL, Zhao YT, Liu QH, et al. Meta-analysis: Noninvasive ventilation in acute cardiogenic pulmonary edema. *Ann Intern Med* 2010;152:590-600.
10. Vital FM, Ladeira MT, Atallah AN. Non-invasive positive pressure ventilation (CPAP or bilevel NPPV) for cardiogenic pulmonary edema. *Cochrane Database Syst Rev* 2008;CD005351.

11. Deis JN, Abramo TJ, Crawley L. Noninvasive respiratory support. *Pediatr Emerg Care* 2008;24:331-338.
12. Antonelli M, Conti G, Rocco M, et al. A comparison of noninvasive positive-pressure ventilation and conventional mechanical ventilation in patients with acute respiratory failure. *N Engl J Med* 1998;339:429-435.
13. Hess DR. Noninvasive positive-pressure ventilation and ventilator-associated pneumonia. *Respir Care* 2005;50:924-931.
14. Carroll CL, Zucker AR. Barotrauma not related to type of positive pressure ventilation during severe asthma exacerbations in children. *J Asthma* 2008;45:421-424.
15. Mehta S, Hill NS. Noninvasive ventilation. *Am J Respir Crit Care Med* 2001;163:540-577.
16. Akingbola OA, Hopkins RL. Pediatric noninvasive positive pressure ventilation. *Pediatr Crit Care Med* 2001;2:164-169.
17. Girault C, Briel A, Benichou J, et al. Interface strategy during noninvasive positive pressure ventilation for hypercapnic acute respiratory failure. *Crit Care Med* 2009;37:124-131.
18. Confalonieri M, Gazzaniga P, Gandola L, et al. Haemodynamic response during initiation of non-invasive positive pressure ventilation in COPD patients with acute ventilatory failure. *Respir Med* 1998;92:331-337.
19. Najaf-Zadeh A, Leclerc F. Noninvasive positive pressure ventilation for acute respiratory failure in children: A concise review. *Ann Intensive Care* 2011;1:15.
20. Thia LP, McKenzie SA, Blyth TP, et al. Randomised controlled trial of nasal continuous positive airways pressure (CPAP) in bronchiolitis. *Arch Dis Child* 2008;93:45-47.
21. Carroll CL, Schramm CM. Noninvasive positive pressure ventilation for the treatment of status asthmaticus in children. *Ann Allergy Asthma Immunol* 2006;96:454-459.
22. Beers SL, Abramo TJ, Bracken A, Wiebe RA. Bilevel positive airway pressure in the treatment of status asthmaticus in pediatrics. *Am J Emerg Med* 2007;25:6-9.
23. Yanez LJ, Yunge M, Emilfork M, et al. A prospective, randomized, controlled trial of noninvasive ventilation in pediatric acute respiratory failure. *Pediatr Crit Care Med* 2008;9:484-489.
24. Essouri S, Nicot F, Clement A, et al. Noninvasive positive pressure ventilation in infants with upper airway obstruction: Comparison of continuous and bilevel positive pressure. *Intensive Care Med* 2005;31:574-580.
25. Teague WG. Noninvasive ventilation in the pediatric intensive care unit for children with acute respiratory failure. *Pediatr Pulmonol* 2003;35:418-426.
26. Calderini E, Chidini G, Pelosi P. What are the current indications for noninvasive ventilation in children? *Curr Opin Anesthesiol* 2010;23:368-374.
27. Cummings JJ, Polin RA; Committee on Fetus and Newborn, American Academy of Pediatrics. Noninvasive respiratory support. *Pediatrics* 2016;137: doi: 10.1542/peds.2015-3758.
28. Marohn K, Panisello JM. Noninvasive ventilation in pediatric intensive care. *Curr Opin Pediatr* 2013;25:290-296.
29. Ramirez A, Delord V, Khirani S, et al. Interfaces for long-term noninvasive positive pressure ventilation in children. *Intensive Care Med* 2012;38:655-662.
30. de Carvalho WB, Johnston C. The fundamental role of interfaces in noninvasive positive pressure ventilation. *Pediatr Crit Care Med* 2006;7:495-496.
31. Chidini G, Calderini E, Cesana BM, et al. Noninvasive continuous positive airway pressure in acute respiratory failure:

Helmet versus facial mask. *Pediatrics* 2010;126:e330-e336.

32. Taccone P, Hess D, Caironi P, Bigatello LM. Continuous positive airway pressure delivered with a "helmet": Effects on carbon dioxide rebreathing. *Crit Care Med* 2004;32:2090-2096.
33. Abadesso C, Nunes P, Silvestre C, et al. Non-invasive ventilation in acute respiratory failure in children. *Pediatr Rep* 2012;4:e16.
34. Cavari Y, Sofer S, Rozovski U, Lazar I. Non invasive positive pressure ventilation in infants with respiratory failure. *Pediatr Pulmonol* 2012;47:1019-1025.
35. Benditt JO. Initiating noninvasive management of respiratory insufficiency in neuromuscular disease. *Pediatrics* 2009;123(Suppl 4):S236-S238.
36. Cummings JJ, Polin RA; Committee on Fetus and Newborn, American Academy of Pediatrics. Noninvasive respiratory support. *Pediatrics* 2016;137: doi: 10.1542/peds.2015-3758.
37. Needleman JP, Sykes J, Schroeder S, Singer L. Noninvasive positive pressure ventilation in the treatment of pediatric status asthmaticus. *Pediat Asthma Allergy Immunol* 2004;17:272-277.
37. Akingbola OA, Simakajornboon N, Hadley Jr EF, Hopkins RL. Noninvasive positive-pressure ventilation in pediatric status asthmaticus. *Pediatr Crit Care Med* 2002;3:181-184.
39. Thill PJ, McGuire JK, Baden HP, et al. Noninvasive positive-pressure ventilation in children with lower airway obstruction. *Pediatr Crit Care Med* 2004;5:337-342.
40. Cambonie G, Milesi C, Jaber S, et al. Nasal continuous positive airway pressure decreases respiratory muscles overload in young infants with severe acute viral bronchiolitis. *Intensive Care Med* 2008;34:1865-1872.
41. Javouhey E, Barats A, Richard N, et al. Non-invasive ventilation as primary ventilatory support for infants with severe bronchiolitis. *Intensive Care Med* 2008;34:1608-1614.
42. Larrar S, Essouri S, Durand P, et al. [Effects of nasal continuous positive airway pressure ventilation in infants with severe acute bronchiolitis]. [Article in French]. *Arch Pediatr* 2006;13:1397-1403.
43. Campion A, Huvenne H, Leteurtre S, et al. [Non-invasive ventilation in infants with severe infection presumably due to respiratory syncytial virus: Feasibility and failure criteria]. [Article in French]. *Arch Pediatr* 2006;13:1404-1409.
44. Padman R, Henry M. The use of bilevel positive airway pressure for the treatment of acute chest syndrome of sickle cell disease. *Del Med J* 2004;76:199-203.
45. Muñoz-Bonet JI, Flor-Macian EM, Rosello PM, et al. Noninvasive ventilation in pediatric acute respiratory failure by means of a conventional volumetric ventilator. *World J Pediatr* 2010;6:323-330.
46. Mayordomo-Colunga J, Medina A, Rey C, et al. Non invasive ventilation after extubation in paediatric patients: A preliminary study. *BMC Pediatr* 2010;10:29. Doi: 10.1186/1471-2431-10-29.
47. Essouri S, Chevret L, Durand P, et al. Noninvasive positive pressure ventilation: Five years of experience in a pediatric intensive care unit. *Pediatr Crit Care Med* 2006;7:329-334.
48. Kovacikova L, Dobos D, Zahorec M. Non-invasive positive pressure ventilation for bilateral diaphragm paralysis after pediatric cardiac surgery. *Interact Cardiovasc Thorac Surg* 2009;8:171-172.
49. Salvo V, Lista G, Lupo E, et al. Noninvasive ventilation strategies for early treatment of RDS in preterm infants: An RCT. *Pediatrics* 2015;135:444-451.
50. Joshi G, Tobias JD. A five-year experience with the use of BiPAP in a pediatric intensive care unit population. *J Intensive Care Med* 2007;22:38-43.
51. Young AC, Wilson JW, Kotsimbos TC, Naughton MT. Randomised placebo controlled trial of non-invasive ventilation for hypercapnia in cystic fibrosis. *Thorax* 2008;63:72-77.
52. Birnkrant DJ, Pope JF, Eiben RM. Topical review: Pediatric noninvasive nasal ventilation. *J Child Neurol* 1997;12:231-236.
53. Hernandez G, Fernandez R, Lopez-Reina P, et al. Noninvasive ventilation reduces intubation in chest trauma-related hypoxemia: A randomized clinical trial. *Chest* 2010;137:74-80.
54. Duggal A, Perez P, Golan E, et al. Safety and efficacy of noninvasive ventilation in patients with blunt chest trauma: A systematic review. *Crit Care* 2013;17:R142. Doi: 10/1186/cc12821.
55. Richter T, Ragaller M. Ventilation in chest trauma. *J Emerg Trauma Shock* 2011;4:251-259.
56. Evans TW. International Consensus Conferences in Intensive Care Medicine: Non-invasive positive pressure ventilation in acute respiratory failure. *Intensive Care Med* 2001;27:166-178.
57. Mayordomo-Colunga J, Medina A, Rey C, et al. Predictive factors of non invasive ventilation failure in critically ill children: A prospective epidemiological study. *Intensive Care Med* 2009;35:527-536.
58. Lum LC, Abdel-Latif ME, de Bruyne JA, et al. Noninvasive ventilation in a tertiary pediatric intensive care unit in a middle-income country. *Pediatr Crit Care Med* 2011;12:e7-e13.
59. Marohn K, Panisello JM. Noninvasive ventilation in pediatric intensive care. *Curr Opin Pediatr* 2013;25:290-296.
60. Munoz-Bonet JI, Flor-Macian EM, Brines J, et al. Predictive factors for the outcome of noninvasive ventilation in pediatric acute respiratory failure. *Pediatr Crit Care Med* 2010;11:675-680.
61. Bernet V, Hug MI, Frey B. Predictive factors for the success of noninvasive mask ventilation in infants and children with acute respiratory failure. *Pediatr Crit Care Med* 2005;6:660-664.
62. Padman R, Lawless ST, Kettrick RG. Noninvasive ventilation via bilevel positive airway pressure support in pediatric practice. *Crit Care Med* 1998;26:169-173.
63. James CS, Hallewell CP, James DP, et al. Predicting the success of non-invasive ventilation in preventing intubation and re-intubation in the paediatric intensive care unit. *Intensive Care Med* 2011;37:1994-2001.

## CME/CE Questions

1. An 11-year-old male patient involved in a multiple vehicle collision on the highway arrives in the emergency department. He has evidence of multiple blunt injuries including multiple nasal and cheek fractures, fractures to his upper extremities, and a large contusion of his right chest wall. He is alert, following commands, and answering questions. There is no evidence of neck trauma, and he is protecting his airway. His oxygen saturation is 83%, and his breathing is labored. After 15 minutes, his respiratory rate increases and oxygen saturation begins to drop despite supplemental oxygen. It is determined that he should receive positive pressure ventilation. Which of the following is true regarding the selection for positive pressure support?
   a. The patient is a good candidate for noninvasive ventilation (NIV) because he is old enough to cooperate with the modality.
   b. The patient is a good candidate for NIV because his airway is intact and he has no altered mental status.
   c. The patient is not a good candidate for NIV because he has facial injuries.
   d. The patient is not a good candidate for NIV because NIV should never be used in trauma patients.
2. A neonate recently born at 31 weeks' estimated gestational age is found to be experiencing apneic episodes. The patient is otherwise doing well and had a relatively uneventful delivery. Which of the following statements is true regarding a possible decision to use high flow nasal cannula (HFNC) in this patient?
   a. HFNC may provide pressure support levels similar to continuous positive airway pressure (CPAP) but exact pressure levels cannot be directly measured.
   b. In preterm infants, HFNC offers similar support to bilevel positive airway pressure (BiPAP) and can be used to replace the support provided via BiPAP without use of a ventilator.
   c. In order to appropriately fit a nasal cannula using high flow, the cannula should be fit snuggly into the nares to avoid air leak and loss of pressure.
   d. The patient is having apneic episodes and requires invasive mechanical ventilation for adequate respiratory support. High flow nasal cannula should not be used in this setting.
3. A 17-year-old female patient has been receiving BiPAP therapy for three hours for treatment of bilateral multilobar pneumonia. Currently, expiratory positive airway pressure (EPAP) is set at 12 cm $H_2O$ and inspiratory positive airway pressure (IPAP) is set at 25 cm $H_2O$. Both settings have been increased repeatedly since initiating therapy. The patient has been receiving 100% $FiO_2$ continuously and has an oxygen saturation of 82%, which has not improved since starting therapy. Her respiratory rate is 25 and heart rate is 105. Her work of breathing has improved, but she continues have moderate respiratory distress. She is sleeping but arouses and is cooperative with the device. Which of the following statements is true?
   a. The patient continues to have inadequate oxygenation. Her EPAP should be increased by 2 mm $H_2O$.
   b. The patient continues to have inadequate oxygenation and inability to wean her $FiO_2$. Transition to invasive mechanical ventilation (IMV) should be considered.
   c. The patient continues to have increased work of breathing. Her IPAP setting should be increased by 2 mm $H_2O$.
   d. The patient is too somnolent to be continued on noninvasive therapy. She should be transitioned to IMV.
4. An 8-year-old boy with asthma arrives in the emergency department after several hours of respiratory distress at home after attending a birthday party at a local petting zoo. His parents have administered several albuterol treatments without improvement. After initial medical therapy in the emergency department is administered, the patient's work of breathing has not improved and his $PaCO_2$ was 55 on a recent arterial blood gas with oxygen saturations of 92%. He is alert and cooperative. He is thought to be a good candidate for a trial of NIV. Which of the following statements about interface selection is true?
   a. Since they tend to be tolerated well, nasal prongs would be preferable regardless of fit.
   b. Despite patient preference, a full-face mask is best to use vs. a nasal mask because it will avoid loss of pressure through an open mouth.
   c. If no pediatric masks are available, an adult mask should be

## CME/CE INSTRUCTIONS

**To earn credit for this activity, please follow these instructions:**

1. Read and study the activity, using the references for further research.
2. Scan the QR code to the right or log on to AHCMedia.com and click on My Account. First-time users will have to register on the site using the 8-digit subscriber number printed on the mailing label or invoice.
3. Pass the online tests with a score of 100%; you will be allowed to answer the questions as many times as needed to achieve a score of 100%.
4. After completing the test, a credit letter will be emailed to you instantly.
5. Twice yearly after the test, your browser will be directed to an activity evaluation form, which must be completed to receive your credit letter.

used by tightening the straps enough to avoid air leaks.
d. Use of an improperly fit device may lead to increased complications, such as tissue injury, and should be avoided.

5. A 16-year-old female was admitted to the ICU with severe sepsis that is believed to be due to a recent soft tissue infection. She has become increasingly tachypneic and tachycardic. She appears fatigued. Recent arterial blood gas reveals a $PaCO_2$ of 55 and was 35 at the time of admission. She remains alert and oriented and is following commands. Which of the following factors present in this patient is a predictor of possible failure of NIV therapy?
   a. Hypercapnea
   b. Presence of tachypnea
   c. Mental status
   d. Underlying etiology
6. Which of the following is an acceptable use of NIV?
   a. Upper gastrointestinal bleed
   b. Impaired level of consciousness
   c. Presence of acute respiratory distress syndrome
   d. Impending airway loss
7. When introducing NIV to a pediatric patient, which of the following is least likely to help tolerance of therapy?
   a. Not allowing trials of different available interfaces
   b. Gradually increasing the pressure settings
   c. Practicing hands-on modeling
   d. Switching to smaller or larger device sizes according patient preference
8. A 17-year-old male with sickle cell anemia presents to the emergency department with cough, difficulty breathing, chest pain, and fever. He is found to have acute chest syndrome and a decision is made to initiate NIV. Which of the following statements regarding advantages of NIV over IMV is true?
   a. Noninvasive ventilation is less likely to cause tissue injury than IMV.
   b. Noninvasive ventilation provides a more secure airway than IMV.
   c. Unlike IMV, NIV allows for normal airway clearance.
   d. Unlike IMV, NIV does not cause worsening hypotension in patients with hemodynamic instability.
9. A 13-year-old female patient with severe pneumonia was placed in BiPAP 20 minutes ago. Initial BiPAP settings were set at a rate of 16, EPAP of 5 cm $H_2O$, IPAP of 10 cm $H_2O$ with $FiO_2$ of 100%. On reassessment, her work of breathing has improved and $PaCO_2$ has dropped from 65 to 45, but her oxygen saturation is unchanged at 93%. Which of the following is the appropriate next step in management?
   a. Increase the IPAP setting by 2 cm $H_2O$ to allow full normalization of $PaCO_2$.
   b. Increase the patient's EPAP by 2 cm $H_2O$ and reassess her oxygenation status frequently.
   c. Increase the respiratory rate to allow normalization of $PaCO_2$.
   d. Transition the patient to IMV because her $FiO_2$ has not been successfully weaned.
10. Which of the following statements regarding modes of NIV is accurate?
    a. Since pressure settings used in BiPAP generally are higher than would be applied in CPAP, patients consistently better tolerate CPAP.
    b. Bilevel positive airway pressure provides the ability to synchronize administration of driving pressures with the patient's own respiratory effort.
    c. Continuous positive airway pressure is best used in patients with more severe distress who require higher levels of respiratory support.
    d. The oxygen flow rate in HFNC can be adjusted to create a reliable amount of pressure support in preterm infants and neonates.

## PEDIATRIC EMERGENCY MEDICINE REPORTS

### *CME/CE Objectives*

Upon completion of this educational activity, participants should be able to:

- recognize specific conditions in pediatric patients presenting to the emergency department;
- describe the epidemiology, etiology, pathophysiology, historical and examination findings associated with conditions in pediatric patients presenting to the emergency department;
- formulate a differential diagnosis and perform necessary diagnostic tests;
- apply up-to-date therapeutic techniques to address conditions discussed in the publication;
- discuss any discharge or follow-up instructions with patients.

***PEDIATRIC EMERGENCY MEDICINE REPORTS™*** (ISSN 1082-3344) is published monthly by AHC Media LLC, One Atlanta Plaza, 950 East Paces Ferry Road NE, Suite 2850, Atlanta, GA 30326. Telephone: (800) 688-2421 or (404) 262-7436.

**Editorial and Continuing Education Director:** Lee Landenberger

**Executive Editor:** Leslie Coplin

**GST Registration No.**: R128870672

Periodicals Postage Paid at Atlanta, GA 30304 and at additional mailing offices.

**POSTMASTER:** Send address changes to ***Pediatric Emergency Medicine Reports,*** P.O. Box 550669, Atlanta, GA 30355.



**Back issues: $65**. Missing issues will be fulfilled by customer service free of charge when contacted within one month of the missing issue's date.

## SUBSCRIBER INFORMATION

**CUSTOMER SERVICE: (800) 688-2421**

Customer Service Email Address:
Customer.Service@AHCMedia.com

Editorial Email Address:
Leslie.Coplin@AHCMedia.com

Website:
AHCMedia.com

**SUBSCRIPTION PRICES**

1 year with 36 AMA, AAP or ANCC Category 1 credits: $399
Add $19.99 for shipping & handling

**MULTIPLE COPIES:**
Discounts are available for group subscriptions, multiple copies, site-licenses, or electronic distribution. For pricing information, please contact our Group Account Managers at Groups@AHCMedia.com or (866) 213-0844.

All prices U.S. only. U.S. possessions and Canada, add $30 plus applicable GST. Other international orders, add $30.

AHC Media

## ACCREDITATION

AHC Media is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

AHC Media designates this enduring material for a maximum of 3.0 *AMA PRA Category 1 Credits*™. Physicians should claim only credit commensurate with the extent of their participation in the activity.

Approved by the American College of Emergency Physicians for a maximum of 3.00 hour(s) of ACEP Category I credit.

This continuing medical education activity has been reviewed by the American Academy of Pediatrics and is acceptable for a maximum of 3.0 AAP credits. These credits can be applied toward the AAP CME/CPD Award available to Fellows and Candidate Members of the American Academy of Pediatrics.

The American Osteopathic Association has approved this continuing education activity for up to 2.50 AOA Category 2-B credits.

AHC Media is accredited as a provider of continuing nursing education by the American Nurses Credentialing Center's Commission on Accreditation. This activity has been approved for 3.0 nursing contact hours using a 60-minute contact hour. Provider approved by the California Board of Registered Nursing, Provider #CEP14749, for 3.0 Contact Hours.

This CME activity is intended for emergency and pediatric physicians and nurses. It is in effect for 36 months from the date of the publication.

This is an educational publication designed to present scientific information and opinion to health professionals, to stimulate thought, and further investigation. It does not provide advice regarding medical diagnosis or treatment for any individual case. It is not intended for use by the layman. Opinions expressed are not necessarily those of this publication. Mention of products or services does not constitute endorsement. Clinical, legal, tax, and other comments are offered for general guidance only; professional counsel should be sought for specific situations.

PEDIATRIC EMERGENCY MEDICINE **REPORTS**

Practical, Evidence-Based Reviews in Pediatric Emergency Care

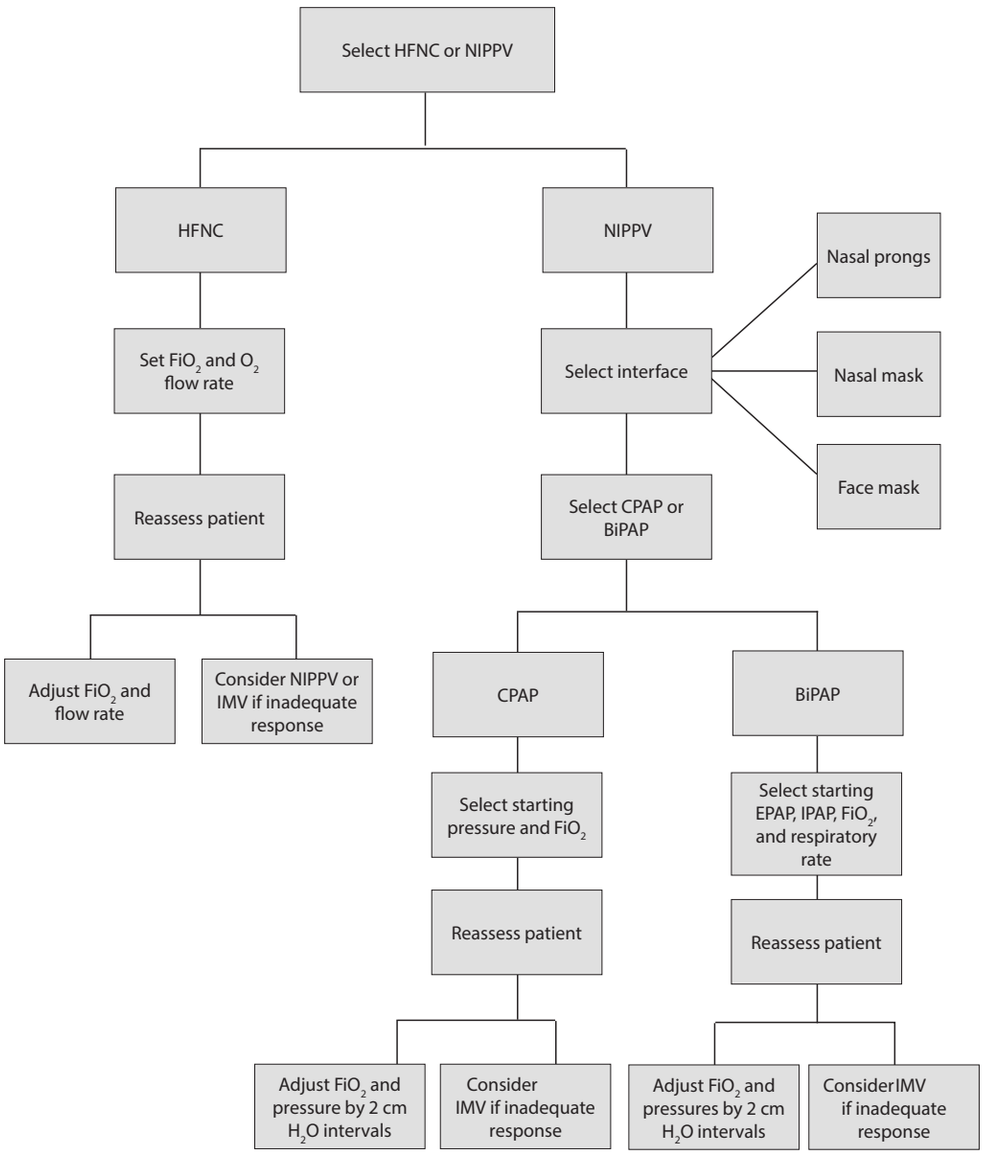
# Noninvasive Ventilation and Acute Respiratory Failure

## Interface Advantages and Disadvantages

| Interface Type | Advantages | Disadvantages |
|---|---|---|
| Nasal Prongs | • Small, less invasive<br>• Easy to apply<br>• Generally well-tolerated | • Risk of air leaks through mouth<br>• Risk of intranasal pressure injuries |
| Nasal Mask | • Generally well-tolerated<br>• Small and less invasive than full face mask | • Risk of air leaks through mouth<br>• Risk of facial tissue injury |
| Full-face Mask | • High degree of control<br>• Less risk of air leaks | • May cause agitation, often poorly tolerated<br>• Risk of facial tissue injury |
| Helmet | • Air leaks unlikely<br>• No direct skin contact | • Large, cumbersome<br>• Limited availability<br>• May lead to $CO_2$ rebreathing |

Source: Author created.

## Steps to Initiation of Noninvasive Ventilation




BiPAP: bi-level positive airway pressure; CPAP: continuous positive airway pressure; EPAP: expiratory positive airway pressure; HFNC: high flow nasal cannula; IMV: invasive mechanical ventilation; IPAP: inspiratory positive airway pressure; NIPPV: noninvasive positive pressure ventilation.

Source: Author created.

## Potential Complications of Noninvasive Venitilation

- Aspiration
- Air leaks
- Tissue breakdown/irritation
- Hemodynamic instability
- Nasal dryness/irritation
- Eye irritation

Source: Author created.

## Mechanisms of Respiratory Support Provided by Noninvasive Ventilation

- Maintain airway patency (decreased work of breathing, eased exhalation)
- Assists alveolar recruitment (improved oxygenation, decreased V/Q mismatch)
- Reduce work of breathing (decreased oxygen demand, decreased energy expenditure)

Source: Author created.

## Conditions with Possible Benefit from Noninvasive Ventilation

- Apnea of prematurity
- Respiratory distress syndrome
- Asthma
- Bronchiolitis
- Dynamic upper airway obstruction
- Pneumonia
- Acute respiratory distress syndrome
- Cystic fibrosis
- Acute chest crisis
- Patients with underlying neuromuscular disorder
- Diaphragm paralysis
- Interstitial edema
- Blunt chest trauma
- Post-extubation failure

Source: Author created.

## Absolute Contraindications to Noninvasive Ventilation

- Impaired level of consciousness
- Impending airway loss
- Inability to tolerate/cooperate
- Hemodynamic instability
- Facial trauma, deformity, or surgery
- Vomiting
- Upper gastrointestinal bleeds

Source: Author created.

## Predictors of Noninvasive Ventilation Failure

| | |
|---|---|
| Severe disease | • High Pediatric Risk of Mortality score<br>• High initial $FiO_2$ requirements<br>• High initial $PaCO_2$ |
| Poor initial response to therapy | • Inability to wean $FiO_2$<br>• Absence of clinical improvement after 1-2 hours of therapy |
| Underlying process | • Acute respiratory distress syndrome<br>• Sepsis<br>• Oncologic process<br>• Immune deficiencies |

Source: Author created.

## Markers of Noninvasive Ventilation Failure

- Elevated $FiO_2$ requirements
- Failure of ability to wean $FiO_2$
- Elevated $PaCO_2$
- Tachypnea
- Respiratory distress
- Tachycardia
- Hypertension
- Agitation

Source: Author created.

Supplement to *Pediatric Emergency Medicine Reports*, September 2016: "Noninvasive Ventilation and Acute Respiratory Failure." Authors: Erin Tromble, MD, University of Arizona, Department of Emergency Medicine and Pediatrics, Tucson; and Aaron N. Leetch, MD, Assistant Professor of Emergency Medicine & Pediatrics, Assistant Residency Director, EM and EM/Peds Programs, Banner University Medical Center, Tucson, AZ.