# Noninvasive ventilation: practical advice

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**Purpose of review**
This critical review discusses the key points that would be of practical help for the clinician who applies noninvasive ventilation (NIV) for treatment of patients with acute respiratory failure (ARF).

**Recent findings**
In recent years, the growing role of NIV in the acute care setting has led to the development of technical innovations to overcome the problems related to gas leakage and dead space. A considerable amount of research has been conducted to improve the quality of the devices as well as optimize ventilation modes used to administer NIV. As a result, also mechanical ventilators have been implemented with modalities aimed at delivering NIV.

**Summary**
The success of NIV in patients with ARF depends on several factors, including the skills of the clinician, selection of patient, choice of interface, selection of ventilation mode and ventilator setting, monitoring, and the motivation of the patient. Recent advances in the understanding of the physiological aspects of using NIV through different interfaces and ventilator settings have led to improve patient–machine interaction, enhancing favorable NIV outcome.

**Keywords**
acute respiratory failure, equipment and supplies, noninvasive ventilation

## INTRODUCTION

Noninvasive ventilation (NIV), the provision of ventilatory assistance by means of techniques that do not bypass the upper airway, has assumed a central role in the treatment of patients with both hypoxemic and hypercapnic acute respiratory failure (ARF) [1,2▪]. The most convincing evidence supporting NIV as a first-line treatment for ARF has been shown in selected patients with either a severe chronic obstructive pulmonary disease (COPD) exacerbation or acute cardiogenic pulmonary edema (CPE) [1,2▪]. The main theoretical advantage of NIV is avoiding the side effects and complications related to endotracheal intubation (ETI) [3], improving patient comfort and preserving airway defense mechanisms.

Once the decision to start NIV has been taken, it is essential to choose a proper NIV interface and ventilation mode, and plan a close monitoring in an adequate hospital location. This overview reports on the use of NIV in patients with ARF or who are at risk of ARF, focusing on the practical aspects of using NIV in the acute care setting. In particular, the areas covered here include criteria for patient selection, choice of interface, ventilation modes, and monitoring.

## INTERFACES

Interfaces connect ventilator tubing to the patient, allowing the delivery of pressurized gas into the airway during NIV. Currently available interfaces include nasal and face masks, helmet, nasal pillows, and mouthpieces [4,5▪] (Fig. 1). The choice of an appropriate interface that fits properly is a key issue for the success of NIV.

Data obtained from physiologic evaluations of NIV delivered by different types of interfaces have been useful to improve devices and patient–ventilator synchrony. A recent study on 60 patients undergoing NIV to treat ARF found total face mask to be more comfortable compared with traditional oronasal mask, allowing patients to tolerate NIV for a longer period [6▪]. In this study, the rate of ETI was

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## KEY POINTS

- Identification of predictors of success or failure may help in recognizing patients who are likely to benefit from NIV and exclude those for whom the technique would be unsafe or ineffective, avoiding dangerous delays before endotracheal intubation.
- Choosing proper interface and ventilation mode, and assuring close monitoring in an adequate hospital location are of primary importance for the success of NIV.
- Patient motivation is a critical issue during NIV to enhance favorable outcomes.

similar with either interface, as was the evolution of clinical parameters, blood gases, and levels of ventilatory support. In clinical practice, alternating different interfaces may be the best strategy to improve patients' tolerance.

## VENTILATION MODE AND VENTILATOR SETTING

Choosing the right ventilation mode is crucial for achieving physiological and clinical benefit during NIV. Each ventilation mode has theoretical advantages and limitations.

Spontaneously breathing patients with respiratory failure of various causes may benefit from continuous positive airway pressure (CPAP) to correct hypoxemia. In acute CPE, CPAP can result in early physiological improvement and reduce the need for intubation and mortality [7,8]. A growing body of evidence supports the benefit of NIV techniques in the management of CPE, and their use as a first-line intervention in CPE patients is becoming more widely used. Although both CPAP and noninvasive intermittent positive pressure ventilation with or without positive end-expiratory pressure (PEEP) showed similar efficacy in decreasing the need for ETI and mortality without increasing the risk of acute myocardial infarction, CPAP could be considered the preferred mode in CPE patients, as it is cheaper and easier to use in various clinical settings.

Selection of ventilation mode may have significant impact in reducing the work of breathing in patients with ARF. In a physiologic study [9] performed in hypoxemic patients with ARF, noninvasive pressure support ventilation (PSV) combined with PEEP improved dyspnea and gas exchange, and lowered neuromuscular drive and inspiratory muscle effort. In these patients, CPAP used alone improved oxygenation but failed to unload the respiratory muscles.

As in the intubated mechanically ventilated patients, application of external PEEP is effective in counterbalancing the effects of dynamic hyperinflation in patients with acute hypercapnic exacerbations of COPD. In these patients, NIV delivered through different ventilator modes can provide respiratory muscle rest and improve respiratory physiologic parameters. No difference in clinical outcome or arterial blood gases between patients ventilated in assist control ventilation (ACV) and PSV modes has been found, even though PSV is in general better accepted by the patients and associated with fewer side effects in comparison with ACV mode [10].

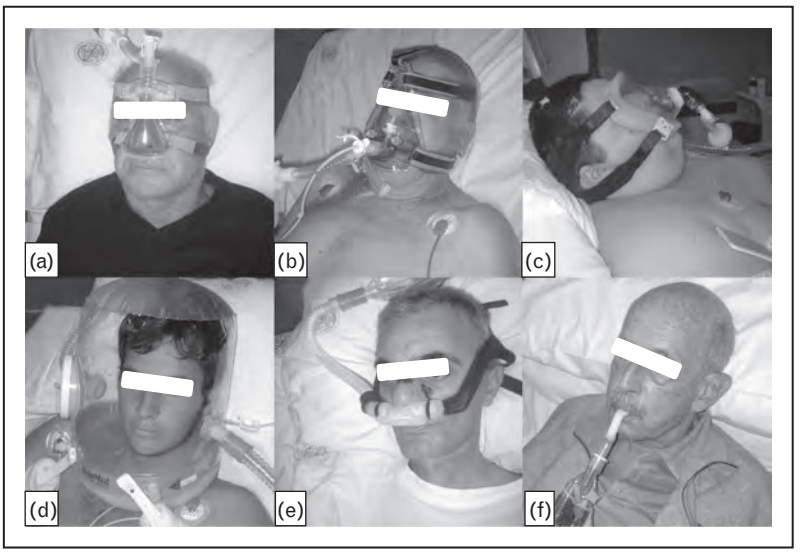


**FIGURE 1.** Interfaces used to deliver noninvasive ventilation. (a) nasal mask; (b) oronasal mask; (c) total face mask; (d) helmet; (e) nasal pillows; (f) mouthpiece. Photographs printed with the permission of the patients.

Volume control ventilation can be useful in patients with changing respiratory impedance. It can be preferred for those patients with severe chest wall deformity or obesity who may need higher inflation pressures.

Triggering systems are critical to the success of NIV in both assist and control modes. During assisted ventilation, flow triggering reduces breathing effort more effectively as compared with pressure triggering, obtaining a better patient–ventilator interaction [11].

There are no clear recommendations or specific requirements from bench studies on the performance of NIV ventilators and interfaces [12▪]. In the absence of specific recommendations, the choice of ventilation mode should be dictated by factors such as personal experience, clinical setting, cause and severity of the pathologic process responsible for ARF. However assisted modes, particularly PSV, are more often used. As regard to pressure-targeted ventilation, it is suggested starting at low pressures to facilitate patient tolerance (appropriate initial pressures are a CPAP of 3–5 cm $H_2O$ and an inspiratory pressure of 8–12 cm $H_2O$ above CPAP) and, if necessary, gradually increase pressures as tolerated to obtain alleviation of dyspnea, decreased respiratory rate, adequate exhaled tidal volume, and good patient–ventilator interaction. Pressures commonly used to administer CPAP in patients with ARF range from 5 to 12 cm $H_2O$. In patients with hypoxemic ARF and bilateral pulmonary infiltrates, undergoing 10 cm $H_2O$ CPAP delivered via a helmet, adding a sigh with 25 cm $H_2O$ for 8 s, once a minute, improved oxygenation [13▪]. Oxygen supplementation should be targeted to achieve an oxygen saturation above 92% or between 85 and 90% in patients at risk of worsening hypercapnia. A modality that provides a backup rate is necessary for patients with inadequate ventilatory drive.

## CARBON DIOXIDE REBREATHING

NIV interfaces behave differently in respect to carbon dioxide ($CO_2$) exchange. The face mask constitutes an additional mechanical dead space, and its effect on $CO_2$ rebreathing is proportional to its internal volume [14]. As this volume is small compared with the patient's tidal volume, the amount of $CO_2$ that is rebreathed is also small. By contrast, $CO_2$ exchange during helmet ventilation follows the model of a semi-closed environment with an air exchange system [15].

During helmet CPAP, the inspired partial pressure of $CO_2$ is independent from the level of CPAP and inversely correlated to the fresh gas flow delivered [16]. Gas flows above 45–60 l/min render the $CO_2$ rebreathing clinically irrelevant [16]. As compared to helmet CPAP, helmet-delivered NIV in PSV mode can provide a more efficient $CO_2$ washout, probably due to the phasic administration of inspiratory flow [17]. In addition, the analysis of $CO_2$ rebreathing during helmet-delivered PSV does not show significant reductions in inspired partial pressure of $CO_2$ by increasing the level of inspiratory assistance [17]. In a sophisticated computational fluid dynamic model to evaluate the effective dead space between different NIV interfaces, Fodil *et al.* [18▪▪] showed that the dead space between the face mask and the helmet differed only modestly (110–370 ml), whereas their internal volumes were markedly different (110–10 000 ml), thus confirming that effective dead space is not related to the internal gas volume included inside the interface. To minimize $CO_2$ rebreathing during disconnection of the fresh gas supply while performing helmet CPAP, it has been advised to utilize large helmets with a large antisuffocation valve [19▪].

## ASYNCHRONY

Optimal synchrony between the patient's spontaneous breathing activity and the ventilator parameters is one of the key factors determining tolerance to NIV. The lack of an optimal patient–ventilator interaction can lead to an increase in the work of breathing and patient discomfort [20]. Patient–ventilator asynchrony may be determined by a number of events including ineffective triggering, double-triggering, auto-triggering, premature cycling, and delayed cycling.

When PSV is used as a noninvasive ventilatory assistance mode, some forms of patient–ventilator asynchrony may occur, causing breathing discomfort. In a prospective multicenter observation study on ARF patients receiving NIV via a face mask in PSV mode, the level of pressure support and the magnitude of leaks were significantly associated with asynchrony [21]. Indeed, eventual air leaks during noninvasive PSV may impede the inspiratory flow decay required to open the expiratory valve, thereby prolonging inspiratory flow. In these circumstances, air leaks should be minimized by optimizing the fitting or size of the interface, or even switching to another type of interface. To reduce leaks, it may also be helpful to decrease ventilator pressure settings as much as allowed by clinical parameters. In older machines, when an air leak occurs, an option to obtain a better patient–ventilator interaction is to select pressure-limited, time-cycled ventilation modes, or even PSV mode with a maximal inspiratory time. With ventilators that allow changing the cycling off criteria (expiratory

trigger), raising the cycling off airflow threshold (i.e., the percentage of peak inspiratory flow at which transition from inspiration to expiration occurs) can activate an earlier switchover to expiration, thus avoiding prolonged insufflations and patient–ventilator asynchrony.

In the presence of significant air leaks, pressure-targeted modes are preferred to deliver NIV as they can maintain delivered tidal volume better than volume-targeted modes [22]. In new ventilators, a NIV algorithm, usually referred to as 'NIV mode', measures and compensates leaks in order to minimize their detrimental impact on patient–machine synchrony [23,24▪]. Neurally adjusted ventilatory assist (NAVA) seems to be a very promising mode to help improve adaptation during NIV [25▪▪–27▪▪].

An optimal ventilator setting that also takes into account the type of interface used to deliver NIV is crucial in determining patient–ventilator interaction. It has been advised that the highest PEEP and pressure support levels clinically indicated and tolerated by the patient should be applied when NIV is administered with the helmet, in order to increase the elastance of the system, enhancing the trigger sensitivity [28]. Vargas *et al.* [29] suggested that increasing both PEEP and pressure support level and using the highest pressurization rate may be suitable when providing NIV through this interface. In their study, the helmet with the same settings as the face mask was associated with less inspiratory-muscle unloading and with worse patient–ventilator asynchrony. In contrast, specific settings with a fast ramp and higher pressures provided results similar to the mask, ameliorating the inspiratory trigger delay, without discomfort.

There is a wide variability in the estimation of leaks and tidal volume among current bilevel positive-pressure systems used for home mechanical ventilation [30▪].

## PATIENT SELECTION

In the acute care setting, NIV should be considered early when patients develop signs of incipient respiratory failure. Clinical indicators of need for ventilatory assistance include dyspnea, tachypnea, accessory muscle use, paradoxical abdominal breathing, and gas exchange deterioration.

To date, the best-established indication for NIV is ARF related to COPD exacerbation or CPE. Various categories of hypoxemic non-COPD patients, particularly those with immunosuppression or in the postoperative setting may also benefit from NIV, providing they are managed in centers with extensive experience. NIV is also frequently proposed to assist the ventilator-weaning process in selected patients under invasive mechanical ventilation.

NIV should be avoided in the following conditions:

(1) coma, seizures or severe central neurological disturbances;
(2) inability to protect the airway or clear respiratory secretions;
(3) unstable hemodynamic conditions (blood pressure or rhythm instability);
(4) upper airway obstruction;
(5) severe upper gastrointestinal bleeding;
(6) recent facial surgery, trauma, burns, deformity, or inability to fit the interface (unless a helmet is used);
(7) recent gastro-esophageal surgery;
(8) undrained pneumothorax;
(9) vomiting.

Patients with altered levels of consciousness due to hypercapnic ARF associated with COPD exacerbation are exposed to high risk of NIV failure, but a cautious attempt with NIV may be performed in these patients, provided that a careful monitoring is available and prompt ETI is accessible [31]. In treatment-responsive patients, recovery of consciousness occurs within 45–60 min after NIV application.

## PREDICTORS OF NONINVASIVE VENTILATION SUCCESS OR FAILURE

Identification of predictors of success or failure may help in recognizing patients who are likely to benefit from NIV and exclude those for whom NIV would be unsafe or ineffective, avoiding dangerous delays before ETI. Moreover, knowing the factors affecting the likelihood of success of NIV may be useful to decide the duration of NIV trial.

Predictors of NIV failure observed in COPD patients with ARF are the following:

(1) lower arterial pH at baseline [32,33];
(2) greater severity of illness, as indicated by Acute Physiology and Chronic Health Evaluation (APACHE) II score [34];
(3) inability to coordinate with the ventilator [34];
(4) inability to minimize the amount of mouth leak with nasal mask ventilation [34];
(5) less efficient or less rapid correction of hypercapnia, pH, or tachypnea in the early hours [34];
(6) functional limitations caused by COPD before ICU admission, evaluated using a score correlated to home activities of daily living (ADL) [33];

(7) higher number of medical complications (particularly hyperglycemia) on ICU admission [33].

Predictors of NIV failure observed in hypoxemic patients with ARF are the following:

(1) higher severity score [Simplified Acute Physiology Score (SAPS) II ≥35 [35] / SAPS II >34 [36]/higher SAPS II [37▪]]
(2) older age (> 40 years) [35];
(3) presence of acute respiratory distress syndrome or community-acquired pneumonia [35,37▪,38];
(4) failure to improve oxygenation after 1 h of treatment ($PaO_2$:$FiO_2$ ≤146 [35]/$PaO_2$:$FiO_2$ ≤175 [36]);
(5) higher respiratory rate under NIV [38];
(6) need for vasopressors [38];
(7) need for renal replacement therapy [38].

## INITIAL APPROACH TO THE PATIENT

Once it has been decided to start NIV, the initial approach should consist in illustrating the various pieces of equipment to the patient and fitting the NIV interface. Patients should be motivated and reassured by the clinician, instructed to coordinate their breathing with the ventilator, and encouraged to communicate any discomfort or fears. Although sedation is infrequently required during NIV, caution is advised if benzodiazepines or opiates are administered to prevent hypoventilation or loss of airway protection. After an initial period of continuous administration, NIV can be intermittently applied, with variable periods of discontinuation, depending on the patient's respiratory conditions. Collaboration among caregivers including physicians, respiratory therapists, and nurses, is critical to the success of NIV (Fig. 2).

## MONITORING

Monitoring of patients undergoing NIV has the aim to determine whether NIV is being performed safely and effectively. NIV should be initiated in a protected environment such as the ICU or the step-down unit. The early use of NIV for less acutely ill patients with COPD on a medical ward seems to be feasible, but if pH is lower than 7.30, admission to the ICU is highly recommended [39]. The ICU should not be the place for starting palliative care or for limiting life-sustaining treatments in patients who have no available therapeutic options. Alike, in selected situations in which the prognosis is unclear, a full code management including all supportive care, such as mechanical ventilation, vasoactive

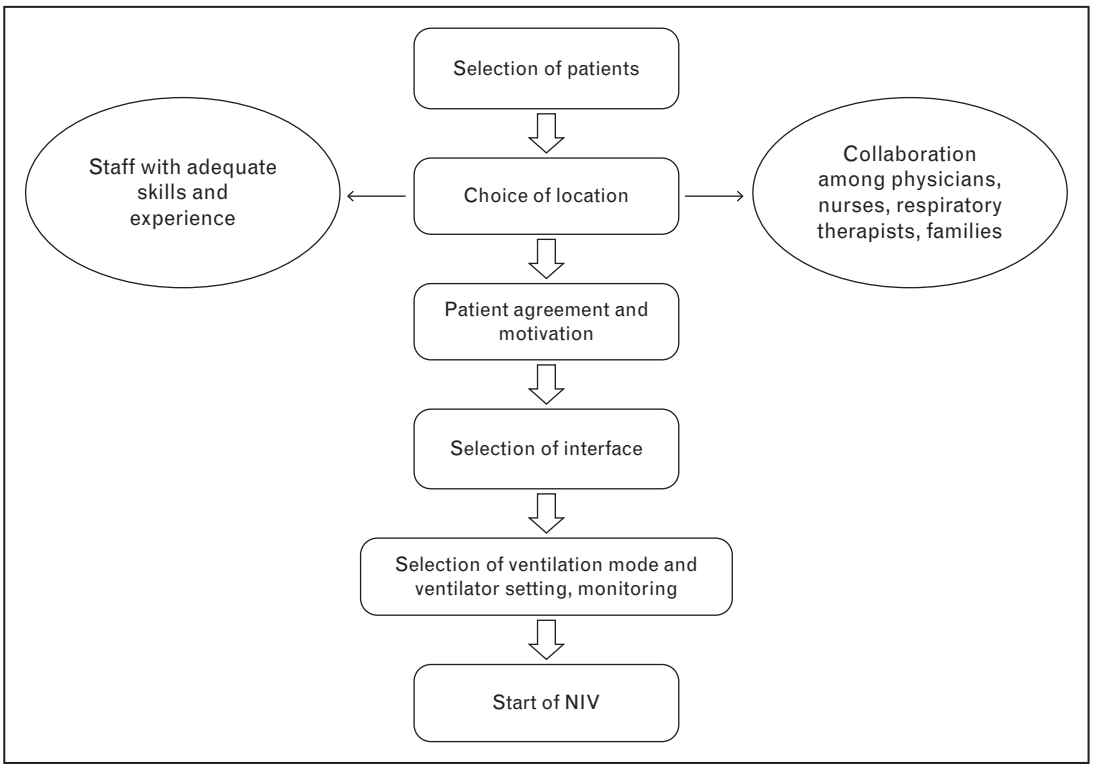


**FIGURE 2.** Sequential steps for delivering noninvasive ventilation in patients with acute respiratory failure.

agents, and renal replacement therapy, should be guaranteed. In these cases an ICU trial, that is, an unlimited treatment for a limited period of at least 3 days before making end-of-life decisions, may be considered.

Monitoring of patients receiving NIV in the acute care setting includes:

(1) level of consciousness;
(2) comfort;
(3) chest wall motion;
(4) accessory muscle recruitment;
(5) patient–ventilator synchrony;
(6) respiratory rate;
(7) exhaled tidal volume;
(8) flow and pressure waveforms;
(9) heart rate;
(10) blood pressure;
(11) continuous electrocardiography;
(12) continuous oximetry;
(13) arterial blood gas at baseline, after 1–2 h, and as clinically indicated.

The potential clinical benefit of close observation of ventilator graphics in patients under NIV has been recently evaluated in patients with acute exacerbation of COPD. The analysis of flow and pressure waveforms on the ventilator screen led to a more rapid normalization of pH at 2 h, a significant improvement of the patient's tolerance and a higher decrease of arterial partial pressure of $CO_2$ ($PaCO_2$) at 2 and 6 h [40▪].

ETI must be rapidly assured, when indicated. Criteria used to perform ETI in ARF patients undergoing NIV are as follows:

(1) patient intolerance;
(2) inability to improve gas exchange;
(3) inability to improve dyspnea or respiratory muscle fatigue;
(4) appearance of severe hemodynamic or electrocardiographic instability;
(5) severe neurological deterioration.

## HUMIDIFICATION

Humidification and warming of the inspired gases during NIV may be required to prevent the detrimental effects of cool, dry gases on the tracheobronchial epithelium. Two humidifying devices are commonly used with ICU ventilators: heated humidifiers, and heat and moisture exchangers (HMEs). The latter are most commonly used due to their simplicity and cost-effectiveness. However, because the HMEs are placed between the Y-piece and the patient, they add a substantial amount of dead space, compared with a heated humidifier. In addition, HMEs may increase flow resistance [41].

Heated humidification during NIV in patients with ARF can minimize work of breathing and improve $CO_2$ clearance. Lellouche *et al.* [42] showed that use of an HME greatly increased work of breathing in comparison with heated humidifier during NIV delivered through a face mask in nine patients with hypercapnic ARF. In these patients, alveolar ventilation was maintained only at the expense of a greater work of breathing with the HME compared with the heated humidifier. In another study on 24 patients with ARF under face mask NIV, Jaber *et al.* [43] found that HME was associated with significantly higher $PaCO_2$ compared with heated humidifier.

Unlike the acute care setting, no firm conclusion can be drawn on the type of humidification system to be used in COPD patients under long-term NIV. A randomized crossover 12-month study on 16 COPD patients receiving NIV with either heated humidifier or HME, showed that compliance with treatment and occurrence of infections were similar with heated humidifier and HME, albeit patients with heated humidifier showed less dryness of the throat [44]. Of note, at the end of this study, a higher number of patients decided to continue NIV with heated humidifier.

## CONCLUSION

A considerable amount of evidence supports the use of NIV to improve gas exchange and avoid ETI and its attendant complications in selected patients with ARF. However, several issues are critical to the success or failure of NIV. Identifying patients who are proper candidates for NIV and those in whom NIV is not likely to be effective can help to avoid inappropriate NIV application or unnecessary delays before starting invasive ventilation. Also, choosing the right interface and ventilation mode, and performing a close monitoring in an appropriate location are of primary importance for NIV success. Finally, effective patient–healthcare provider communication should be an integral part of clinical practice before and during NIV, as it may enhance favorable NIV outcome.

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### Conflicts of interest

*There are no conflicts of interest.*
*None of the authors received any funds for conducting this study.*

## REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

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