Noninvasive Positive Pressure Ventilation in the Emergency Department

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Noninvasive ventilation is defined as the provision of ventilatory assistance to the respiratory system without an invasive artificial airway. Noninvasive ventilators consist of both negative and positive pressure ventilators. Because negative pressure ventilation is so rarely used today, discussion is limited here to positive pressure ventilation.

One of the earliest descriptions of a “pulmonary plus pressure machine” was in 1936 when Poulton described using an Electrolux or Hoover vacuum cleaner to supply air at positive pressure to treat patients with “cardiac and bronchial asthma”. He also wisely cautioned that: “the machine should be run for some minutes first of all to get rid of the dust” [1].

Before the 1960s, the use of negative pressure ventilation in the form of the tank ventilator or the “iron lung” was the most common form of mechanical ventilation outside of the anesthesia suite. It was not until the 1952 polio epidemic in Copenhagen that anesthesiologist Bjorn Ibsen showed that he could improve the survival of patients who had respiratory paralysis by using invasive positive pressure ventilation.

Despite this, negative pressure or iron lungs were the mainstay of ventilatory support for patients who had chronic respiratory failure until as late as the mid-1980s. In the early 1980s, nasal continuous positive airway pressure (CPAP) was introduced to treat obstructive sleep apnea. These tight-fitting masks proved to be an effective means of assisting ventilation and noninvasive positive pressure ventilation (NPPV) quickly displaced...
traditional negative pressure ventilation as the treatment of choice for chronic respiratory failure in patients with neuromuscular and chest wall deformities. Current NPPV devices are able to provide a set respiratory rate, set tidal volume, and set amount of inspiratory oxygen. The use of NPPV has also been integrated into the acute inpatient setting where it is now used to treat acute respiratory failure [2].

This article reviews the indications for NPPV in the treatment of acute respiratory failure, the evidence for its application in the emergency department (ED), and some relative and absolute contraindications for NPPV. The use of high flow nasal cannulae and their potential treatment benefit in patients with respiratory distress is also discussed.

Definitions

The current literature uses different definitions for NPPV. Although some authors use NPPV as umbrella terms that include CPAP and bilevel positive airway pressure, more recently other authors have used the term NPPV as synonymous with bilevel and consider CPAP a separate entity. The terms NPPV and noninvasive intermittent positive pressure ventilation (NIPPV) are often used interchangeably with bilevel.

As its name suggests, CPAP supplies continuous positive pressure via a tight-fitting facemask. NPPV or bilevel provides an inspiratory pressure (set as IPAP or inspiratory positive airway pressure) in addition to end-expiratory positive pressure (set as EPAP or expiratory positive airway pressure) and breaths are usually triggered by the patient. On many such devices, backup rates may be set, that deliver bilevel pressures even if patients fail to initiate a breath.

Rationale for using noninvasive positive pressure ventilation

The most important advantage of NPPV is avoiding the complications associated with invasive mechanical ventilation. It has been well documented that invasive mechanical ventilation increases the incidence of airway and lung injury, and it augments the risk of nosocomial pneumonia. NPPV avoids these complications by keeping the upper airway defense mechanisms intact and allows the patient to retain the ability to eat, clear secretions, and communicate normally when NPPV is used intermittently [2]. NPPV has the potential to reduce the mortality of a selected group of patients with acute respiratory failure and may shorten hospital stay, thereby reducing costs. Specific to the ED, appropriate initiation of NPPV may avoid unnecessary intubation of selected patients, hence avoiding ICU admissions, reducing costs, decreasing complications, and improving mortality.
Pathophysiological effects of noninvasive positive pressure ventilation

CPAP increases alveolar recruitment and size, enhancing the area available for gas exchange, and improves ventilation-perfusion relationship, thus improving hypoxemia. The term CPAP is synonymous with extrinsic PEEP (PEEPe) and the bilevel expiratory positive airway pressure (EPAP). It can also negate the effects of intrinsic positive end expiratory pressure (PEEPi) also referred to as auto-PEEP or dynamic hyperinflation. In patients with dynamic hyperinflation (asthma or chronic obstructive pulmonary disease [COPD]), an increased PEEPi increases the magnitude of the drop in airway pressure that the patient must generate to trigger a breath. This causes an increase in the work of breathing for the patient. Careful application PEEPe can reduce this gradient and decrease the patient’s work of breathing. Positive pressure ventilation creates an increase in intrathoracic pressure. This causes preload to decrease due to diminished venous return and also decreases transmural pressures and afterload [1].

In NPPV or bilevel, the inspiratory positive airway pressure (IPAP) is similar to pressure support and, when combined with expiratory positive airway pressure (EPAP), further augments alveolar ventilation and allows some respiratory muscle rest during the inspiratory phase.

Indications for initiating noninvasive position ventilation

Acute exacerbation of chronic obstructive pulmonary disease

Numerous studies have shown that NPPV can reduce the need for intubation, length of the hospital stay, and also in-hospital mortality rate in patients presenting with acute exacerbations of COPD. One of the earliest, prospective, randomized studies was done by Bott and colleagues [3] in 1993 where they reported a reduction in mortality with the use of nasal NPPV in patients who had COPD. This study was followed by a large multi-center, prospective, randomized trial by Brochard and colleagues [4], which confirmed selected patients who had acute COPD exacerbations did benefit from NPPV, compared with standard medical care alone. In this study, NPPV decreased intubation rates compared with standard medical treatment (11/43 [26%] versus 31/42 [74%]); hospital mortality was 9% in the NPPV group compared with 29% in the standard medical therapy group. Since then, several systematic reviews have confirmed that NPPV reduces in-hospital mortality and decreases the need for endotracheal intubation in patients who have acute, severe COPD exacerbations. A systematic review by Keenan suggested that the patients who benefited most from NPPV treatment were those with severe exacerbations as manifested by a pH of < 7.3 [5]. This finding, however, has not been borne out in other reviews [6].

Interestingly, Conti and colleagues [7] showed that if NPPV is started later, after the failure of medical treatment, the benefits conferred by...
NPPV (hospital mortality, length of ICU stay, number of days on the ventilator, overall complications) are eliminated. This emphasizes the importance of initiating NPPV early, alongside standard medical therapy.

It is reasonable to consider early implementation NPPV in patients who present to the ED with an acute exacerbation of COPD.

Asthma

In many ways, an acute asthmatic attack is similar to a COPD exacerbation. There is pronounced airway obstruction, significant dynamic hyperinflation and, increases in PEEPi. CPAP has been reported to have a bronchodilatory effect in asthma, unloading fatigued muscles, and improving gas exchange. The PEEPe from NPPV can also offset the PEEPi that occurs during an asthmatic attack as mentioned earlier [8].

Soroksky conducted a prospective, randomized, placebo-controlled study in 30 patients who presented to the ED with a severe asthma attack (excluding patients with signs of concurrent pneumonia). Half the patients were assigned to NPPV (for 3 hours) and conventional therapy, while the other half received conventional therapy and subtherapeutic pressures via a sham device.

He found that patients who received NPPV had significantly improved lung function test results. There was also a significant reduction in the need for hospitalization in the treatment group (17.6% versus 62.5%, P = .0134). Therefore in selected patients who have severe asthmatic attacks, the use of NPPV may be a useful adjuvant, which potentially alleviates the attacks faster and decreases the need for hospitalization [8].

Acute cardiogenic pulmonary edema

The great majority of patients who have acute cardiogenic pulmonary edema (ACPE) present to the ED. When these patients do not respond to conventional medical treatment, ventilator assistance becomes necessary. CPAP ventilation has been shown to be efficacious in ACPE. An early systematic review by Pang and colleagues [9] revealed that CPAP could reduce the rate of intubation and led to a trend toward decreasing mortality. A later, pooled analysis by Collins and colleagues [10] suggested that CPAP and NPPV both reduced the risk of subsequent intubation in the ED, although the mortality benefits were less convincing.

The data for NPPV or bilevel has been mixed, with an early article by Mehta and colleagues [11] describing an increase rate of acute myocardial infarction in patients who have ACPE treated with NPPV. Since this study, there have been several trials that have refuted this increased risk of myocardial infarction. Most of these have been small studies, the largest being a multicenter trial randomizing 130 patients who have ACPE to either NPPV or conventional therapy. This study found that the patients treated
with NPPV had faster improvements in oxygenation, respiratory rates, and sensation of dyspnea. No difference was noted between the two groups with regard to rates of intubation, hospital mortality, length of stay, or myocardial infarction [12]. More recently, Ferrari and colleagues [13] compared CPAP and NPPV head-to-head in 52 patients with ACPE. They found no significant difference in the rates of intubation and hospital stay. Both techniques were found to be effective in improving gas exchange and vital signs in patients who have ACPE. More importantly, no significant difference was observed in the rate of acute myocardial infarction in the two groups.

In the largest study of patients presenting with ACPE in the ED, author Newby has reported in Chest Physician (October 2007) that in his study of 1,069 UK patients, both CPAP and NPPV were effective in resolving patient’s symptoms (eg, dyspnea), but the mortality rate at 7 and 30 days after treatment was similar in the three groups (CPAP, NPPV and passive oxygen therapy).

It seems that it is safe to use either CPAP or NPPV for patients who present with ACPE. Although it seems that neither therapy improves mortality, it does seem to improve symptoms and may decrease intubation rates in the ED, thus avoiding the associated complications of intubation and potentially avoiding an ICU admission.

**Hypoxemic respiratory failure**

The data for NPPV in patients with acute hypoxemic respiratory failure is mixed. The largest study examined 105 patients who had acute hypoxemic respiratory failure (PaO$_2$ < 60 mmHg, SpO$_2$ < 90% on oxygen by facemask). Patients who had hypercapnia were excluded. These 105 patients were assigned randomly to NPPV or oxygen therapy. The authors reported marked reductions in rates of endotracheal intubation, septic shock, ICU and cumulative 90-day mortality in the patients who were treated with NPPV [14]. This group also included patients who had cardiogenic pulmonary edema.

Antonelli and colleagues [15] looked at whether NPPV could be beneficial in patients who had acute hypoxemic respiratory failure and who would otherwise need intubation. They studied 64 patients who presented with acute hypoxemic respiratory failure and excluded patients who had COPD. The authors found that NPPV was as effective as conventional ventilation in improving gas exchange, and NPPV was associated with fewer serious complications (particularly pneumonia and sinusitis) and resulted in shorter stays in the ICU. The etiology for the respiratory failure in this cohort of patients was variable, and included patients who had cardiogenic pulmonary edema.

For patients who have pneumonia causing acute respiratory failure, the evidence is even more controversial, with some papers suggesting a decrease in intubation rates, while others have found no difference in intubation rates or in-hospital mortality [16,17].
In summary, although some of the literature suggests that NPPV may be beneficial in the setting of acute hypoxemic respiratory failure, doubts still exist, in part due to the heterogeneity of patients included in previous studies. A large multicenter trial of NPPV in patients who have acute hypoxemic respiratory failure that excludes patients who have cardiogenic pulmonary edema and COPD may help to clarify the use of NPPV in this setting.

**Immunosuppressed patients**

NPPV can also be useful in patients who are profoundly immunosuppressed, either due to solid organ transplantation or from hematological conditions. In these patients, mortality after endotracheal intubation is particularly high, therefore any attempts to avoid this procedure may result in improved survival.

One study randomized 40 patients with acute hypoxemic respiratory failure after solid organ transplant to conventional treatment, including oxygen via facemask or NPPV. The patients assigned to NPPV had a lower rate of endotracheal intubation, shorter ICU stays, and lower ICU mortality. Inhouse mortality did not differ significantly between the two groups [18].

Another study included immunosuppressed patients who had pulmonary infiltrates, fever, and acute respiratory failure. This study also included patients who were immunosuppressed from: chemotherapy; bone marrow transplantation for hematologic cancers; corticosteroid or cytotoxic therapy for a nonmalignant disease; or, AIDS. They found that in these patients, early initiation of NPPV was associated with significant reductions in the rates of endotracheal intubation and serious complications, with lower rates of death in the ICU and in the hospital [19]. Of note, all of the patients who developed ventilator-associated pneumonia died in the ICU, in both aforementioned studies (2/26 in the NPPV group; 6/26 in the standard treatment group in Hilbert’s study). This emphasizes the potential dangers of intubation in this group of patients.

When faced with a severely immunosuppressed patient with acute hypoxemic respiratory failure in the ED, early initiation of NPPV may be beneficial in avoiding the serious complications of endotracheal intubation.

**Do not intubate patients**

Although most studies of NPPV have focused on patients with acute respiratory failure who desire maximum life-prolonging treatment, there is an emerging interest in using NPPV for patients who have made the decision to forego endotracheal intubation (DNI). A recent review article on this topic suggests that with good patient–family–physician communication, NPPV can successfully be used in these patients on a trial basis [20].

In DNI patients willing to undergo NPPV, success would be measured by improved ventilation or oxygenation. NPPV can provide support for the
patient while the underlying cause of the respiratory failure is treated. NPPV should be discontinued if it is not producing the desired response or if the patient is unable to tolerate it. In these circumstances, a decision should be made by the health care team, the patient, and their family to discontinue NPPV and make the transition toward comfort measures.

The authors suggest that in patients who have chosen to forego any life-prolonging therapy and are receiving comfort care measures only, NPPV might be used as a form of palliative care, in an attempt to reduce associated dyspnea. In this circumstance, the use of NPPV is considered successful if it alleviates the patient’s symptoms. If it causes any discomfort to the patient, it should be discontinued because the primary goal is patient comfort. This use of NPPV is controversial and there are no studies that have assessed the benefits of NPPV in this group of patients [20]. Another use of NPPV in patients who have chosen comfort care measures is a time-limited trial of NPPV to achieve the goal of survival until the arrival of family and friends. In this situation, NPPV would be used to provide life support until friends and family can achieve closure.

Even if a patient with a known DNI advanced directive presents to the ED with acute respiratory failure of reversible etiology, it still can be beneficial discussing the use of NPPV with the patient and their family. In this situation, communication about expectations and goals of care is of utmost importance.

**Facilitation of weaning and extubation**

Recent studies have shown that NPPV can potentially be useful in the discontinuation of mechanical ventilation in patients when respiratory failure is due to COPD. A recent meta-analysis found that in those patients who have COPD who failed a spontaneous breathing trial, extubating to NPPV decreased mortality, hospital length of stay, incidence of ventilator-associated pneumonia, and total duration of mechanical ventilation [21]. Although it is rare to extubate a patient in the ED, one does sometimes encounter patients with exacerbations of their COPD who were prematurely intubated in the field, or who have improved remarkably since arrival to the ED. These patients can be considered for extubation to NPPV on a case-by-case basis if there are no contraindications to extubation, and only if the clinician is confident that the patient can be re-intubated if necessary.

**Feasibility of using noninvasive positive pressure ventilation in the emergency department**

Most of the earlier NPPV studies were performed in the ICU. With the growing clinical and fiscal pressures to avoid endotracheal intubation whenever feasible, there has been an increasing interest in using this technology in the ED. Pollock showed in his study that the use of NPPV was feasible and had the potential utility in the management of patients with respiratory
distress [22]. This early intervention had the potential to avoid the risks and complications of endotracheal intubation and shorten or possibly eliminate intensive care admissions. There is very little literature on the safety of using NPPV in the ED, how to identify patients who would benefit from this treatment or how long these patients should be treated with NPPV in the ED. There is also controversy over which type of mask should be used.

Nasal masks had been traditionally used in the setting of chronic home therapy and they were initially the masks of choice in the acute setting. Because dyspneic patients tend to be mouth breathers, it is thought that face-masks are preferable for the treatment of acute respiratory failure in the ED [1]. Poponick and colleagues, as well as Merlani and colleagues, have sought to define and identify those patients who might benefit from NPPV and conversely, identify what factors would predict failure of NPPV in the ED. Poponick and colleagues [23] investigated factors associated with NPPV failure in the emergency setting in 58 patients receiving a 30 minute trial of bilevel. Lack of improvement of pH and PaCO₂ level were identified as indicators for endotracheal intubation. Merlani and colleagues [24] retrospectively analyzed a total of 104 patients admitted to the ED and found that factors associated with failure of NPPV in the univariate analysis included Glasgow Coma Scale < 13 at ED admission, or a RR > 20/min, or a pH < 7.35 after one hour of NPPV. In the multivariate analysis, pH < 7.35 and RR > 20/min after one hour of NPPV were independently associated with NPPV failure and subsequent intubation of these patients. Both these studies looked at patients who had acute respiratory failure and the studies included predominantly patients who had COPD and congestive heart failure.

These two studies emphasize the importance of close follow-up of patients who are started on NPPV in the ED. It is important to serially assess patient response as soon as 30 minutes after the initiation of NPPV. Those who are persistently tachypneic and acidemic should be considered for intubation sooner rather than later.

**Initiation of noninvasive positive pressure ventilation**

There is no standard approach to the initiation of NPPV. Different methods have been used in clinical trials, yet these methods have never been compared. There are two main strategies: a high-low approach and a low-high approach.

In the high-low approach, one initially starts with a high IPAP (20–25 cmH₂O) and then lowers this if the patient is unable to tolerate such high pressures. In the low-high approach, one starts with a lower IPAP (8–10 cmH₂O). This is gradually increased as tolerated to achieve alleviation of dyspnea, decreased respiratory rate, increased tidal volume, and patient–ventilator synchrony. The EPAP is usually set at 3–4 cmH₂O, unless the patient has a significant amount of autopeep or PEEPi. In these patients, one would start with an EPAP between 4–8 cmH₂O. The FiO₂ is titrated to keep
the pulse oximetry $\geq 90\%$. Much like conventional ventilation, the EPAP can be adjusted to improve oxygenation and the $\Delta$ IPAP-EPAP can be adjusted to create a higher minute ventilation and thus mitigate hypercapnia.

As mentioned in the previous section, it is imperative to closely observe the patient for deterioration. Blood gases should be checked within 1 to 2 hours after initiation of NPPV to assess treatment success or failure. Patients who do not improve clinically should be considered for intubation.

**Cautions for use of noninvasive positive pressure ventilation**

Most studies involving NPPV have excluded patients who were hemodynamically unstable, had an altered level of consciousness, or were unable to protect their airway. This was based on the concern that a depressed sensorium would predispose the patient to aspiration. The International Consensus Conference in Intensive Care Medicine on Noninvasive Positive Pressure Ventilation in Acute Respiratory Failure held in April 2000 considered the presence of severe encephalopathy, as manifested by a GCS $< 10$ to be a contraindication for NPPV [25].

Other accepted contraindications to NPPV are listed below: (Box 1).

Recently there have been studies looking specifically at the use of NPPV in patients presenting with hypercapnic coma secondary to acute respiratory failure. This was based on the observation that some DNI patients who declined intubation had successful outcomes using NPPV therapy despite their initial comatose presentation. Diaz and colleagues [26] conducted an observational study and found that success rates were comparable between the comatose and noncomatose group. Scala and colleagues [27,28] performed two studies, both showing that NPPV could be used successfully in treating patients with COPD exacerbations with hypercapnic encephalopathy. Their 2007 study showed that the use of NPPV performed by an experienced team led to similar short-term and long-term survivals, fewer nosocomial infections, and shorter durations of hospitalization compared with patients who were placed on mechanical ventilation. Of note, the above

**Box 1. Contraindications to the use of noninvasive ventilation**

- Impending cardiovascular collapse or respiratory arrest
- Severe upper gastrointestinal bleeding
- Facial surgery, trauma or deformity, limiting placement of the NPPV mask
- Upper airway obstruction
- Inability to cooperate/protect the airway, altered mental status
- Inability to clear respiratory secretions
- High risk for aspiration
studies were conducted in the ICU [26] or specialized respiratory care units [28], with a nursing ratio of at least 1:3. The patients were also very closely monitored by staff while they received NPPV. This high level of nursing to patient ratio may not be feasible in a busy ED.

The other key point in these studies was the rapid improvement in neurologic status that occurred 1–2 hrs after the initiation of NPPV. The importance of close monitoring of patients started on NPPV is crucial in identifying those who will fail this therapy.

High flow nasal cannula

The high flow nasal cannula (HFNC) is a relatively new oxygen delivery system. Conventional nasal cannula uses a low flow system; at higher flows (>6 L/min), it can cause nasal dryness, epistaxis and patient discomfort. The HFNC system (Fig. 1) is a novel device, combining oxygen, pressurized air, and warm humidification to deliver tolerable flows of up to 40 L/min through a nasal cannula. The FiO₂ and flow rates can be adjusted. With higher flows, less air entrapment occurs and the higher flow rates match the dyspneic patient’s increased minute ventilation.

Use of the HFNC has been more extensively studied in neonatal respiratory care where ongoing studies suggest that HFNC may be as effective as nasal CPAP in the preterm neonate [29]. One study looked at the effect

Fig. 1. High flow nasal cannula system. A) High flow flowmeter, B) oxygen blender, C) low flow flowmeter, D) nasal cannula, E) low compliance, heated-wire circuit, F) high flow humidifier, G) water reservoir, H) air/O₂ supply.
of HFNC on exercise performance in adults with COPD [30]. Currently, there are no published studies investigating the use of HFNC in patients who have acute respiratory failure. Anecdotally, this system has been used with some success in adults in the ICU, targeting immunosuppressed patients in hopes of avoiding intubation. It seems to be better tolerated than NPPV and, at higher flows, it is believed to provide a certain amount of continuous positive pressure. More studies will have to be performed before this technology becomes a mainstay treatment of patients with acute respiratory failure.

Summary

NPPV has been shown to work well in patients with reversible conditions and acts as a bridge while allowing medical therapy (eg, bronchodilators, steroids, diuretics) to take effect, thus potentially avoiding the need for endotracheal intubation. Those with less reversible causes of their acute respiratory failure (ARDS, pneumonia) may be less likely to respond. With careful patient selection, NPPV can be safely initiated in the ED, giving time for the medical treatment to work, and potentially avoiding an ICU admission. Patients who are being considered for intubation should be evaluated for the potential use of NPPV.

Close monitoring and follow-up of patients placed on NPPV is crucial in determining whether the therapy has been successful or if further intervention is needed. Therefore, in EDs where the staff have been adequately trained, selected patients, even those who present in a hypercapnic coma can be considered for a short trial of NPPV, with the caveat that extreme diligence in monitoring these patients must be employed and if improvement is not seen in 1–2 hours, intubation should not be delayed.

References


