Current Heart Failure Reports (2019) 16:89–97
https://doi.org/10.1007/s11897-019-00429-y

EMERGENCY MEDICINE (FRANK PEACOCK, SECTION EDITOR)

Noninvasive Ventilation in Acute Heart Failure

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Published online: 30 May 2019

Abstract

Purpose of Review To assess the role of noninvasive ventilation (NIV) in acute heart failure (AHF).

Recent Findings NIV rapidly improves the respiratory distress and reduces the need for intubation and even mortality in patients with acute cardiogenic pulmonary edema (ACPE). Therefore, NIV is indicated as first line therapy in ACPE. NIV may also be considered in some cases of cardiogenic shock after stabilization. CPAP is an easier and cheaper technique that is recommended as first-line therapy, particularly in pre-hospital or low-equipped areas. Noninvasive pressure support ventilation is equally effective in these scenarios, and may be preferable in patients with mild fatigue or significant hypercapnia, including those with associated chronic obstructive pulmonary disease (COPD). High flow nasal cannula is an alternative for patients who need prolonged ventilation or those who show poor tolerance to these techniques.

Summary NIV should be used as a first-line therapy in all patients with ACPE and should be considered in stable cardiogenic shock and AHF associated to COPD.

Keywords Noninvasive ventilation · Acute heart failure · CPAP · Pressure support · High-flow nasal cannula

Introduction

Acute respiratory failure (ARF) is a frequent complication in clinical practice, and it is usually managed with conventional oxygen therapy (COT), mainly high-flow "Venturi" masks, or low-flow reservoir masks and thin nasal cannulas. However, ARF is not often fully compensated with COT and requires greater respiratory support. Noninvasive ventilation (NIV), a technique that emerged in the 1980s, consisting of the application of positive intrathoracic pressure to conscious patients through different interfaces, has shown to be useful in this setting by reducing the need for EI and invasive mechanical ventilation (IMV) and decreasing some of its associated risks, mainly ventilator-associated pneumonia [1]. Since its introduction, NIV has been extended to different areas of the hospital, the pre-hospital setting and even care at home, while IMV has remained limited to critical units or the operating theater. NIV is currently used to treat ARF in different acute scenarios [2••] (Table 1), having COPD exacerbation and acute cardiogenic pulmonary edema (ACPE) as the strongest indications.

This article is part of the Topical Collection on *Emergency Medicine*

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Acute Respiratory Failure in AHF Syndromes

Although nearly 90% of acute heart failure (AHF) patients complain of dyspnea [3] and most of them show some degree of lung congestion [4], less than half present ARF with hypoxemia [5]. Among the different AHF scenarios [4, 6, 7], significant ARF is essentially seen in ACPE, in cardiogenic shock (CS), and in cases of AHF associated with other lung alterations.

Acute Cardiogenic Pulmonary Edema Acute cardiogenic pulmonary edema is produced by a rapid increase in pulmonary capillary hydrostatic pressure with fluid filtration that exceeds the lymphatic interstitial drainage capacity [8]. ARF occurs when an excess of interstitial and alveoli flooding results in a significant reduction of gas exchange and a concomitant shunt effect. Therefore, the key findings are the combination of ARF (hypoxemia and/or hypercapnia) with significant

Table 1 Main indications for NIV in acute respiratory failure

	Certainty of evidence	Recommendation
Hypercapnia with COPD exacerbation	++++	Strong
Cardiogenic pulmonary edema	+++	Strong
Immunocompromised	+++	Conditional
Post-operative patients	+++	Conditional
Palliative care	+++	Conditional
Trauma	+++	Conditional
Prevention of post-extubation failure in high-risk patients	++	Conditional
Weaning in hypercapnic patients	+++	Conditional

respiratory distress (tachypnea and increased work of breathing). Criteria for the diagnosis have been recently published [9••] (Table 2) [10, 11]. Patients frequently present hypertension on admission. Hypertensive ACPE more frequently have preserved left ventricular (LV) ejection fraction (EF), hypercapnia, and better prognosis than those with lower blood pressure (BP) [12]. Some of them may have a very rapid presentation, "flash ACPE," without previous accumulation of fluids and mostly diastolic LV dysfunction [13].

Table 2 Diagnostic criteria for acute pulmonary edema

Clinical criteria (all of them)
• Acute respiratory distress[a]
• Physical examination[b]
• Orthopnea
• Respiratory failure[c]
Diagnostic Confirmation (at least two of the following)
• Clear signs of pulmonary congestion on chest radiography or CT scan
• Multiple B-lines on lung ultrasound[d]
• Elevated pulmonary capillary pressure on catheterization
• Increased total lung water on pulse contour and thermodilution analysis system
• Signs of elevated filling pressures on echocardiography[e]
• Significant elevation of natriuretic peptides[f]

RR respiratory rate, *CT* computer tomography

[a] Respiratory distress: acute increase in the work of breathing (assessed by single inspection), significant tachypnea (RR > 25breaths/min)[1] , may be with the use of accessory muscles or abdominal paradox

[b] Crackles +/– wheezes over the lungs, third heart sound[2]

[c] Oxygen saturation on room air by pulse-oximetry (SpO_2) < 90%. Arterial blood gases may also show PaO2 < 60 mmHg, PaCO2 > 45 mmHg, or $PaO_2/FiO_2 < 300$mHg

[d] ≥ 3 B-lines in 2 chest zones on each hemithorax (references 7,8)

[e] E/E′ > 15. Other parameters of elevated left atrial pressure may also be considered

[f] Nt-ProBNP >900 (or >1800 in older than 75)

[1] RR may be lower, and orthopnea may be absent in obtunded patients

[2] Patients with low systolic blood pressure (i.e., < 90 mmHg) may be considered to have cardiogenic shock rather than ACPE

[3] In "flash pulmonary edema," BNP may be lower

(Taken from reference 9 in the text)

Cardiogenic Shock Patients have significant ARF for several reasons. There are pulmonary edema and ventilation-perfusion inequality due to an increase in pulmonary dead space due to a fall of lung perfusion. In addition, the circulatory failure reduces the central venous oxygen content (SvO_2) secondary to a greater tissue extraction.

Other Scenarios Patients with AHF may also have COPD, pneumonia, asthma, large pleural effusion, pulmonary embolism, or atelectasis, which may precipitate or aggravate ARF. In cases with isolated right ventricular (RV) failure, ARF is mainly seen in cases of acute pulmonary thromboembolism or decompensated chronic pulmonary hypertension.

Effect of NIV in AHF

Positive airway pressure increases oxygenation and decreases the work of breathing [14]. Ventilatory support additionally improves alveolar ventilation with further decreases in the work of breathing and carbon dioxide level [15]. NIV has shown to produce faster improvement of the ARF, shortening the critical phase, decreasing the risk of endotracheal intubation, and, potentially, reducing mortality in high-risk patients. However, in patients with isolated RV failure, positive pressure should be avoided because it increases RV afterload, impairing RV function [16].

Modalities of NIV

The main modalities in AHF are continuous positive airway pressure (CPAP), noninvasive pressure support ventilation (NIPSV), and, more recently, high-flow nasal cannula (HFNC).

CPAP CPAP is the simplest technique and consists of the application of a high flow in the mask exceeding the breathing demand of the patients, leading to a continuous positive pressure into the lungs. It can be applied without the aid of a ventilator, by using a source of air or oxygen and a mask equipped with PEEP valve, or with the Boussignac system [17].

NIPSV This modality requires a ventilator. It is programmed with two levels of pressure: expiratory pressure (EPAP) or positive end-expiratory pressure (PEEP), and inspiratory pressure (IPAP), which is obtained with pressure support. It is also called noninvasive intermittent positive pressure ventilation (NIPPV), or sometimes bilevel or BiPAP. This method requires some experience for setting the ventilator to the changing needs of the patient. Adequate synchrony is essential. The respiratory rate is not pre-set and depends exclusively on the patient.

High-Flow Nasal Cannula This system delivers a heated and humidified high flow (up to 60–80 L/min) that exceeds patients' spontaneous inspiratory demand through a nasal cannula adjusted to the nostrils (Fig. 1). The technique provides three beneficial effects: first, a low level of PEEP (< 5 cmH_2O) that requires closed mouth [18] which could be a disadvantage in cases of severe dyspnea like ACPE where the patients generally breath by the mouth; second, a washout effect in nasopharyngeal, which may reduce CO2 in the dead space, like tracheal gas insufflation; third, a reduction of the upper airway resistance [19].

Evidence for the Use of NIV in AHF Syndromes

CPAP and NIPSV in ACPE

Several small randomized trials performed at the end of the 1980s using CPAP showed faster improvement of ARF than COT [20, 21] with a reduction in the endotracheal intubation (EI) rate [21]. The first randomized trial of NIPSV in ACPE, published in 2000, showed similar results [22]. Several meta-analyses [23–25] revealed both techniques reduced the EI rate and tended to reduce mortality as compared with COT, a trend that was statistically significant for CPAP. However, in 2008, a large randomized trial (3-CPO) including 1069 patients with acidotic (pH < 7.35) ACPE assigned to CPAP, NIPSV, or COT [26] showed no difference in mortality, although both NIV techniques improved respiratory distress faster than COT. Differences in the population [27] and a high intergroup crossover rate using NIV as a rescue therapy could explain the discrepancy with meta-analyses. However, subsequent meta-analyses including this trial showed that both modalities reduced the EI rate and still, CPAP reduced mortality (relative risk 0.64 [95% CI, 0.44 to 0.92]), mainly in high-risk patients with acute coronary syndromes [28, 29].

Several studies have shown beneficial effects of the early application of CPAP in the pre-hospital care of patients with ACPE, improving ARF faster than COT, with a tendency to reduce the EI rate [30–32]. Because CPAP does not require special training or expensive equipment, it can be the recommended technique in this setting.

Fig. 1 High-flow nasal cannula administered through a ventilator

HFNC in AHF

In adults, HFNC has recently shown to be effective in the weaning of patients from mechanical ventilation [33, 34] and in hypoxemic RF from different etiologies [35].

In AHF, the data is scarce, with only one small randomized study published in 2017 showing a greater decrease in respiratory rate after 60 min without differences in all other parameters [36••]. HFNC has been used in class III patients [37] and in AHF patients needing prolonged ventilation support [38]. HFNC seems to be better tolerated than NIPSV [39] and subsequently is showing an expansion of the technique [40•].

Other Modalities of NIV in AHF

Other techniques like *proportional assist ventilation* or *adapted servoventilation* have been used in some trials in patients with ACPE without showing an impact in the main outcomes [41, 42].

Other Scenarios of AHF Where NIV Can Be Used

NIV is not indicated in patients with AHF not showing significant respiratory distress and ARF, which are most of the patients with AHF. As aforementioned, positive pressure should be avoided in patients with isolated RV failure [16]. However, in cases with ARF of mixed origin (COPD with pulmonary edema), NIV may be especially useful because it may benefit both underlying conditions [43].

NIV and Myocardial Infarction

Two trials in the 1990s suggested that NIPSV could increase the risk of acute myocardial infarction (AMI) [44, 45]. However, no other trial has reproduced these results, including randomized studies specifically designed to assess this issue [46–48]. One randomized trial analyzed the effect of CPAP in patients with AMI showing advantages over COT [49]. In addition, in 3-CPO, NIV was safely used in patients with AMI, who accounted for nearly 50% of the population enrolled, with no differences in the incidence of AMI between groups [26].

NIV in Cardiogenic Shock

There are no studies analyzing NIV in CS. However, in the international registry "Cardshock study" [50], NIV was used in nearly 13% of the patients, after correction of hypotension, avoiding EI in the majority [51••]. Therefore, although the indication of NIV remains limited in hypotensive patients, it may be cautiously considered in selected CS patients.

CPAP or NIPSV

Although theoretically NIPSV should be superior to CPAP because it provides inspiratory help for breathing, no trials or meta-analyses have demonstrated a clear advantage of one technique over the other for important outcomes but patients treated with NIPSV have shown faster improvement in several physiological variables [45, 52, 53]. In several case series of patients with ACPE, NIPSV was most clearly effective in those with hypercapnia [22, 54]. In addition, in patients with ARF from different etiologies, CPAP has been most often used in hypoxemic patients, while NIPSV may be more effective in those with hypercapnia. Consequently, although either technique can be used as a first-line treatment in ACPE, it seems reasonable to prefer NIPSV in patients with severe hypercapnia, including those with COPD.

Recommendations for NIV in AHF

NIV has shown an expansion in the last decades, particularly in ACPE [55•]; however, there is a wide variation among centers, from nearly 0 to almost 100% [56]. ACPE is currently the second most frequent indication for NIV [57]. Data from 2430 patients who required ventilatory support in the ADHERE registry supported the use of NIV to avoid EI [15]. The latest ESC guidelines gave NIV a class IIa recommendation with level of evidence B [58, 59] in patients with AHF and respiratory distress (respiratory rate > 25 breaths/min, SpO2 < 90%). The NICE guidelines in AHF recommended NIV in patients with ACPE with severe dyspnea and acidemia [60]. Finally, recent guidelines from ERC/ATS recommended NIV, either bilevel NIV or CPAP, for patients with ARF due to ACPE and suggested it in the pre-hospital setting [2••].

Figure 2 shows a recently proposed algorithm for the use of NIV in the management of patients with AHF [61–63].

How to Use NIV

It is important to choose the appropriate interface. In order to avoid leaks, a tight seal between the patient's face and the device is essential. There are different types of interfaces, mainly masks (oro-nasal, total-face, full-face, and nasal), helmet, or nasal cannulas (see Fig. 3) [64]. Other interfaces like nasal pillows, mouthpieces, or laryngeal masks are not considered in AHF. Total-face mask and helmet provide better patients' adaptation.

There are three types of ventilators: portable, transport, and ICU-ventilators, all equipped with specific settings for CPAP and NIPSV. The latest generation of ventilators are equipped with display monitoring, alarm setting, leakage compensation, different triggers, cycling, and flow ramp control, which allow the achievement of a better patient-ventilator synchrony [65]. Skin protectors and heat humidification or heat and moisture exchangers may be useful [66].

Before starting the technique, contraindications for NIV should be considered (Table 3).

For NIPSV, low levels of pressure (IPAP 10–12 cmH_2O/EPAP 3–4 cmH_2O) are recommended to start with, increasing PS progressively according to how well the patient has adapted, ensuring expired tidal volumes > 4–6 mL/kg (pressure can be lower in COPD patients). High pressures may cause excessive air leakage, asynchrony (especially in patients with high RR), and discomfort.

When using CPAP, it is advisable to start with 5 cmH_2O and increase to 7.5 or 10 cmH_2O, according to the response.

When using HFNC in critically ill patients, it is often started with a F_IO_2 of 100% and the maximum tolerated flow up to 50 L/min, titrating later F_IO_2 and flow rate according to SpO_2 [18] and patient's demand. In less severe cases, it is usually started with lower flow and F_IO_2.

During the application of NIV, besides standard physiologic parameters, RR (patient's effort), oxygen saturation (minimal required F_IO_2), and pH/$PaCO_2$ (to assess efficacy) should be monitored. General reassessment is recommended at 60 and/or 90–120 min. The key issue is optimal synchronization with the ventilator [67–69]. Excessive leakage is often involved in cases of asynchrony, which may be reduced by adjusting the mask, shortening inspiration time, giving sedation, reducing PS, or changing inspiratory and expiratory triggers (when available). In general, a leak < 0.4 L/s may be tolerated (< 25 L/min).

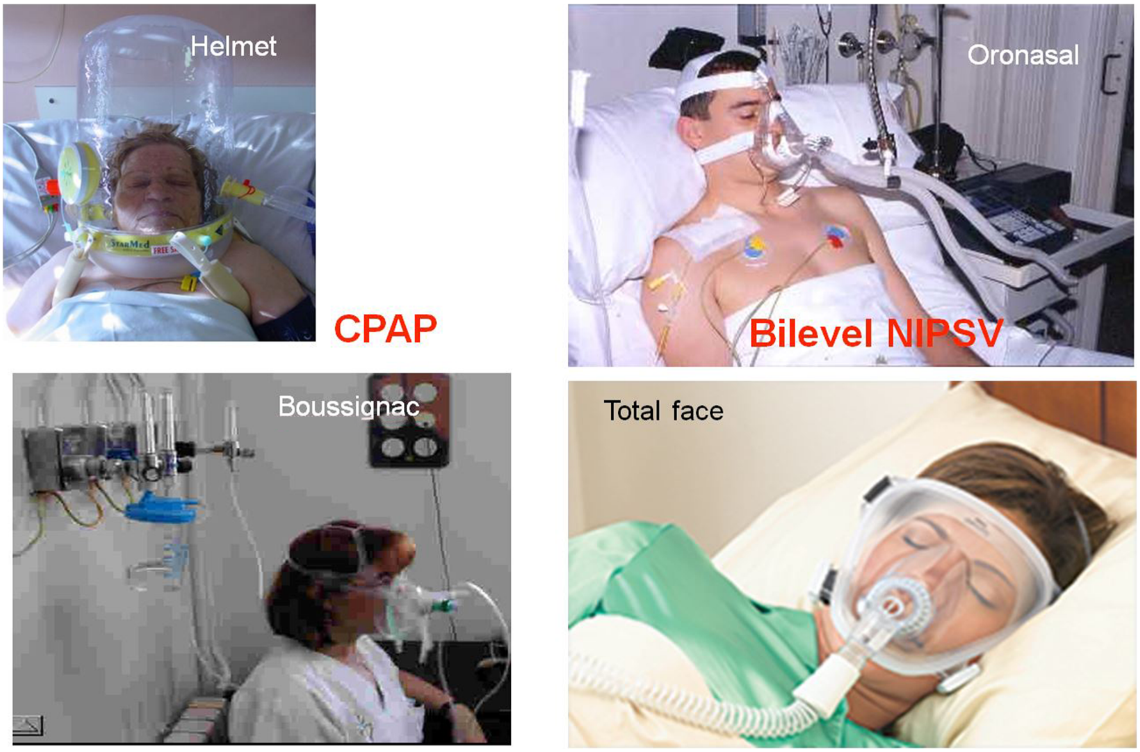

Fig. 2 Algorithm for the use of NIV in AHF (taken from reference 9)

Sedation Mild sedation is used nearly in 20% of the patients treated with NIV to decrease RR and intolerance [70–72]. It should be used only when patients show poor synchrony with the ventilator after nonpharmacological approaches have failed [73, 74]. Minimal intermittent doses of a single drug may be preferable to continuous infusions or combinations of

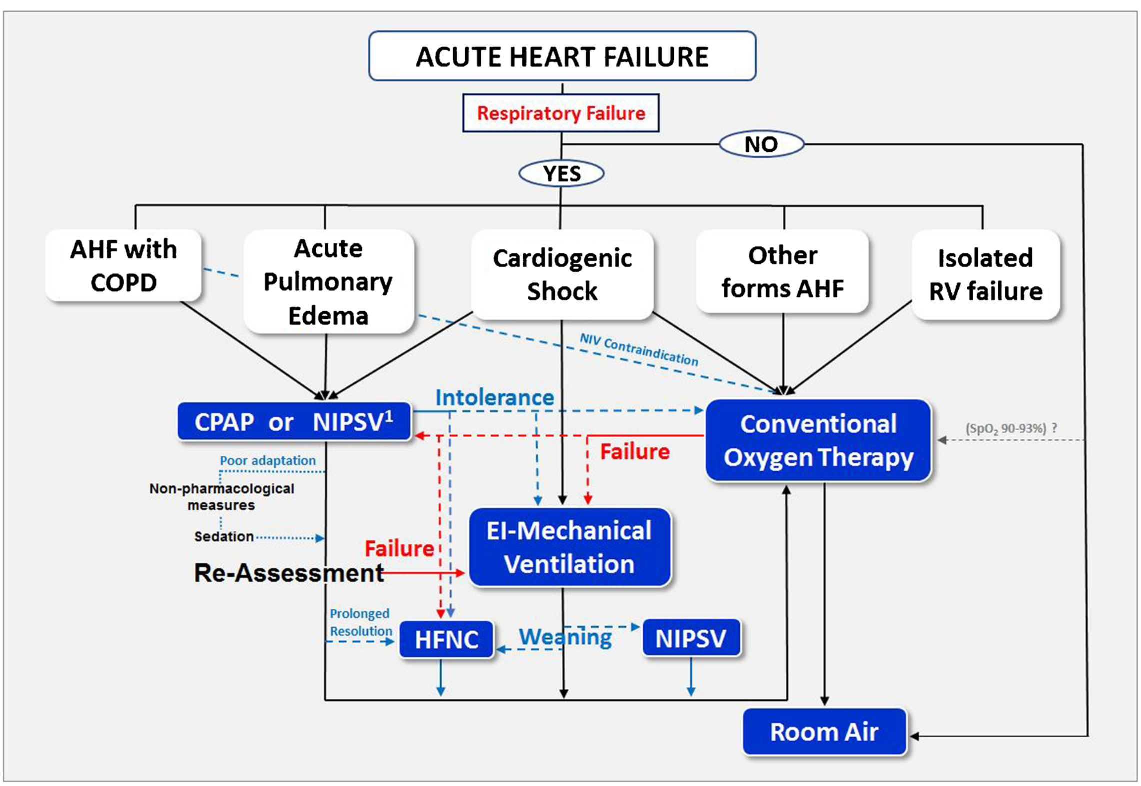

Fig. 3 Different interfaces used to treat patients with AHF

Table 3 Contraindications of NIV

Absolute	Cardiac or respiratory arrest
	Anatomical abnormality (unable to fit the interface)
	Inability to keep patent airway (uncontrolled agitation, coma[1], or obtunded mental status)
	Refractory hypotension
Relative	Mild agitation or poor cooperation
	Mild hypotension
	Upper gastrointestinal hemorrhage or vomiting
	Inability to expectorate copious secretions
	Recent frail upper gastrointestinal or airway surgery
	Severe multi-organ failure
	Isolated right ventricular failure

[1] Modalities like NIV with volume controlled or "average volume assured pressure support" have been used in hypercapnic encephalopathy

different agents [62, 63]. Opiods (morphine, remifentanil), propofol, midazolam, and more recently dexmedetomidine have been used in this context [63, 64].

NIV is usually stopped when a satisfactory recovery has been achieved (usually 2–5 h in ACPE) or conversely, there are signs of NIV failure, requiring EI (Table 4). With $F_IO_2 < 0.5$ and flow rate < 20 L/m, HFNC can be safely replaced by COT.

Conclusions

In patients with ACPE, NIV improves faster and more effectively respiratory distress than conventional oxygen therapy, reducing the need for EI and mortality in severe cases as are those with ACS. Therefore, it should be used as a first-line therapy in all patients with ACPE. It can also be used in some

Table 4 Risk factors for NIV failure and criteria for endotracheal intubation

Risk factors for NIV failure	
Before initiation:	Lung infection
	Altered mental status
	Hypotension
	High severity scores
	Copious secretions
	Extremely high respiratory rate
	Severe hypoxemia in spite of high F_IO_2
After initiation:	Inappropriate ventilator settings
	Nonfitting the interface
	Excessive air leakage
	Asynchrony with the ventilator*
	Poor tolerance to NIV
After 60–90 min:	No reduction in respiratory rate or carbon dioxide
	No improvement in pH or oxygenation (↓SpO_2 or ↓PaO_2/FiO_2)
	Signs of fatigue
	Neurological or underlying disease impairment
Criteria for endotracheal intubation	
Cardiac or respiratory arrest	
Progressive worsening of altered mental status	
Progressive worsening of pH, $PaCO_2$, or PaO_2 despite NIV	
Progressive signs of fatigue during NIV	
Need to protect the airway	
Persistent hemodynamic instability	
Agitation or intolerance to NIV with progressive respiratory failure	

patients with cardiogenic shock without refractory hypotension and in patients with AHF associated with lung disease showing ARF. CPAP is cheaper and easy to use, and it is mainly indicated in low-equipped areas, whereas NIPSV is preferred in cases with significant hypercapnia, although requires some expertise and adequate setting. HFNC may be considered in patients with ARF who can keep the mouth closed and require prolonged ventilation or not tolerating other forms of NIPSV.

Compliance with Ethical Standards

Conflict of Interest The author declares that he has no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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