Noninvasive Ventilation and Oxygenation Strategies

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KEY POINTS

- NIV does not bypass the upper airway.
- Contraindicated in patients who have facial trauma, GCS </10, inability to protect airway, or clear secretions, upper airway obstructions, severe upper gastrointestinal bleed, or requires urgent intubation.
- Different modalities can be used to deliver NIV: nasal cannula, simple mask, nonrebreather, high-flow nasal cannula, CPAP, and BPAP.
- NIV can be attempted in patients with acute COPD exacerbations, trauma, cardiogenic pulmonary edema, COVID-19, and in certain cases ARDS.

INTRODUCTION

It is not an uncommon clinical scenario in medicine and surgery whereby one encounters a hypoxemic patient due to a myriad of reasons. The ability to understand and use different noninvasive ventilation (NIV) modalities is a valuable tool to have in your armamentarium before transitioning to more invasive strategies. This article will review some essential noninvasive oxygenation and ventilation strategies most commonly used in the surgical arena, hoping that it will provide a good reference when deciding which modality to choose in a hypoxic patient.

In adults, hypoxemia is commonly defined as a Pa_{O_2} less than 80 mm Hg on room air at sea level. As mentioned before, there are numerous reasons why a patient may become hypoxemic, including subambient $Fi0_2$, hypoventilation, V/Q mismatch, shunt, or diffusion defects which can manifests clinically as tachycardia, arrhythmias,

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feeling short of breath, dyspnea, tachypnea, altered mental status, and use of accessory muscles and indicate the need for supplemental oxygen. Providing supplemental oxygen, whereas relatively free of complications, through noninvasive oxygenation and ventilation modalities are helpful as one investigates the underlying etiology for the patient's hypoxemia.[1]

NIV has gained more popularity as it provides ventilation to the patient without using an artificial airway and does not bypass the upper airway.[2] Invasive methods bypass the upper airway and include options such as an endotracheal tube, a laryngeal mask, or a tracheostomy.[3] Compared with invasive ventilation, NIV is more comfortable while preserving the patient's airway defense mechanism. Moreover, complications directly related to intubation and mechanical ventilation can be avoided, such as aspiration, trauma to surrounding structures, barotrauma, ventilator-associated pneumonia.[4] Of note, while supplemental oxygen is widely available, inexpensive, and safe, there are complications such as hyperoxemia that increases risk in mortality, nitrogen washout atelectasis, O2-induced hypoventilation, airway/nasal/oral dryness, gastric insufflation, and mechanical pressure wounds from the delivery source that need to have precautions taken to monitor and avoid them.[1,5,6]

There have been recent guidelines for the clinical use of NIV, including the 2017 European Respiratory Society (ERS) and American Thoracic Society (ATC) and the 2017 British Thoracic Society (BTS), an Intensive Care Society, which makes recommendations about when or when not to use NIV and offer technical and pragmatic advice on its use.[3,7–9] This is beyond the scope of this article, which will focus on the basic NIV strategies and modalities most commonly available with a discussion of their use in only some of the more common clinical scenarios.

NONINVASIVE VENTILATION/OXYGENATION MODALITIES

To begin the discussion of some NIV strategies, there are different categories of oxygen delivery/therapy systems, mainly low-flow (variable-performance) and high-flow (fixed-performance) devices. Examples of low-flow (variable-performance) delivery systems include a nasal cannula, simple mask, and nonrebreather. An example of a high-flow (fixed-performance) device would be Fisher Paykel Optiflow or AIRVO 2 devices, or Vapotherm (**Table 1**).

Low-flow nasal cannulas (NC) are a relatively old, simple, and commonly used method to deliver oxygen therapy.[10,11] Nasal cannula prongs come in a variety of sizes and styles to fit pediatric up to adult patients. Usually, the nasal cannula is secured using an elastic band over the head or loops of tubing that fit over the patients' ears. In theory, standard NC can deliver flows from 1L up to 6L with an expected delivery of Fio_2 of 0.22 to 0.24 at 1 L/min up to 0.4 at 5 to 6 L/min. Factors that affect inhaled volume such as flow, inspiratory flow and time, respiratory rate, and factors that affect O2 concentration or air dilution such as open or closed-mouth breathing

Table 1	
Indications and contraindications to NIV	
Indications	**Contraindications**
Tachypnea	Facial trauma ± deformity
Acute COPD exacerbation	Upper airway obstruction
Medically stable	Severe upper GI bleed
	Decreased GCS </10
	Inability to protect airway or clear secretions
	Reasons that would necessitate intubation

and anatomic factors that would act as a reservoir and dead space, the actual Fio_2 inspired is likely much less and variable between patients.[1,10,11] Other downsides to nasal cannula are the drying of the nasal mucosa with an inability to effectively humidify or heat the oxygen delivered and potential discomfort of the pressure of the prongs or tubing when used for a significant amount of time.

A simple mask can be used when a higher Fio_2 is needed. It also comes in a variety of sizes suitable for infants up to adults with a small O2 supply tubing that attaches to its base. The mask fits over the bridge of the nose and is held in place with an elastic band over the patient's head. The mask typically has an aluminum strip to help avoid leakage toward the eyes and covers the nose and mouth down to the chin. Exhaled air leaves through side boles and between the mask and face as there is no sealing device, allowing for the inhalation of room air around the mask interface. The mask acts differently than NC as it has approximately a 100 to 200 mL reservoir in an adult-sized mask that allows for an increase in inspired O2 concentration. The Fio_2 concentration delivered theoretically is approximately 0.3 to 0.8 with flows capable of ranging from 5 to 10 L/min, but given the design and ability to intake room air from around the mask, the actual delivered Fio_2 is variable and dependent on mask volume O2 flow and pattern of ventilation. The mask also allows for CO2 accumulation during exhalation, so O2 flow should be high enough to washout the mask and prevent rebreathing.[12]

A nonrebreather is essentially a simple mask with an attached 300 to 600 mL reservoir bag with a valve between the bag and the mask and one of the side exhalation ports. This valve prevents exhaled gas from flowing into the reservoir and flows out of the mask ports. During inhalation, the mask exhalation port valve closes, allowing minimal room air from being inhaled and allowing inhalation of the 300 to 600 mL reservoir bag. There is also no sealing device, so while Fio_2 concentrations of 0.6 to 0.9 are theorized it is variable. The flow rate for this mask allows up to 15 L/min.

The Venturi Mask is a facemask that allows the delivery of a predetermined Fio_2.[13] The mask operates using the Bernoulli principle, which allows a constant high flow of oxygen through a narrow tube that entrains room air through openings on the sides. This mode can deliver Fio_2 in a controlled and accurate manner between 24% and 60%.[14,15] Disadvantages include patient discomfort from the displacement of the mask in addition to a dry sensation from the delivery of nonhumidified oxygen.[13]

High-flow/fixed-performance devices such as Optiflow. High-flow/fixed-performance devices allow for blending of 100% O2 and room air to produce gas with the desired Fio_2 at a high enough flow, up to 60 L/min, to prevent dilution with room air while providing heated humidified air. The physiologic mechanisms that high flow provides are washout of physiologic dead space, decreased respiratory rate, increased tidal volume, increased end-expiratory volume, and some small degree of positive end-expiratory pressure.[16–19] High flow allows for the delivery of air volumes greater than what a patient ventilates physiologically and essentially washes out the pharyngeal dead space so that the Co2 is replaced by oxygen thus creating greater oxygen diffusion gradient allowing for improved breathing efficiency and patient oxygenation.[16,19] Mundel and colleagues provided several physiologic studies that showed HFNC could decrease respiratory rate and also increase tidal volume.[20] Parke and colleagues and Frat and colleagues have shown with closed mouth breathing high flow nasal cannula could approximate 1 mm Hg of PEEP for every 10 L/min of flow.[21,22]

Continuous positive airway pressure (CPAP) therapy continuously applies a constant level of positive end-expiratory pressure (PEEP) to a spontaneously breathing patient.[23] More specifically, this phenomenon occurs during both inspiration and expiration as PEEP is the pressure within the alveoli at the end of expiration.[24] The

delivered PEEP increases the patient's functional residual capacity (FRC), opens underventilated alveoli, decreases atelectasis, and improves lung compliance. Oxygenation is also improved while decreasing the patient's work of breathing.[4] PEEP additionally has a positive effect on cardiac function. An increase in PEEP thereby increases intrathoracic pressure, simultaneously increasing intrapleural pressure. The difference between the left ventricle systolic pressure and intrapleural pressure determines the left ventricular afterload.[25] Thus, an increase in PEEP alternatively decreases left ventricular afterload and enhances cardiac output.[4,25]

Many commercial devices compatible with CPAP have an oronasal mask. However, not all patients can tolerate CPAP due to the discomfort from the mask and constant airflow. Thus, various face mask interfaces are available for better patient adherence. Recommended settings start at a level of 4 cm H2O and increase by 1 to 2 cm H2O intervals to a maximum of 20 cm H2O.[24] Fio_2 can be set starting at 21% to 100%.[26] If the patient does not have improved gas exchange or a reduced work of breathing at maximum settings, then alternative respiratory adjuncts should be considered.

Bilevel positive airway pressure (BPAP) therapy is another mode of delivering NIV and uses a pressure-cycling mode. The device alternates delivering inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP). The difference between the 2 preset pressures determines the tidal volume. If the respiratory rate is constant, a larger tidal volume increases alveolar ventilation.[24] BPAP is contraindicated in those with facial traumas not amenable to face mask interfaces and in patient's inability to control their secretions.

BPAP settings start at different levels tailored to various respiratory conditions. Minimal settings are 8 cm H2O for IPAP and 4 cm H2O for EPAP. IPAP is increased by levels of 2 cm H2O to a maximum of 20, whereas EPAP is titrated to a maximum of 10. Providers must be present at the bedside to determine how much titration is indicated to improve the patient's respiratory drive. Caution must be taken as increasing EPAP too much may inadvertently decrease the tidal volume delivered.[27]

COMMON CLINICAL SCENARIOS

Now that noninvasive oxygenation and ventilation modalities have been reviewed, discussion of using them during common disease states can occur. The ATS and the BTS have formulated some guidelines and recommendations for the utilization of NIV in specific disease processes (Table 2).

NIV is a modality commonly used in postsurgical extubation. Reintubation rates are generally 20% for all patients but can be 40% following abdominal surgeries due to respiratory muscle dysfunction, which may linger for 7 days.[23] Postoperatively, NIV

Table 2 Types of NIV	
Nasal Cannula	• Delivers oxygen through nasal prongs
Simple Mask	• Oronasal mask interface • Can deliver higher Fi02 with 100–200 mL reservoir
Nonrebreather	• Same interface as a simple mask • Larger reservoir (300–600 mL)
CPAP	• Mask interface • Delivery of continuous pressure
BPAP	• Mask interface • Delivery of IPAP and EPAP

has been shown to increase lung aeration, arterial oxygenation, and decrease atelectasis to counteract the physiologic effects of surgery and anesthesia.

Reintubation is associated with increased mortality. Thus, NIV is a strategy that can be used to prevent or treat postextubation. Options available are HFNC, CPAP, and BPAP, and their use is based on both patient factors and clinical judgment. The ERS and the (ATS) provide guidelines for NIV use in various clinical settings.[8]

Hernandez and colleagues conducted an RCT that demonstrated HFNC not superior to BPAP in patients considered high risk of extubation failure, with reintubation occurring in 60 patients (19.1%) in the NIV group and 66 patients (22.8%) in the high-flow group (risk difference, −3.7%; 95% confidence interval (CI): −9.1% to ∞. Patients who fulfilled at least 1 of their listed criteria were considered high risk, which was not limited to age >/65, heart failure as main indications for intubation, moderate to severe COPD, APACHE II score >/12, BMI >/30, airway patency issues, unable to clear secretions, and prolonged weaning.[28] Another study conducted by Ferrer and colleagues revealed decreased respiratory failure in patients who received NIV immediately after extubation vs those in the control group with Venturi Masks (P = .029). Benefits were seen in patients with chronic respiratory disorders and hypercapnia during the spontaneous breathing trial.[29] However, there is no additional advantage in low-risk patients or in patients who developed respiratory failure after extubation.[8]

The trauma population is susceptible to respiratory failure due to the nature of their injuries in conjunction with their comorbidities. Many of these patients present with more than one injury, which contributes to the complexity of their care while placing them at an increased risk for developing hypoxemic respiratory failure. Hypoxemia in these patients is due to ventilation-perfusion mismatch and a right to left shunt from a lung contusion, atelectasis, inability to clear secretions, pneumothorax, or a hemothorax.[30,31]

RCTs have produced insufficient evidence and yielded low-grade recommendations resulting in no established consensus for NIV use in trauma patients.[8,30,32] Nonetheless, an agreement exists for situations in which NIV is not an appropriate option, which includes facial deformities, inability to protect airway or cooperation, upper airway obstruction, respiratory or cardiac arrest, hemodynamic instability, organ failure, severe upper gastrointestinal bleed, and GCS less than 10. The duration of NIV use also remains for further discussion. NIV in trauma patients requires close monitoring as a clinical response is anticipated in 1 to 4 hours. If the patient has a refractory response, the patient should be promptly intubated and ventilated to decrease mortality.[30]

Chronic obstructive pulmonary disease (COPD) is prevalent in our society, and NIV application has been extensively researched. Generally, a patient has compensatory pulmonary mechanisms in chronic COPD. The increased flow resistance impairs full expiration before the next inspiration and produces hyperinflation and use of accessory muscles.[2] However, the patient's compensatory mechanism diminishes during an acute exacerbation. Respirations are compromised as increased respiratory rate leads to low tidal volumes, which increases respiratory acidosis and induces increased energy expenditure and fatigue.[8] NIV provides external PEEP to offset the effects of an acute exacerbation but has been beneficial only in acidotic patients.[8,33] Keenan and colleagues further showed NIV was poorly tolerated in minimally acidotic patients with increased patient discomfort.[34]

Acute respiratory distress syndrome (ARDS) is an inflammatory lung condition that leads to leakage of fluid into the lung spaces causing hypoxemia. The use of NIV for supportive treatment in ARDS is controversial. Ding and colleagues demonstrated

that early application with HFNS in patients with moderate ARDS might help avoid intubation.[35] This was also seen in Antonello and colleagues' study that showed NIV reduced the need for endotracheal intubations in ~54% of the time and correlated with a meta-analysis of randomized and observational studies. However, given the heterogeneity of the studies, other outcome measures could not be interpreted.[36,37] Patel and colleagues found NIV delivered via helmet significantly reduced intubation rates than face masks.[38] Frat and colleagues investigated sequential applications of HFNC and NIV and found intubation rates of 36% in patients with a P/F ratio less than 300, including patients with ARDS.[39] It is not uncommon for NIV to be used in 20% to 30% of ARDS patients and most hypoxemic patient.[40,41] The potential benefits of avoiding mechanical ventilation such as complications of sedation, muscle paralysis, pneumonias, delirium, and earlier mobilization have been theorized but the evidence is based on a relatively small sample size. The LungSafe study, which was a prospective, multicentered observational study demonstrated that NIV was used among all ARDS severity categories and that the inspiratory pressures required to improve work of breathing could increase tidal volumes high enough to exacerbate lung injury potentially. It also demonstrated the risk of NIV failure increased with increasing severity of ARDS.[41] The higher inspiratory pressures could also lead to increase mask leaks, gastric distention, and patient tolerance.[42] The ERS/ATS and the BTS mention in their guidelines that the use of NIV has shown to decrease inspiratory effort than no inspiratory assistance but the ERS/ATS guidelines left no recommendation for its use given the small amount of data and the BTS guidelines state that those with the potential failure of NIV should be monitored in the ICU.[42] So while use is common in patients with ARDS, it is recommended that only select patients in carefully monitored units undertake an NIV trial.

Less controversial is the use of NIV in pulmonary edema and, more specifically, cardiogenic pulmonary edema. In cardiogenic pulmonary edema, there is an increase in extravascular lung water, decreased lung volume and lung compliance, and increased airway resistance.[43] Bello and colleagues review of the literature showed that the uses of NIV can decrease the systemic venous return and left ventricular afterload, which would reduce LV filling pressure and limiting pulmonary edema, and that CPAP showed improvement in vital signs of patients and decreased need for endotracheal intubation and hospital mortality than conventional oxygen therapy.[2,44] The BTS guidelines recommend CPAP as it has been shown effective in patient with cardiogenic pulmonary edema and that NIV should be reserved for those for whom CPAP is not successful.[3] The ERS/ATS guidelines recommend either bilevel NIV or CPAP for patients with acute respiratory failure due to cardiogenic pulmonary edema.[8]

The global pandemic of COVID-19 has been deadly, and with some countries and ICUs short of ventilators, the use of NIV has proven helpful, especially with early studies out of China, Italy, and other countries out of Europe showing those who ended up intubated had higher mortality. A study out of Germany suggests that NIV be used as an additional support measure early in the disease course and part of a stepwise algorithm.[45] There are some theoretical concerns about not recommending NIV or HFNC until the patients are cleared of COVID-19 due to transmission risks to health care professionals due to aerosols.[46,49] A study out of China that demonstrated early intervention with HFNC and NIV could lead to lower mortality.[47] The Society of Critical Care Medicine came out with recommendations supporting HFNC and recommended that modality over NIPPV in its 2019 paper, which was not without controversy as some argued HFNC was no safer than NIPPV as most of the work looking at HFNC and NIPPV had been done in SARS and that NIPPV offers a closed system versus HFNC.[48,49]

SUMMARY

It is hoped that this article effectively reviews the most common NIV and oxygenation strategies and modalities used in surgical patients. It is also hoped that the clinical pathologies mentioned in this article serve as a good reference for clinicians who would like guidance on the use of NIV in their patients.

CLINICS CARE POINTS

- NIV is only seen beneficial if used early in the postextubation phase.
- NIV is suggested for use in COPD with those who have acidosis for acute exacerbations of COPD.
- NIV can be used in ARDS but is most successful in patients with mild ARDS. There is an increase in NIV failure rates with increasing severity of ARDS and is associated with worse mortality.

DISCLOSURE

The authors have nothing to disclose.

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