Managing Acute Respiratory Failure With Facemask Noninvasive Ventilation

Alexander Bracey, MD*; Brian J. Wright, MD

*Corresponding Author. E-mail: braceya@amc.edu.

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INTRODUCTION

The use of noninvasive ventilation has expanded considerably revolutionizing the management of acute respiratory failure in the emergency department (ED). Noninvasive ventilation may reduce mortality and morbidity in many conditions,[1-4] though proper patient selection, appropriate noninvasive ventilation titration, and troubleshooting are necessary to realize these benefits. Despite its routine use in the ED, there is little guidance for emergency physicians on how to utilize noninvasive ventilation devices beyond the default settings, as titration is often performed by other services. This review will focus on masked noninvasive ventilation for the management of acute respiratory failure in the ED.

INDICATIONS

Noninvasive ventilation is best utilized in diseases with acute, readily reversible exacerbations where ventilatory assistance is temporarily required. It is most efficacious in patients with isolated respiratory failure with minimal nonpulmonary organ system dysfunction.[5]

Common indications for noninvasive ventilation are chronic obstructive pulmonary disease exacerbations with hypercapnic respiratory failure and cardiogenic pulmonary edema with acute hypoxemic respiratory failure, where its use may reduce rates of intubation and mortality.[2,3] Noninvasive ventilation also benefits patients with asthma exacerbations and neuromuscular disease.[1-3,6]

The use of noninvasive ventilation in acute respiratory failure due to pneumonia and/or acute respiratory distress syndrome is controversial.[1,6,7] There is a higher rate of noninvasive ventilation failure in these scenarios, which may result in worse outcomes for many reasons.[1,5,7] A short trial of noninvasive ventilation therapy with careful observation for clinical improvement and with a low threshold for intubation may be performed in these scenarios. In any circumstance, patients should be screened for absolute contraindications before proceeding with noninvasive ventilation (Table 1).

CHOOSING A NONINVASIVE VENTILATION STRATEGY

Clinical circumstances dictate which noninvasive ventilation strategy to employ (Figure). When indicated, noninvasive ventilation should be initiated early. After a history and physical examination, clinicians should use diagnostic testing (eg, chest radiograph, point-of-care ultrasound [POCUS], blood gas) to aid in diagnosing the cause of respiratory failure and guide treatment and titration of noninvasive ventilation. Features suggestive of acute hypoxemic respiratory failure may include low pulse oximetry (SpO_2), consolidations or interstitial infiltrative process on chest radiograph, B-lines on POCUS, or hypoxemia by blood gas. In such cases, a strategy focusing on restoring appropriate SpO_2 and normalizing respiratory effort via delivery of continuous positive airway pressure/expiratory positive airway pressure (CPAP/EPAP) and increased fraction of inspired oxygen (FiO_2) should be employed. Alternatively, features of acute hypercapnic respiratory failure may include hyperexpanded lung fields on radiograph, A-line pattern on POCUS, altered mentation, and acute hypercapnia on blood gas. A strategy focusing on supporting work of breathing and improving minute ventilation should be employed in such instances.[8]

Mixed conditions are common. When present, a trial of noninvasive ventilation may be reasonable and should be performed with bilevel positive airway pressure (BPAP), as this mode is capable of augmenting both oxygenation and ventilation (Table 2). Close monitoring to determine clinical response to noninvasive ventilation therapy will dictate subsequent management (eg, escalation to intubation and invasive mechanical ventilation, continuing noninvasive ventilation, or de-escalation).

Table 1. Absolute and relative contraindications to masked noninvasive ventilation.

Absolute Contraindications	Cardiac or respiratory arrest Airway obstruction High risk of aspiration Severe vomiting or upper gastrointestinal tract bleeding Facial or esophageal trauma Recent esophageal or upper airway anastomosis surgery or perforation
Relative Contraindications	Depressed mental status Shock, hemodynamic instability or unstable cardiac dysrhythmia Recent upper airway or gastrointestinal tract surgery Pneumonia as a cause of hypoxemia Acute right heart failure Pneumothorax

MANAGEMENT STRATEGY FOR ACUTE HYPERCAPNIC RESPIRATORY FAILURE

Acute hypercapnic respiratory failure occurs when alveolar ventilation decreases resulting in the loss of adequately expired carbon dioxide. This may manifest as increased work of breathing, rapid and shallow breathing, or as obtundation with relative bradypnea depending on the degree of ventilatory failure. The use of noninvasive ventilation with BPAP for the management of acute hypercapnic respiratory failure centers around improving respiratory mechanics and optimizing alveolar ventilation (Figure E1, available at https://www.annemergmed.com). This is indirectly accomplished by providing pressure support to offload the respiratory muscles and augmenting tidal volume and minute ventilation.

Mode

BPAP features 2 common modes: spontaneous/timed and average volume assured pressure support (AVAPS). In spontaneous/timed mode, the operator sets the inspiratory positive airway pressure (IPAP), EPAP, respiratory rate, and FiO_2. BPAP-spontaneous/timed mode requires the operator to manually adjust the pressure support and respiratory rate to augment minute ventilation in response to dynamic clinical circumstances.

Alternatively, AVAPS allows the operator to set a target respiratory rate, tidal volume, EPAP, and pressure support minimum and maximum range. The noninvasive ventilation will use varying levels of pressure support within this range to achieve the tidal volume. This mode differs from spontaneous/timed mode in that the operator can set a goal minute ventilation. There is no evidence to suggest this mode is superior to spontaneous/timed mode.[9]

Inspiratory Positive Airway Pressure

IPAP is the pressure administered by the ventilator during inspiration. The difference between IPAP and EPAP is the pressure support. Augmenting the pressure support by modifying the difference between the IPAP and EPAP is crucial in the management of acute hypercapnic respiratory failure with noninvasive ventilation. The application of pressure support will augment tidal volume and CO_2 elimination (ie, improve ventilation), and reduce respiratory distress by offloading the respiratory muscles. In spontaneous/timed mode, increasing the IPAP while leaving the EPAP static will increase the pressure support, which usually results in a larger tidal volume and improve ventilation. We recommend goal tidal volumes of 8 mL/kg ideal body weight.

Respiratory Rate

The operator can set the respiratory rate when a patient's intrinsic rate is inadequate. Ventilator-initiated breaths will be administered when set above the patient's intrinsic respiratory rate. However, the patient's respiratory drive should be utilized when possible, as patient-triggered breaths are both more comfortable and more effective than ventilator-initiated breaths. We recommend starting at a respiratory rate of 16 breaths/min.

Expiratory Positive Airway Pressure

EPAP in acute hypercapnic respiratory failure can help counteract auto-PEEP. However, overaggressive EPAP will limit pressure support. Therefore, EPAP should be set low and titrated to maintain an SpO_2 of 88% to 92%. Many BPAP devices do not allow EPAP to be set below 4 or 5 cmH_2O, which is therefore our recommended starting point. If additional EPAP is required to achieve a minimal oxygen saturation, the IPAP should be increased by the same increment to maintain a given pressure support and, thus, tidal volume. We do not recommend matching EPAP to a patient's auto-PEEP in the setting of obstructive lung disease as it is not clinically meaningful and may be distracting.

Fraction of Inspired Oxygen

FiO_2 is used to augment oxygen saturation. Unlike acute ventilatory conditions (eg, opiate overdose), chronic ventilatory conditions with acute presentations may have relatively lower baseline blood oxygen saturation. Overly

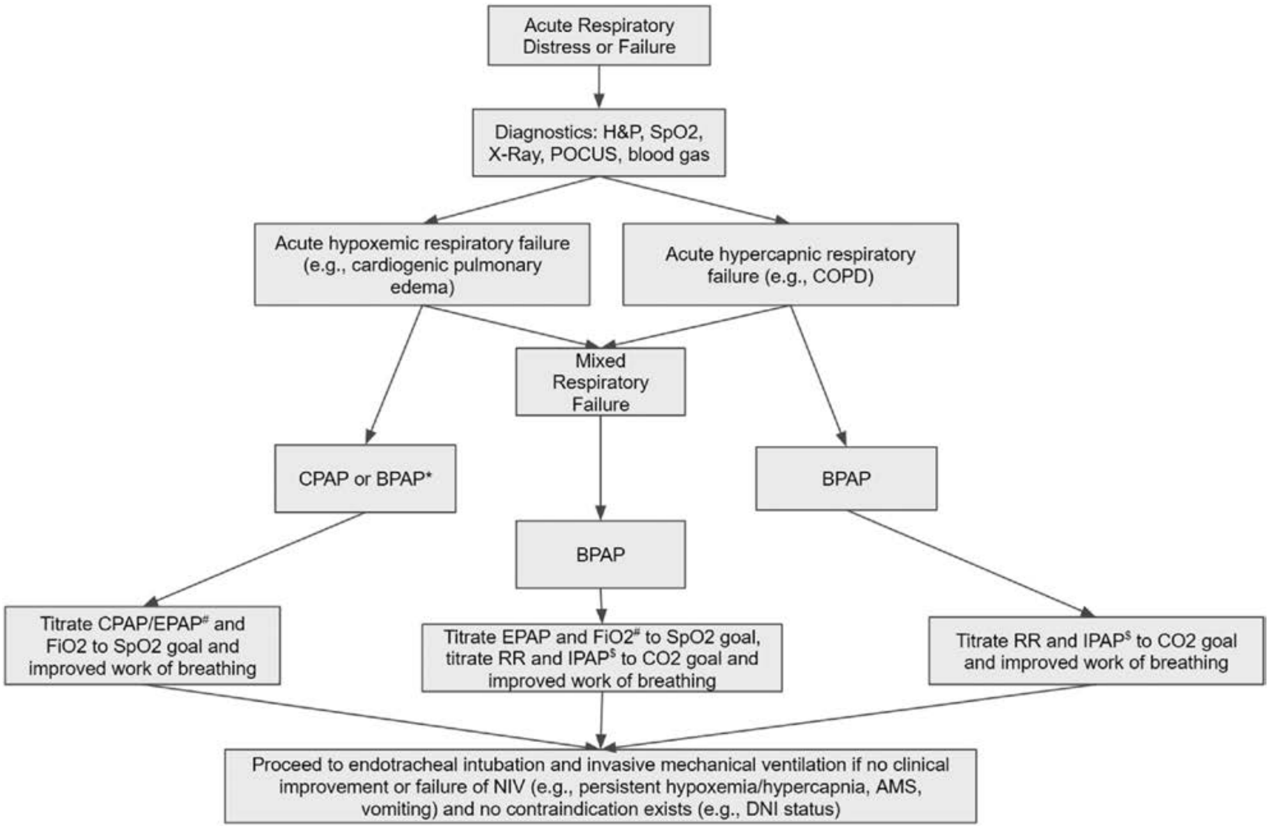

Figure. Diagnostic algorithm for masked noninvasive ventilation selection and titration by type of respiratory failure. *AMS*, altered mental status; *BPAP*, bilevel positive airway pressure; *CPAP*, continuous positive airway pressure; *COPD*, chronic obstructive pulmonary disease; *DNI*, do not intubate; *EPAP*, expiratory positive airway pressure; *FiO_2*, fraction of inspired oxygen; *H&P*, history and physical; *IPAP*, inspiratory positive airway pressure; *NIV*, noninvasive ventilation; *POCUS*, point-of-care ultrasound; *RR*, respiratory rate; *SpO_2*, oxygen saturation. *BPAP may be preferable in patients with concomitant COPD, patient preference, etc. #Titrate FiO_2 from 100% toward 60%; if unable to achieve 60% or lower, begin uptitrating CPAP/EPAP. $Titrate IPAP to improved work of breathing, adequate tidal volumes, and appropriate CO_2 goal to a maximum pressure of 20 cmH_2O.

aggressive oxygenation can lead to diminished respiratory drive and hypercapnia via the Haldane effect.[10] Therefore, we recommend using the lowest FiO_2 possible to achieve an oxygen saturation of 88% to 92%. This can be achieved by choosing either starting at 100% FiO_2 and weaning down or starting at 40% FiO_2 and increasing. FiO_2 can be adjusted incrementally by 10% every 2 to 5 minutes to achieve the oxygen saturation goal.

MANAGEMENT STRATEGY FOR ACUTE HYPOXEMIC RESPIRATORY FAILURE

Noninvasive ventilation confers benefit in acute hypoxemia respiratory failure by providing supplemental oxygen to overcome room air entrainment and recruiting atelectatic or fluid-filled alveoli to reduce shunt fraction (Figure E2, available at https://www.annemergmed.com). In acute cardiogenic pulmonary edema, noninvasive ventilation has the added benefit of reducing both preload and left ventricular afterload by increasing intrathoracic pressure.

Mode

In conditions of isolated hypoxemia, either CPAP or BPAP can be utilized. BPAP is advantageous over CPAP when additional pressure support is needed (eg, mixed respiratory failure or hypoxemia with concomitant chronic obstructive pulmonary disease, increased work of breathing, etc).

Continuous Positive Airway Pressure/Expiratory Positive Airway Pressure

The mainstay of correcting acute hypoxemic respiratory failure with noninvasive ventilation is to reverse shunt physiology. This is achieved by increasing the main airway pressure throughout the respiratory cycle by adjusting

Table 2. Noninvasive settings and descriptions by mode.

NIV Mode	Setting	Function	NIV Range*
CPAP and BPAP	FiO_2	Improves oxygenation by increasing the fraction of oxygen entrained into the medical gas	30%-100%
	CPAP/EPAP†	Improves oxygenation by alveolar recruitment and improving shunt physiology	4-20 cmH_2O
BPAP only	IPAP	Improves ventilation by increasing the pressure support during each breath, thereby increasing TV (assuming a static EPAP)	10-20 cmH_2O
	RR	Improves ventilation by increasing the number of respirations per minute	12- 20 breaths/min

BPAP, Bilevel positive airway pressure; *CPAP*, continuous positive airway pressure; *EPAP*, expiratory positive airway pressure; *FiO_2*, fraction of inspired oxygen; *IPAP*, inspiratory positive airway pressure; *NIV*, noninvasive ventilation; *TV*, tidal volume; *RR*, respiratory rate.
*Although these ranges may technically be wider, we recommend them for safe NIV use.
†EPAP is the naming convention on BPAP mode, whereas CPAP is the naming convention on CPAP mode. Both modes provide PEEP.

CPAP or EPAP depending on noninvasive ventilation mode (Table 2). CPAP/EPAP is usually set to 5 cmH_2O and then titrated upward to 15 to 20 cmH_2O, usually 2 cmH_2O at a time. If using BPAP, the EPAP and IPAP should be increased together to maintain adequate pressure support.

Fraction of Inspired Oxygen

In acute hypoxemic respiratory failure, we recommend starting at 100% FiO_2 and then downtitrating to the minimum FiO_2 required for a goal SpO_2 of 88% to 92%. If SpO_2 begins to drop before 60% FiO_2, CPAP/EPAP should be increased in a paired fashion per the ARDSNet PEEP table.[11]

Inspiratory Peak Airway Pressure

IPAP is often unnecessary for patients with pure acute hypoxemic respiratory failure as they can generate adequate minute ventilation, though it may be useful in those with concomitant conditions requiring additional inspiratory support (eg, chronic obstructive pulmonary disease, asthma, etc). The addition of IPAP may offload the diaphragm and intercostal muscles, allowing them to fully relax and diminish respiratory distress and work of breathing. When employed, it should be titrated to improve work of breathing and patient comfort, and to restore adequate tidal volumes.

Respiratory Rate

Most patients with pure acute hypoxemic respiratory failure have an adequate intrinsic respiratory rate; however, in instances of bradypnea, an increased respiratory rate may be beneficial. We typically start at a rate of 16 breaths/min with the goal of adequate ventilation. Bradypnea in the setting of hypoxemia is abnormal and necessitates close monitoring and a search for the cause (eg, opiate overdose, increased intracranial pressure, hypercapnea, etc).

NONINVASIVE VENTILATION MONITORING AND FAILURE

Monitoring

Noninvasive ventilation use necessitates frequent assessments and adjustments based on dynamic clinical circumstances. Recognizing noninvasive ventilation failure is critical as it is associated with worse patient outcomes.[7,12] Multiple ventilator and patient factors need to be monitored to determine noninvasive ventilation efficacy. Ventilator factors include tidal volumes, minute ventilation, air leak, breath stacking, and peak pressures. Equally important are patient factors such as subjective discomfort or sensation of dyspnea, objective work of breathing with accessory muscle use, lung auscultation, changes in mental status, airway patency, and continuous pulse oximetry. Venous blood gas is adequate for diagnosis and trending of pH and CO_2.

Failure

Noninvasive ventilation may fail in several ways. First, there is an increased risk of aspiration with facemask noninvasive ventilation devices. Increasing pressures may overcome lower esophageal sphincter tone and thus increase the risk of aspiration.[13,14] Therefore, we recommend limiting pressures to 20 cmH_2O or less. Remove the mask immediately if vomiting occurs. If mechanical respiratory support is still required, reassess the risk of further vomiting or aspiration and consider intubation. Furthermore, noninvasive ventilation exposes patients to the same risk of positive pressure breathing as invasive mechanical ventilation (eg, barotrauma, volutrauma). Therefore, we recommend goal tidal volumes of 8 mL/kg ideal body weight with maximum pressure of 20 cmH_2O. Inability to increase tidal volume despite increasing pressure support and optimal mask and patient positioning is a sign of noninvasive ventilation failure and may necessitate intubation.

Additionally, facemask noninvasive ventilation requires an adequate mask seal to be effective. The operator should monitor for leak and optimize the seal by adjusting the straps, potentially shaving facial hair, and ensuring proper mask size.

Exceptions to the CPAP/EPAP recruitment strategy outline above are as follows: (1) preload dependent conditions (eg, hypovolemia, distributive shock, cardiac tamponade), (2) CPAP/EPAP refractory conditions (eg, mucus plugging, unilateral lung disease, anatomical shunts), and (3) acute right ventricular failure. In preload dependent conditions, the increase in intrathoracic pressure from noninvasive ventilation can lead to a drop in venous return and cardiac output resulting in a decrease in both oxygen saturation and oxygen delivery. In unilateral lung disease, excessive CPAP/EPAP may overdistend healthy lung, paradoxically increasing pulmonary shunt and decreasing SpO_2. In such cases, lower PEEP and increased FiO_2 along with proper positioning (ie, lateral recumbent with "good lung" down) are necessary. Finally, facemask noninvasive ventilation strategies are typically not utilized in acute right heart failure given the negative effects of positive pressure on the right ventricle. In such instances, high flow nasal cannula may be utilized to correct hypoxemia without significantly increased intrathoracic pressures, though this is beyond the scope of this article. Finally, it is crucial to downtitrate FiO_2 to a goal of 88% to 92% as hyperoxemia may worsen outcomes.[15]

Peri-intubation

Noninvasive ventilation is useful in the peri-intubation period. If intubation becomes necessary, the same noninvasive ventilation settings mentioned previously can be used to prepare and optimize pulmonary physiology in the peri-intubation period (Figure E3, available at https://www.annemergmed.com). The application of a sealed mask with titratable FiO_2 and CPAP/EPAP is superior to a nonrebreather or bag-valve mask for preoxygenation and may increase the duration of normoxia during the apneic period.[4] Noninvasive ventilation used for a delayed sequence intubation strategy can improve pre-intubation conditions, and to potentially obviate the need for intubation altogether in certain conditions.[16] Furthermore, in those with acidosis, BPAP can be used to provide ventilation through the peri-intubation period.

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Author affiliations: From the Department of Emergency Medicine (Bracey), Albany Medical Center Hospital, Albany, NY; and Department of Emergency Medicine (Wright), Stony Brook University Hospital, Stony Brook, NY.

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