

# Noninvasive Ventilation in Prehospital Settings: A Narrative Review

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## Abstract

The prehospital use of noninvasive ventilation (NIV) by emergency medical services is increasing. Applying NIV in the prehospital setting began to gain more attention in the late 1990s when the primary form of noninvasive positive pressure ventilation emerged as a substitute to endotracheal intubation. For the last several years, NIV has become the standard of care for acute cardiogenic pulmonary edema and exacerbation of chronic obstructive pulmonary disease patients in the prehospital setting. A remarkable number of studies demonstrate a reduction in mortality and intubation rates in comparison to standard care when NIV is initiated in the prehospital setting, though there is a lack of evidence to strongly recommend the use of prehospital NIV as a first choice. An in-depth understanding of the science and technological background of NIV machines and interfaces can help attending clinicians in the prehospital setting and thus enhance therapeutic effectiveness by maximizing patient comfort, safety, and stability. Selections of the patients, devices, and interfaces, as well as achieving good patient-ventilator synchrony, are the key aspects of a successful outcome.

**Keywords:** Ambulance, interface, noninvasive ventilation, prehospital, respiratory failure

## INTRODUCTION

Noninvasive ventilation (NIV) has proven to be an effective modality with different forms of acute respiratory failure (ARF), in particular, chronic obstructive pulmonary disease (COPD) and cardiogenic pulmonary edema (CPE).<sup>[1,2]</sup> NIV as a modality delivers different forms of NIV support such as continuous positive airway pressure (CPAP) only or CPAP with pressure support, functions such as spontaneous breathing mode, and bi-level positive airway pressure, which mostly acts as an assisted breathing mode or controlled ventilation.<sup>[3,4]</sup> NIV has shown to significantly improve vital signs, peripheral circulation, and arterial blood gases.<sup>[3,5-7]</sup> Therefore, early initiation of NIV is essential in ARF emergencies to avoid endotracheal intubation and to improve patient outcomes,<sup>[3,8,9]</sup> particularly in prehospital settings. The efficacy of NIV is well established and robust in hospital settings with ARF of different etiologies. However, there is limited knowledge about NIV use in prehospital settings;<sup>[10,11]</sup> in addition, there are inherent differences in emergency medical service (EMS) systems.<sup>[12]</sup> This review will focus on the essentials of NIV practice in prehospital ambulance settings.

## PHYSIOLOGY OF NONINVASIVE VENTILATION

Pathophysiology of different etiologies of ARF includes an imbalance between an increased respiratory mechanical load and decreased respiratory muscle capacity, which results in reduced gas exchange, due to either intrapulmonary shunt or ventilation-perfusion mismatch, and cardiovascular function deterioration.<sup>[13]</sup> The goal of NIV is to ensure the adequacy of lung gas exchange and normalize the increased load of work of breathing in diverse etiologies. NIV uniformly shows a reduction in inspiratory efforts when spontaneous breathing is assisted and hence reduces dyspnea.<sup>[14]</sup> This substantial reduction in inspiratory efforts is evident by reduced diaphragmatic electromyography during NIV application.<sup>[15]</sup> Respiratory mechanics are also improved with NIV. Application of inspiratory support alone would relieve work of breathing by providing a greater proportion

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of transpulmonary pressure during the inspiratory phase (the “push-pull” effect).<sup>[13]</sup> Adding NIV will increase dynamic lung compliance by 17%–50% with a decrease in dynamic intrinsic positive end-expiratory pressure (PEEP) in diseased lung.<sup>[14]</sup>

Nasal CPAP and PEEP affect cardiovascular function. Evidence shows that nasal CPAP of more than 15-cm H<sub>2</sub>O in healthy participants reduces cardiac output by 20%–30% and reduces cardiac output by approximately 20% in patients with stable COPD. However, in congestive heart failure patients, NIV helps to decrease inspiratory efforts and left ventricular afterload and thus leads to increased cardiac output.<sup>[13,14]</sup> Lung gas exchange is also improved by optimal settings of NIV. Such improvement is evident in blood gas values by increased pH, improved PaO<sub>2</sub>, and decreased PaCO<sub>2</sub>.<sup>[14]</sup>

Physiologically, NIV has been revealed to reduce respiratory workload and increase tidal volume, which improves dyspnea and pulmonary mechanics. However, at high levels of inspiratory support, it is important to pay attention to mask leak, and gastric insufflation may occur, which causes the failure of the NIV modality.<sup>[14]</sup>

## EFFECTIVENESS OF PREHOSPITAL NONINVASIVE VENTILATION

### Noninvasive ventilation therapy in acute respiratory failure

ARF is a complex condition, which could be a result of different pulmonary and nonpulmonary problems. ARF can be either hypoxemic or hypercapnic. ARF results in acute or acute-on-chronic respiratory acidosis and occurs because of respiratory muscle failure to meet adequate alveolar ventilation demands regardless of increased activity of the diaphragm.<sup>[16]</sup>

ARF is very common in prehospital medical services and a potential cause for life-threatening emergency that leads to increase of morbidity and mortality, as well as increased costs.<sup>[17]</sup> In hypercapnic ARF in COPD particular patients in particular, NIV supports breathing to reduce the load placed on airways,<sup>[16]</sup> whereas in ARF due to hypoxemia, such as CPE, NIV helps to prevent alveolar collapse and redistribution of intra-alveolar fluid, leading to improved lung compliance and reduced pressure load on breathing.<sup>[11]</sup>

NIV use in prehospital settings is still contradictory in terms of outcomes. Some studies show no benefit of NIV in prehospital contexts in regard to the rate of intubations, length of stay in intensive care units (ICUs), mortality, or hospital stay,<sup>[18]</sup> whereas other studies showed a significant decrease in endotracheal intubation and mortality rates in patients of ARF using NIV modality.<sup>[11]</sup>

### Indications and contraindications of noninvasive ventilation

The use of early NIV in ARF has shown a higher success rate.<sup>[8]</sup> NIV has been proven to be effective with exacerbated COPD,<sup>[19,20]</sup> CPE,<sup>[21]</sup> and cardiac failure<sup>[22]</sup> and can be used to

support other etiologies with ARF. However, it showed poor evidence with severe acute respiratory distress syndrome.<sup>[23]</sup> Table 1 summarizes the goals and indications of NIV in acute settings.<sup>[24]</sup> In emergency seniors, endotracheal intubation and invasive ventilation must be initiated immediately. Perseverance with NIV application in these cases and undue delay in the application of invasive ventilation has been linked with increased mortality.<sup>[25]</sup> Table 2 lists several absolute and relative contraindications of the use of NIV that may lead to invasive mechanical ventilation.<sup>[25,26]</sup>

### Noninvasive ventilation in ambulance care

Prehospital care is normally delivered by ambulance services. Patients with ARF require proper prehospital management while transportation to hospital. The cause of ARF in these patients depends on the underlying causes, which is difficult to determine at this stage. Therefore, prehospital treatment usually follows a common pathway to treat ARF rather than a specific protocol, which usually happens in hospital settings. The risk of increased mortality in ARF patients increases significantly with distance traveled in an ambulance to the hospital from 10% at <10-km distances versus 20% at >20-km distances.<sup>[27]</sup> This mortality rate can be explained by the unavailability of respiratory support as prehospital treatment for patients with acute hypoxemic respiratory failure (RF) in particular.

Prehospital NIV practice has been studied in many studies, with the outcomes suggesting reduced mortality and rate of intubations, but these studies have limitations, including small

**Table 1: Goals and indications of NIV in acute settings**

| Goal of NIV application in acute care            |
|--|
| Improve patients' comfort                        |
| Relieve symptoms                                 |
| Decrease work of breathing                       |
| Improve lung gas exchange                        |
| Avoid intubation                                 |
| Decrease length of hospital stay                 |
| Acute indications of NIV application             |
| Exacerbated COPD patients                        |
| Acute cardiogenic pulmonary edema                |
| Postoperative respiratory failure                |
| Difficult weaning                                |
| Respiratory infection in immunocompromised state |
| Hypoxemic respiratory failure                    |
| COPD: Chronic obstructive pulmonary disease      |

**Table 2: Absolute and relative contraindications of NIV**

| Absolute | Relative                               |
|----------|--|
|          | Facial deformity                       |
|          | Poor cough reflex                      |
|          | Confusion                              |
|          | Moderate bulbar weakness               |
|          | Unstable angina/Myocardial infarction  |
|          | Esophageal or gastric surgery (recent) |

**Table 3: Types, potential advantages and disadvantages of popular products available in the market**

| Device Type   | Advantage  | Disadvantage  | Products in the market  |
|---|--|---|---|
| Valved CPAP Systems   | Economical and Easy to use   | Gravity dependant   | Pulmodyme O2 Max  |
| Threshold resistors   | Acceptable range of pressure and FiO <sub>2</sub> Delivery.  | Restricted patient movement   | Pulmodyme GO-PAP  |
| Weighted-ball<br>Spring-loaded  | Pressure delivered is not affected by the flow changes in the system (Sigh/Cough)<br>Gas consumption is low  | No Alram or monitoring<br>Noisy   |   |
| Continuous flow generators  | Easy to use<br>Fixed & variable flow adjustment is possible.<br>All in one knob pressure/O <sub>2</sub> level adjustment<br>WOB is reduced due to high peak flow rates   | Pressure delivered is affected by changes in flow through the system.<br>FIO <sub>2</sub> and pressures delivered are flow dependent.<br>Consumption of gas is high, it varies from 30LPM-100LPM<br>WOB is comparatively high.  | Respironics Whisperflow<br>Vital Signs-Downs fixed and adjustable flow generators<br>Emergent Respiratory-Port O <sub>2</sub> Vent<br>The Boussignac CPAP - Vygon                               |
| Portable Demand-Flow devices  | Demand flow system delivers CPAP without wasting oxygen.<br>No batteries required  | Monitoring of the Patient Device interaction is limited   | MACS CPAP - Airon<br>Emergent Respiratory-PortO2Vent  |
| Mechanical ventilators for Pre-hospital NIV (Portable, noninvasive, and critical care ventilators.) | Precise oxygen delivery<br>Enhanced patient safety and comfort.<br>Better flow delivery<br>Demand systems to reduce the WOB.<br>Quantify and compensate leaks<br>Patient-monitoring.<br>Alarms for disconnection, System failure.<br>Option to switch to assisted Ventilation.<br>Turbine Operated.<br>Adjustable inspiratory Flow.<br>Back up ventilation | Long triggering delay.<br>Less responsive<br>Trigger sensitivity.<br>Risk of rebreathing when there is no adequate flow to facilitate the intentional leak.<br>Flow dependent Expiratory Cycling.<br>No guaranteed VT.<br>Pressure generation varies.<br>Need expertise to operate.<br>Weight varies from 2.5kgs to 27kgs<br>Variable oxygen delivery in the absence of blenders. | Philips Respironics BiPAP S/T, Trilogy100.<br>Resmed Inc. Stellar/Astral/Elisee Series.<br>Draeger Oxylog3000/Carina<br>Hamilton MR1<br>Maquet Inc. Servo Air<br>Medtronic.Inc Newport ht70Plus |

CPAP: Continuous positive airway pressure, NIV: Noninvasive ventilation, WOB: Work of Breathing, LPM: Liter per minute, VT: Tidal Volume, BiPAP: Bilevel positive airway pressure, S/T: Spontaneous Time

sample size and inconsistent findings.<sup>[28]</sup> During prehospital NIV application and hospital transfer, it is important to remember that the EMS or paramedics are away from the in-hospital critical care services and support in case of deterioration. In addition, the NIV equipment may be limited by space inside the ambulance during transfer. These factors may play a role in the certainty of NIV effectiveness in prehospital settings.

Prehospital NIV can reduce the rate of mortality if used earlier in the ambulance as opposed to waiting until arrival at the hospital.<sup>[28]</sup> Hubble *et al.*<sup>[29]</sup> showed in their study that around 4/1000 patients were eligible to be transported by ambulance services for NIV treatment. Garuti *et al.* also reported in a prehospital setting that when helmet NIV interfaces were used by a trained nurse, the mortality rate was reduced by 94%.<sup>[30]</sup> This suggests that prehospital NIV can be effective with certain cases only if ambulances are technically equipped and EMS or paramedics are well trained on this modality. One crucial factor to address is that NIV success is associated with early initiation during the deterioration of RF.<sup>[31]</sup>

## TECHNOLOGY AND EQUIPMENT FOR PREHOSPITAL NONINVASIVE VENTILATION

A diverse range of equipment is available for establishing NIV in prehospital transport. Each has its own discrepancies

in performance and topography. They range from disposable devices to fully loaded transport ventilators with NIV capabilities. Clinicians must have a thorough understanding of the functions and settings to meet the operational necessities. The earlier devices had many limitations with regard to the power backup/battery life, type and source of gas supply, lack of suitable modes, oxygen source, etc., whereas the latest generation of devices offers a wide range of opportunities, including but not limited to switching the patients from NIV to invasive modes without changing the device and connections.<sup>[32-34]</sup>

## IDEAL DEVICES FOR PREHOSPITAL NONINVASIVE VENTILATION

All lightweight, compact, durable, and easy-to-navigate devices are ideal for prehospital NIV, especially during transport. Turbine-driven NIV machines have the advantage of being free from compressed air, lightweight, and hold back the space. However, some modern machines have the option to switch between compressed air and turbine settings.<sup>[35]</sup> An interchangeable battery with a good operating time can prolong the use of NIV without complications. When used in the prehospital and transport settings, NIV machines need to be secured well to avoid issues associated with sudden movement such as disconnection or inadvertent falls. It is

**Table 4: Frequently used interfaces**

| Device          | Benefits                              | Drawbacks                                 |
|-----------------|---------------------------------------|---|
| Nasal mask      | Minimal danger of aspiration          | Mouth leak                                |
|                 | Lesser claustrophobia                 | Higher resistance through nasal passages  |
|                 | Aid to communicate, eat & expectorate | Less effective with nasal obstruction     |
|                 | Easy to tailor and secure             | Nasal irritation and rhinorrhea           |
| Oronasal mask   | Less dead space                       | Mouth dryness                             |
|                 | Better oral leak control              | Greater dead space                        |
|                 | More effective in mouth-breathers     | Claustrophobia                            |
| Total face mask | One size fits all & Easy to fit       | Greater risk of aspiration & Asphyxiation |
|                 |                                       | Difficult to speak                        |
|                 | Less risk of facial skin breakdown    | Potential for drying of the eyes          |
|                 |                                       | Cannot deliver aerosol medications        |
|                 |                                       | Potentially more dead space               |

preferred to have an attachable support to hook to the bed or a wall-mounted stand with a charging station for the machine. A sophisticated leak compensation feature improves triggering and eliminates asynchrony, especially during the initial phase of application, which is crucial for establishing tolerance.<sup>[24]</sup> A highly visible and audible alarm profile with quick feedback helps the clinician to diagnose and treat adverse events such as disconnections, excessive leaks, and life-threatening apneas.

Table 3 summarizes the most commonly used devices as well as their advantages and disadvantages.<sup>[36-39]</sup>

## INTERFACE SELECTION FOR THE PREHOSPITAL NONINVASIVE VENTILATION

Important factors in selecting the right interface are type of RF, patient condition, and tolerance. Precautionary measures must be taken in order to avoid asphyxia/carbon dioxide narcosis as a result of ventilator failure or disconnection before choosing the interface. Choice of interface also depends on the type of machine circuits used. The need for anti-asphyxia valves (i.e., vented or nonvented masks) depends on the type of circuit. Respiratory therapists and attending personnel must be responsive to this imperative difference between ventilators.<sup>[40,41]</sup> Frequently used interfaces and their advantages and disadvantages are listed in Table 4. Regardless of the device used and patient condition, however, a well-fitting interface is an indispensable part of successful NIV in prehospital care.<sup>[12]</sup>

## CLINICAL OUTCOMES OF PREHOSPITAL NONINVASIVE VENTILATION

Studies examining the impact of prehospital NIV use have yielded inconsistent outcomes. Although there is a consensus that the use of prehospital NIV, mainly CPAP, improves vital signs in patients with ARF with an inclination toward the rate

of intubation, the impact on mortality is unclear. Mal *et al.*, in their systematic review and meta-analysis of randomized controlled trials (RCTs) on prehospital CPAP/NIV, correlated a decrease in requirement for inhospital invasive ventilation and mortality when prehospital noninvasive positive pressure ventilation was initiated.<sup>[42]</sup> This review included only just randomized and controlled studies, where seven heterogeneous studies on both CPAP and NIV, with a total of 632 patients, were pooled in a meta-analysis. This revision comprised primarily 361 studies, which was then developed based on exclusion criteria to seven RCTs, which were thought to have a relatively small risk of bias.

Another review by Simpson and Bendall stated that prehospital CPAP/NIV seems to be a prudent and viable therapy that marks quick progress in physiological status and that it may possibly help to reduce the requirement for intubation related to late management in the emergency care department.<sup>[43]</sup> They also found that there is a paucity of evidence that NIV might reduce mortality.

Simpson and Bendall documented diverse methods of NIV but did not distinguish among them. Bakke *et al.*, in their systemic review of controlled studies on the use of CPAP and NIV in prehospital treatment of patients with ARF, found an increasingly exponential trend toward a reduction of intubation rate, but there is a scarcity of evidence to strongly recommend the use of prehospital NIV.<sup>[3]</sup> Hensel *et al.*, in their prospective observational study steered in a prehospital setting to examine the usefulness of NIV used in patients with COPD exacerbation or CPE with particular reference to the impact of the extent of prehospital NIV treatment, found a significant improvement in the physiological values in NIV groups compared to the historical controlled group.<sup>[44]</sup> They also found that the patients with COPD exacerbation and CPE benefited significantly irrespective of the distance between the scene of emergency and the emergency and the nearest emergency department or hospital.

## ESSENTIALS FOR NONINVASIVE VENTILATION SUCCESS

### Personnel and training

Initiating NIV in prehospital settings is time-consuming and requires close monitoring and attention, and staff expertise for adequate adaptation and success management and treatment. Therefore, continuous staff training has shown to diminish time and patient-to-staff ratio.<sup>[45]</sup> Proper training is an important goal for better NIV outcomes in prehospital settings.<sup>[45]</sup> Expertise in NIV by maintaining proper training and accumulative experience over time, especially in acute RF, is essential for successful treatment<sup>[46]</sup> and also contributes to an improved clinical practice and better prognosis if applied earlier.<sup>[47]</sup> During transportation, an experienced staff member who is well trained in airway management and cardiopulmonary resuscitation should accompany patients on NIV.<sup>[48]</sup> In addition, it is essential that the personnel involved during transportation are skilled and confident in NIV application and knowledgeable

in type of ventilators, accessories, and different interfaces with NIV use.<sup>[49]</sup>

Preparation, education, and coaching from health-care providers are essential for patients to become comfortable and use the NIV device. In an acute respiratory distress situation, the prehospital care provider will need to act fast and assemble the NIV device quickly in order to avoid further deterioration that requires invasive intubation. Anxious or agitated patients in emergencies need proper management so that they do not fight the machine or become claustrophobic from the full mask. Proper preparation during prehospital care includes careful handling of the connection between the NIV and filled oxygen sources. Initial action includes applying the mask to the patient's face with coaching while taking in deep breaths. Once the patient can accept and tolerate the interface, then the head strap can be applied. Continuous assessment for patient respiratory function status is important for the success of NIV application in prehospital settings.<sup>[50]</sup>

## CONCLUSION

NIV is beneficial to selected patients in the form of shorter ICU stays, reduced mortality, and intubation rates when applied in the prehospital setting. By stipulating that NIV treatment is provided by a proficient emergency crew, a negligible amount of additional time is needed to apply NIV. With technology advancements, implementation of care plans/protocols, and extensive training of resource personnel, CPAP deemed to be the first choice of intervention, since it is inexpensive and easy to execute in clinical routine. However, this issue demands more research, and larger RCTs are essential to consolidate an evidence base for NIV use in prehospital settings.

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