

Management of acute respiratory failure with noninvasive ventilation in the emergency department

FERNANDO AYUSO BAPTISTA¹, GABRIEL JIMÉNEZ MORAL², FRANCISCO JAVIER FONSECA DEL POZO³

¹EPES 061 Córdoba. Secretaría Científica y de Calidad de SEMES-Andalucía. Spain. ²EPES 061 Córdoba. Spain. ³Medicina Familiar y Comunitaria. Servicio de Cuidados Críticos y Urgencias. Hospital Valle de los Pedroches. Pozoblanco, Córdoba. Spain. Secretaría de Urgencias de SEMERGEN. Spain.

CORRESPONDENCE:

Fernando Ayuso Baptista
ESPE 061
Córdoba, Spain
E-mail: fayuso@co.espes.es

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Noninvasive ventilation (NIV) offers the emergency physician a way to provide initial support for the patient with acute respiratory failure. Application of NIV in emergency care settings can have a decisive effect on clinical course. Clear advantages that conclusively support the use of NIV over invasive mechanical ventilation include the preservation of the cough reflex and the patient's ability to talk and eat; furthermore, NIV avoids invasion of the airway, with all the associated complications that implies. Recent years have seen the publication of many studies whose results encourage the early application of NIV in appropriately selected patients. Following the appearance of the consensus statements of the American Thoracic Society in 2001 and the British Thoracic Society in 2002, in which various modes of NIV were included in the therapeutic arsenal for managing either hypoxemic or hypercapnic acute respiratory failure, NIV use has spread in hospital emergency and ambulance services. Likewise, it is being used increasingly for home treatment of patients with chronic respiratory failure. In the immediate future, the challenge will be to train emergency department staff, to equip them with essential pathophysiologic concepts and the skills for managing acute respiratory failure, while preserving the chain of care by creating consensus on protocols to govern interdepartmental responsibilities. [Emergencias 2009;21:189-202]

Key words: Mechanical ventilation. Acute respiratory failure. Emergency health services.

Introduction

Non-invasive ventilation (NIV) is a form of support for spontaneous patient ventilation or respiratory support that does not require invasive techniques of orotracheal intubation (OTI), or any other device that creates an artificial way (laryngeal mask, combitube etc.) to ventilate the patient, but is done through an external device or interface (nasal or facial mask, helmet, etc.)¹. In the past the only option for the treatment of acute respiratory failure (ARF) resistant to conventional treatment was OTI, which subjects the patient to invasive mechanical ventilation, but these techniques are related with many serious complications that may be life-threatening².

The fact that professionals attending pre-hospital health emergencies can use this technique in selected patients with ARF is crucial for their subsequent evolution. The training of emergency department (ED) doctors and nursing staff in the management of NIV patients, with early application of an effective technique, will undoubtedly improve their prognosis.

For this review, the primary sources of reference material were the Cochrane Central Register of Controlled Trials and Medline until March 2008, using keywords such as non-invasive ventilation, cardiogenic pulmonary edema, respiratory insufficiency, respiratory failure and Chronic Obstructive Pulmonary Disease.

History of NIV

Historically, non-invasive procedures began to be used at the beginning of last century, such as the iron tank or the negative pressure chamber perfected by Phillip Drinker and Louis Shaw, as from 1928 after the poliomyelitis epidemics, in what was called an iron lung (Figure 1). Dräger in 1907 was the first to patent and use a time-cycle respirator - the Pulmotor. Brunel in 1912 applied a device that delivered a mixture of air and oxygen (O₂) under pressure to the airway of patients with ARF after thoracic surgery. In 1940 Barach defined and applied the principles of NIV in patients with cardiogenic pulmonary edema (CPE). In 1947 the principle of intermittent ventilation appeared with positive pressure in non-intubated patients, but it was not until 1971 that Gregory applied NIV and specifically continuous positive pressure to the airway, which he called Continuous Positive Airway Pressure (CPAP), used in child respiratory distress³. In recent decades progress in NIV techniques has been significant, especially applied in the field of exacerbated respiratory disease³.

NIV objectives in the ED

The essential point to optimize ventilation with this technique is the adequate selection of patients with ARF, which excludes those cases not meeting the inclusion criteria for the use of NIV. Used appropriately, NIV offers^{1,4-7}:

1. Decreased early respiratory work for the patient, as well as optimizing the exchange of gases,



Figure 1. Hospital ward for poliomyelitis patients in the first decade of the twentieth century, replete with iron lung devices. By courtesy of the Archives of the University of Pennsylvania (USA).

which reduces the sensation of breathlessness and respiratory fatigue. In the pre-hospital care setting, time with the patient is limited and therefore the primary objective is to alleviate signs of hypoxemia and respiratory fatigue and avoid OTI, if possible, in these initial stages, ensuring that the patient tolerates the procedure.

2. Decreased number of patients arriving at ED with OTI and invasive mechanical ventilation or, once there, requiring it, thereby reducing the number of patients requiring admission to the intensive care unit (ICU), with complications, increased hospital stay and the expenses involved.

Advantages of NIV

NIV has numerous advantages over the use of conventional mechanical ventilation, in patients meeting the inclusion criteria, primarily because it allows spontaneous coughing, removal of secretions, reducing the need for sedation, and makes self feeding and social interaction possible^{1,6-8}.

It also prevents muscle atrophy typical of patients undergoing prolonged mechanical ventilation, since deep sedation and muscle relaxants are not administered. Furthermore, it diminishes the typical complications of mechanical ventilation in patients with OTI, is better tolerated and easier to progressively remove⁹.

Selection of patient candidates for NIV in emergencies (Table 1)

Patients clearly benefiting from the use of NIV, especially when applied early, are those with potentially reversible conditions or those requiring respiratory support on being weaned off prolonged mechanical ventilation, as well as patients whose baseline condition discourages aggressive measures like invasive mechanical ventilation, such as those with very advanced chronic diseases^{1,5-7,9-11}.

Regarding the indications for NIV (Table 2)^{1,5-7,11-14} at present, there is abundant scientific evidence that patients with ARF who meet the criteria for NIV evolve favourably faster with this respiratory therapy than patients administered traditional oxygen therapy^{10,14-17}.

The results are beyond doubt in exacerbated chronic obstructive pulmonary disease (COPD) and CPE, but there is some variability in the findings of studies on pneumonia, adult respiratory distress syndrome (ARDS) and post-extubation respiratory failure¹⁸.

Table 1. Patients who are candidates for NIV¹¹

1. Absence of contraindications for NIV application (see below).
2. Presence of spontaneous breathing.
3. Patient collaboration.
4. Patient with sufficient level of consciousness to expectorate and cough.
5. Patient with established ARF initially unresponsive to conventional treatment: tachypnoea with respiratory rate higher than 24 breaths/minute, oxygen saturation below 90% after application of FiO₂ greater than 0.5, use of accessory muscles and thoracoabdominal asynchrony.
6. If gasometric data are available, we should include patients with ARF who, in addition to the above clinical signs, also present PaCO₂ > 45 mmHg pH < 7.35 and PaO₂/FiO₂ < 200.

NIV: noninvasive mechanical ventilation, ARF: acute respiratory failure.

As a criterion for the initiation of NIV in emergencies, we can include all patients who present with ARF and failure to respond to traditional oxygen therapy associated with specific pharmacological treatment, situations of uncontrolled dyspnea as well as refractory hypoxemia with insufficient PaO₂/FiO₂, progressive hypercapnia with acid pH and increased respiratory work^{11,13}.

The success of the technique depends on the appropriate selection of patients who meet the well established criteria for indication of NIV and present no reason for exclusion.

The training and experience of the physician responsible, as well as of the support team attending patient, are essential for the correct performance of NIV. The treatment should be initiated as soon as possible, applying the most appropriate interface and controlling the vital constants: familiarity with the equipment is also most important for correct implementation of the technique^{10,11,13}.

Patients with hypercapnic ARF, which is the most severe form of COPD exacerbation, are those who show most favourable response to NIV therapies^{18,19}. The results of the NIV associated with non-hypercapnic ARF appear to be less clear regarding decreased patient mortality, but are good in terms of morbidity and evolution of the picture^{20,21}.

Finally, a key element in the successful use of this technique is knowing the situations where its use is contraindicated^{5-7,10-13,20,21} (Table 3), initially or during evolution after starting treatment.

Conditions for withdrawal of NIV in emergencies (Table 4)

The criteria for withdrawal of NIV are: clinical deterioration of the patient, the appearance of some other reason for counter-indication, and clin-

Table 2. Indications for NIV^{1,5-7,10-13}

- Exacerbation of COPD.
- Acute pulmonary edema.
- Moderate asthma attack.
- Weaning off conventional mechanical ventilation.
- Pneumonia.
- Acute bronchiolitis.
- Postoperative phrenic paralysis.
- Acute Interstitial lung disease.
- Alveolar Hypoventilation secondary to CNS involvement (syndrome Guillain Barre syndrome, Arnold Chiari syndrome, Ondine syndrome, hydrocephalus, CNS tumors, myelomeningocele, syringomyelia, spinal muscular atrophy, poliomyelitis, amyotrophic lateral sclerosis, myasthenia gravis, muscular dystrophies, myopathies, acute spinal cord injury etc.).
- Kyphoscoliosis.
- Malformation of the thoracic cavity.
- Obstructive sleep apnea syndrome (OSAS).
- PIC syndrome.
- Pulmonary fibrosis.
- Post-surgery chest.
- Palliative therapy in patients with indication for OTI.

NIV: non-invasive mechanical ventilation, COPD: Chronic Obstructive Pulmonary Disease; CNS: central nervous system. OTI: orotracheal intubation.

ical improvement after controlling the causative agent of ARF^{1,6,7,11-14,22,23}. The patient should present a respiratory frequency (Rf) of less than 24 breaths per minute, a heart rate (HR) of less than 100 bpm; O₂ saturation above 92% with nasal spectacles at 2 l/m; improvement of gasometric parameters, pH greater than 7.35, PaO₂/FiO₂ above 200 and progressively reduced need of pressure support or inspiratory positive airway pressure (IPAP), exhaled tidal volume greater than 8 ml/kg in hypoxemic patients or greater than 6 ml/kg in patients with obstructive airways.

It is recommended that, once NIV is deemed appropriate and is tolerated by the patient, it should be maintained for at least 24 hours continuously, assuming the patient tolerates it and there are no contra-indications, until gasometrical and clinical improvement is evident, while treatment is administered to deal with the causal agent triggering the ARF (pneumonia, CPE, COPD exacerbation, etc.). Withdrawal of NIV should be performed in a progressive manner, gradually increasing the periods of breathing with high-flow oxygen therapy and reducing those corresponding to the NIV therapy maintained, if necessary, during the night periods. When clinical and gasometric signs show improvement, one can change to high-flow oxygen therapy with a Venturi mask, and tolerance to this approach monitored. Progressive "weaning" off NIV depends on the patient's evolution and, when initiated, the patient should be strictly monitored.

Most authors agree that the clinical and gasometric response to the first hour of treatment

Table 3. Contraindications for NIV^{5-7,10-13,20,22}

1. Respiratory arrest or gasping.
2. Hemodynamic instability (SBP below 90 mmHg despite adequate fluid replacement or inotropics) with signs of hypoperfusion.
3. Myocardial ischemia.
4. Heart rhythm disorder.
5. Low level of consciousness that makes protection of the airway impossible.
6. Excessive respiratory secretions.
7. Status asthmaticus.
8. Pneumothorax.
9. Severe chest trauma.
10. Agitated or non-collaborative patient who does not tolerate the technique.
11. Persistent emetic picture.
12. Facial trauma.
13. Facial burns or airway.
14. Maxillofacial surgery.
15. Anatomical facial defect that interferes with the adjustment of the interface.
16. Tracheostomy.
17. Recent esophageal or gastric surgery.
18. Patient with indications for intubation.
19. No possibility of thorough control or monitoring of the patient.

NIV: non-invasive mechanical ventilation; SBP: Systolic blood pressure.

with NIV is fundamental. The technique will fail when some criterion of contra-indication appears (hemodynamic instability, decreased level of consciousness, lack of control of respiratory work with persistent persistent fatigue, intolerance to the interface with uncontrolled agitation, uncontrolled persistence of bronchial secretions, a $p\text{CO}_2$ greater than 45 mm Hg, appearance of ARDS and pneumonia with unfavorable $p\text{O}_2/\text{FiO}_2$ below 150^{10,11,13,20}.

Complications in the application of NIV

Complications associated with the application of NIV include cases of decubitus skin necrosis (10%), aspiration pneumonia (5%), hypotension (5%), gastric distension (3%) and dry eyes and mouth^{1,6}. However, OTI is associated with more adverse effects and potential complications, including: loss of verbal communication, impaired oral and pharyngeal flora, impaired mucociliary clearance, increased airway resistance, problems with weaning after prolonged OTI time, sedation and muscle relaxants, nosocomial pneumonia, laryngotracheal stenosis and the need for tracheotomy.

Modalities of NIV

The modalities of NIV most commonly used in emergency departments are CPAP (Continuous Positive Airway Pressure), BiPAP (Bilevel Positive

Table 4. Predictors of success and failure of NIV^{10,11,13,14}

Predictors of success

- PH 7.25-7.35
- Improvement of pH, PaCO_2 and respiratory rate after 1 hour of NIV
- Adequate level of consciousness

Predictors of failure

- High APACHE II
- Pneumonia on chest x-ray
- Excessive respiratory secretions
- Patients without teeth
- Poor nutritional status
- Low level of awareness

NIV: non-invasive mechanical ventilation.

Airway Pressure) and PSV (Pressure Support Ventilation)^{6,10,23,24} (Figures 2 and 3).

1. CPAP. Continuous positive pressure above atmospheric pressure, applied throughout the respiratory cycle in the airway of a patient breathing spontaneously. This allows control of the levels of pressure in $\text{cm H}_2\text{O}$, air flow, FiO_2 and trigger with demand valve in the event of mechanical NIV devices being available. A meta-analysis performed in 2006 found that the initial use of CPAP in CPE reduces mortality more significantly than double pressure NIV²⁴⁻²⁶.

2. BiPAP. The dual pressure level or BIPAP mode is a system where the pressure pattern and the volume depend on the patient. The expiratory positive airway pressure (IPAP) is the pressure preset at inspiration. The inspiratory positive airway pressure (EPAP) is the pressure set during expiration^{7,11}.

The application of IPAP generates increased tidal volume (TV) that improves ventilation and arterial oxygenation, whereas EPAP or CPAP recruits previously collapsed alveoli, thus preventing the phenomenon of decruitment.

The NIV modality BIPAP with face mask is initially indicated in hypercapnic ARF treatment, because of its proven usefulness in reducing respiratory effort. NIV with two levels of pressure is applied with ventilators that include a turbine which extracts atmospheric air continuously (until reaching the pre-established pressure level by means of a valve), and delivers it to the patient via the interface; the pressure differs according to the phase of the cycle, inspiratory (IPAP) or expiratory (EPAP)¹¹. The valve remains closed during inspiration and opens when it ends, until the preset expiratory pressure level is reached. The ventilator usually requires an initial setup which stipulates the flow needed, to be shared between the nozzles, the patient's airway, mask leaks and the orifices, to achieve the set pressures. We can preset the IPAP and EPAP levels, a minimum respira-

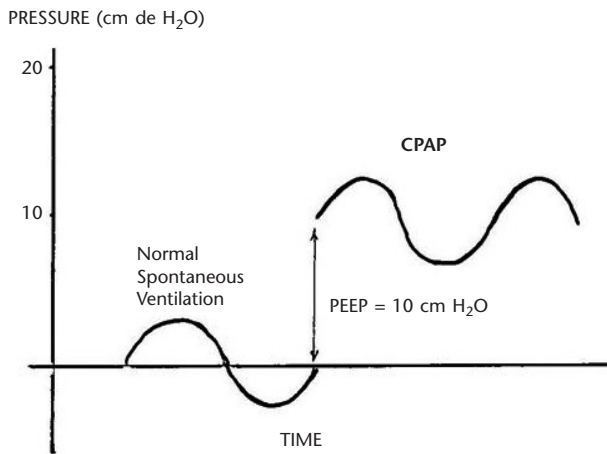


Figure 2. Graphic representation of the CPAP mode, compared with normal spontaneous ventilation. CPAP: Continuous airway pressure. PEEP: Positive end expiratory pressure.

tory frequency (Rf), both the inspiratory and the expiratory trigger, the pressurization ramp or speed, and limit inspiratory time and the levels of FiO_2 .

All the ventilation cycles are triggered by the patient inspiratory effort. A flow of gas is administered to the patient's airway, which aids inspiration, until reaching the selected pressure level, then the delivery of the flow is maintained until it reaches 25% of initial peak flow. On reaching the pre-set level of pressure, the flow is slowed to keep inspiratory pressure constant, when it stops and allows expiration. From breath to breath, the patient regulates inspiratory time, enabling better patient-ventilator interaction¹¹. The patient's inspiratory effort (trigger) is captured by the ventilator which initiates the delivery of gas, and allows the patient to control the duration of inspiration and

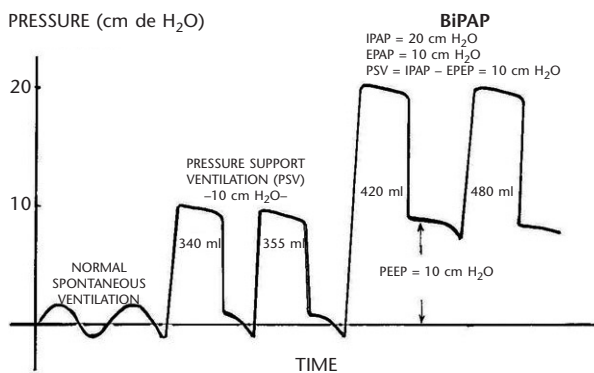


Figure 3. Graph representing the modalities PSV (Pressure support ventilation) and BiPAP (Bilateral positive pressure) on normal spontaneous ventilation. CPAP: Continuous airway pressure. PEEP: Positive end expiratory pressure.

the Rf, allowing proper synchronization with the ventilator and a reduction in respiratory work. BiPAP can improve ventilation and vital signs more rapidly than CPAP; it may also reduce respiratory work more effectively and provide greater effectiveness in the treatment of hypercapnic ARF, although at present there are no studies that demonstrate the superiority of IPAP over CPAP in CPE²⁷.

Peter et al, in a meta-analysis performed in 2002²⁸, showed a reduction in mortality, need for OTI and hospital stay with use of BiPAP for the treatment of acute respiratory failure; this result was particularly significant in the subgroup of acute COPD.

3. PSV. This is a flow-cycled, pressure-limited system of ventilation, where each inspiration can be triggered by the patient, which sets the RF of the device. Conceptually, PSV is the difference in pressure between the established levels of IPAP and EPAP. If the EPAP level is zero, we have a pure PSV mode, where respiratory support is provided for each breath IPAP. If the IPAP and EPAP levels coincide, we have a CPAP mode¹¹.

Pathophysiology of NIV

Regarding ventilation effects^{7,13} NIV reduces hypoxemia faster and more effectively than providing supplemental oxygen, increases the mean pressure of the airway and improves ventilation in areas of collapsed lung by alveolar recruitment, reduces the shunt effect (optimizing the relation V/Q) and increases VT as well as functional residual capacity (FRC), in a similar way to what is achieved with PEEP in patients undergoing mechanical ventilation with OTI. It can be said that NIV increases the number of alveolar units available for adequate gas exchange and optimal redistribution of extravascular lung water in EPC, facilitating its passage to the peri-alveolar interstitial space, optimizing the relation V/Q and improving compliance^{6,7,10,11,23,24}.

Lung recruitment increases in direct proportion to how the pressure levels are applied in the airway and transmitted to the alveolar sacs. With respect to the hemodynamic effects of NIV^{7,13}, increased pressure in the airway results in an increase in pulmonary vascular resistance, which increases right ventricular (RV) pressure and intra-thoracic pressure. This decreases venous return and the preload of both ventricles (telediastolic volumes). Increased pressure in the RV dis-

places the inter-ventricular septum towards the left ventricle (LV), which induces increased intrathoracic pressure, reducing its distensibility and output. This in the healthy heart helps to reduce the ejection fraction and cardiac output of the LV. This decrease in cardiac output secondary to the application of NIV should be considered in patients with reduction of extracellular volume (hypovolemic, dehydrated), sepsis, left ventricular failure and cor pulmonale^{6,7,10,12,23-25}. In patients with CPE and LV systolic dysfunction, CPAP may increase cardiac output by reducing the LV preload in a patient with previously increased filling pressure, because compromised myocardium has a special characteristic: it is afterload-dependent, while the healthy myocardium is pre-load dependent^{7,11}.

Regarding the effects of NIV on the respiratory muscles, patients with ARF have increased respiratory work for various reasons, the main one being oxygen deficit and the stimulus this represents for the bulbar receptors. Increased resistance to the flow and decreased pulmonary compliance are often present in patients with long-term chronic respiratory disease.

NIV improves respiratory dynamics and relieves breathing fatigue and respiratory work; these effects are more pronounced when patient-ventilator synchronization is achieved. Factors contributing to respiratory fatigue are hypoxemia, associated septic pictures (pneumonia), malnutrition in the chronically ill and long-term treatment with corticosteroids. Respiratory fatigue produces major hypoxemia and hypercapnia thus further increasing Rf and respiratory work, with greater respiratory fatigue, which contributes to the onset of lactic acidosis^{7,10,24,25}.

In addition to the respiratory muscles normally involved in breathing (diaphragm, intercostal, scalene), others such as the sternocleidomastoid, the trapeze and the abdominal muscles are characteristically involved in decompensated ARF^{7,11}.

Management of hypoxemic ARF with NIV

Hypoxemic or type I ARF encompasses a group of clinical entities characterized by severe isolated hypoxemia, such as in CPE, pneumonia, pulmonary contusion and ARDS, where NIV study findings are less conclusive than in hypercapnic ARF^{6,7,11,30,31}. Studies on the use of NIV during the immediate post-intubation period show contradictory results, but this topic is beyond the scope of this review of emergency patients.

Cardiogenic Pulmonary Edema

NIV is superior to conventional oxygen therapy in reducing the rate of OTI in CPE patients, with a tendency to lower mortality rates^{6,7,11,32-34}. Patients initially treated with conventional oxygen therapy should be evaluated and in cases of persistent hypoxemia and tachypnea (SaO₂ less than 90% and RF above 30 breaths per minute), early NIV should be considered³⁵.

In a study by Berstein et al³⁶ on patients with CPE treated with CPAP, clinical and gas exchange improved more rapidly than in the group treated only with oxygen therapy.

No patient in the CPAP-treated group required OTI, and ICU stay was shorter, although there was no reduction in hospital mortality. Rasanen et al³⁷ concluded that CPAP in CPE patients decreased the rate of OTI rate from 42.5% in the control group to 17.5% in the CPAP group, although no significant differences were found for mortality.

In a study by Metha³⁸ on CPE with both CPAP with BiPAP, the latter showed faster improvement in clinical and gasometric parameters, without differences in ICU stay, need for OTI or mortality between the two groups. A surprising finding was the higher rate of non-transmural acute myocardial infarction in the group treated with BiPAP, probably because patients with CPE and chest pain were not excluded.

The clinical guidelines of the British Thoracic Society (BTS)¹⁰ state that CPAP has been shown to be effective in hypoxic CPE despite maximum medical treatment, and that BiPAP should be reserved for patients who do not respond adequately to CPAP due to uncontrollable dyspnea or added hypercapnia. These assertions have been corroborated by many studies, especially important being those of Massip^{39,40}.

Although its methodological rigor has been widely questioned, the study by Newby⁴⁵ compared patients with CPE treated with CPAP (n = 342), PSV (n = 351) and conventional oxygen therapy (n = 365), and found no significant difference in results. The severity of hypoxemic ARF in emergencies is assessed on the basis of pO₂, pO₂/FiO₂ oxygenation index, respiratory acidosis index (pH/pCO₂), Borg scale or visual analog scale of disnea⁴².

The CPAP modality for NIV is indicated in the initial management of hypoxemic ARF. All clinical guidelines on CPE include CPAP as a therapeutic technique. In CPE, CPAP transmitted to the alveolar-capillary membrane not only reduces the

signs of muscle fatigue, but positively affects hemodynamic instability, increasing cardiac output in patients with LV dysfunction. The treatment of CPE should never be performed with only conventional drug treatment and supplemental oxygen, because collapsed or fluid-filled alveoli induce a shunt effect, and do not oxygenate the blood passing through them. Therefore, positive pressure is needed during the whole respiratory cycle to recruit and keep alveoli open and contribute to alveolar fluid extravasation to the intravascular space, thus helping to reduce the shunt^{39,40,42}. There is a clear difference between the contribution of high-flow oxygen systems (Venturi effect with mask and regulator of FiO₂) and a CPAP system, as the former do not contribute to recruitment of collapsed or deficient alveolar units, nor do they affect respiratory muscle fatigue^{39,40}.

There is extensive experience of managing these patients with NIV in the field of both pre-hospital and hospital emergencies as from the late 1990s, compared with oxygen therapy and traditional OTI^{15,39,40,42,43}. NIV has also been useful, but to a lesser extent than in COPD exacerbation or CPE, in situations of ARDS resulting in non-cardiogenic pulmonary edema secondary to inhalation of toxic materials, near-drowning, severe pneumonia etc., associated with a marked shunt effect and a clear decrease in functional respiratory capacity functional^{41,44,45}. These patients usually require ICU attention. Hypoxemic ARF patients older than 40 years are often associated with poor prognosis after NIV, presenting frank tachypnea (Rf greater than 37 breaths/min) after the first hour of treatment, a PaO₂/FiO₂ index below 146, and coexistence of ARDS or pneumonia⁴⁴.

Pneumonia

The literature contains contradictory findings: some indicate favourable initial evolution, but different rates of OTI and no differences in the mortality rates of pneumonia patients. There seems to be a positive prognostic factor in these patients if they have a history of COPD^{5,11,44-46}.

ARDS

The usefulness of NIV in ARDS is far from clear, according to the results of different studies. This therapy is recommended initially in mild to moderate situations without organ failure, but not in severe situations requiring OTI^{41,44,45,47}.

Management of hypercapnic ARF with NIV

The clinical entity that most faithfully represents ARF is hypercapnic COPD, where most studies have been performed on the effects of NIV. No one disputes the scientific evidence from numerous studies showing the superiority of NIV over conventional oxygen therapy and/or OTI in hypercapnic ARF^{6,7,11,12,19,20,48}. The work of Brochard et al in 1995¹⁹ showed more rapid clinical improvement in gas exchange with NIV than with conventional therapy. The percentage of OTI in the patients studied was 28% in those treated with NIV compared to 66% in the other group; hospital stay was 23 versus 35 days, ICU stay was 13 versus 32 days and mortality rates were 9 versus 29%. These results show that NIV for COPD exacerbation is a therapeutic technique whose utility is beyond all reasonable doubt. A meta-analysis by Keenan et al in 1997³⁰ strengthened the previous results, showing significantly reduced mortality and need for OTI in NIV-treated patients.

The work of Brochard¹⁹ and Plant⁴⁹ found reduced hospital mortality associated with NIV (9 and 10% respectively, compared to 29 and 20% with traditional therapy, in target populations in excess of 200 patients). Based on these and other studies, numerous international consensus guideline^{19,50} and recommendations¹² deem NIV an essential part of the treatment of both hypercapnic and hypoxemic ARF.

The positive response of patients with COPD exacerbation to NIV applied jointly with specific drug treatment (corticosteroids, aerosol therapy bronchodilators, aminophyllines) is due to the effect of NIV on the exchange of gases, muscle fatigue and pulmonary hyperinflation. Comparing the effects of NIV with OTI in these patients with acute phase disease, we observe improved prognosis, reduced ICU stay and fewer complications associated with OTI¹⁶.

It is very important to note that there are patients with hypercapnic ARF where NIV is not indicated (see Contraindications), either initially or during NIV application because of inadequate response (failure of the technique). These patients should be detected early and treated with mechanical ventilation after OTI¹⁶. Poor response to NIV in patients with COPD exacerbation is associated with pH below 7.22, low level of awareness, high scores on scales such as APACHE II or SAPS II and coexisting diseases (malnutrition, cor pulmonale)⁴⁹.

There is a B level of evidence indicating that, to achieve satisfactory results using NIV, a higher

level of work, time and dedication of the professionals serving these patients is required⁵¹. There are no studies showing the benefit of NIV in COPD exacerbation in pre-hospital settings, but experience suggests that more favorable results from early application of this technique.

We may conclude that patients with hypercapnic ARF meeting the inclusion criteria and treated with NIV show results with a level of evidence A regarding decreased hospital stay, ICU stay, mortality rate and costs^{19,20,52}.

Management of asthma attacks with NIV

NIV must be used early in cases of ARF secondary to an asthma attack that does not respond to traditional treatment (corticosteroids, aerosol), in an emergency department with experienced staff trained in this technique; delaying, if possible, the use of OTI for the risks involved (barotrauma, pneumonia, hemodynamic instability)^{53,54}.

NIV in these patients helps to reduce autoPEEP (excessive alveolar inflation).

However, it should be applied with great caution, by staff who are experts in treating severe asthma attacks, because a significant percentage of cases evolve adversely, especially if high levels of CPAP are used. We have no conclusive indication for NIV from randomized controlled studies, and it is risky to postpone OTI in severe cases of asthma. Recent publications on patients treated with NIV, delivering helium gas mixed with oxygen (presenting low density) are most promising⁵⁵.

Methodology in the implementation of NIV

When faced with an ARF patient meeting the NIV inclusion criteria, we must consider the most appropriate modality for applying NIV (CPAP, BiPAP, PSV)^{6,11}.

Prior administration of oxygen, specific pharmacological treatment and continuous monitoring of the patient (see monitoring) are recommended. Initially in hypoxemic ARF, CPAP should be used starting with 5 cm H₂O and increasing gradually the pressure until the FiO₂ requirements are lower and a PaO₂ above 60 mm Hg or O₂ saturation above 92% are achieved.

In hypercapnic ARF, initially we can use BiPAP with IPAP 8-12 cm and EPAP 2-3 cm H₂O and H₂O adjusted to achieve a VT higher than 400 ml, with FiO₂ to maintain O₂ saturation above 90%. It

is essential to perform gasometry initially and again after the first hour of treatment. If necessary, slight sedation should be administered. If the patient tolerates it, NIV is maintained during the first 8 hours, and then gradual withdrawal can be considered, evolution permitting, with supplemental oxygen being delivered during periods of withdrawal^{6,11}.

Interfaces

The term interface in NIV refers to the device connecting the patient to the ventilator, through which gas is delivered with a preset pressure to favour mechanical ventilation. Knowing which interface to use is a key factor for the success of this technique⁵⁶⁻⁵⁸.

The NIV interface may be an oronasal or nasal mask, or a full face mask or helmet (Figure 4). Nava et al in 1997⁵¹ examined the response of patients with chronic hypercapnic ARF to different types of interface, concluding that the nasal interface was best tolerated of all, while the oronasal mask was associated with more rapid decrease in pCO₂. Nasal masks are not the most appropriate in patients with acute respiratory disease, since they breathe through the mouth and this increases leakage. They may be useful in home treatment of patients with chronic respiratory disease, such as obstructive sleep apnea syndrome (OSAS)⁵⁶⁻⁵⁸.

Clearly, we must seek to provide maximum patient comfort and use the lowest possible force in securing the interface, allowing small leaks initially, to favour tolerance⁵⁶.

The facial mask is the most commonly used interface in emergencies, which includes an oronasal area. In an attempt to improve the tolerability of this interface, a full face mask has been designed: it includes the entire face and prevents excess pressure on the facial structures such as the bridge of the nose⁵⁹.

The helmet system, made of transparent latex, is well tolerated and allows patients to communicate and feed themselves without producing facial injury due to pressure, so it is most useful for delivering CPAP in ARF during prolonged periods of hypoxemia, using adjustable PEEP devices and oxygen flow of at least 30 l/m with no leakage, but dead space is higher. It has a circuit of inspiratory nozzles and another for expiratory nozzles to be connected to the ventilator, and a connection that allows passage of a nasogastric tube. Different sizes are available on the market. It is

adjusted by two cross straps under the armpits. Positive results regarding tolerance and good evolution in Italian pre-hospital patients have been reported by Fotti and Antonelli of the Conti Group^{11,60,61}.

Algorithm of NIV management of type 1 ARF emergency patients (Figure 5)

When faced with a patient with signs of ARF, the appropriate NIV device should be applied as soon as possible for respiratory support.

Firstly, we must establish that there are no contraindications, ensure that all monitoring elements are prepared and check on the availability of nurses. We must also ensure that the material required for OTI is prepared in case of need, since 20% of cases require this despite good initial response to NIV¹. In this regard, it is important that all staff in charge of patient care are properly trained and able to detect early signs of NIV failure^{1,5,7}.

NIV devices in the emergency department

Non-mechanical Boussignac®

CPAP NIV device

This is an open system that connects to a face mask, CPAP being transmitted to the patient's spontaneous breathing airway (Figures 6 and 7). The pressure is produced by passing a stream of gas (O₂ or air) through microchannels in the device, resulting in acceleration of the gas molecules, producing, as a virtual valve, turbulence by a jet effect, like a large turbine in a tunnel.

This device is very light, easy to use, allows communication with the environment and prevents CO₂ poisoning. Pressure level can be measured with a manometer and only depends on the airflow that we determine. We can add a Venturi effect FiO₂ regulator that comes with the device, and a system to apply aerosol therapy simultaneously with CPAP^{1,5-7,11}. We can adjust flows up to 40 l/m giving us pressures of 15 cm H₂O. The FiO₂ administered to the patient varies according to need according to O₂ saturation levels.

Whisperflow by Caradyne®

This system delivers CPAP over the whole respiratory cycle in patients who are breathing spontaneously. There are two types of flow generators:

a. Variable generator: the value of FiO₂ can be



Figure 4. Interfaces. Left: Helmet. Upper right: the nasal mask, more appropriate for patients with chronic respiratory disease (by courtesy of www.medscape.com) and Lower right: orofacial and whole face mask.

varied from 28% to 100%. This is the type of generator used in intensive care.

b. Fixed flow generator: provides an FiO₂ of 28% to 33% depending on the flow and the different CPAP valves used. This is the system usually used in the ED. It is a precision Venturi device that employs a supply of oxygen together with air input to generate an output flow. It may generate flows of more than 150 l/min at 28% FiO₂^{1,7}.

Mechanical NIV devices

Oxilog 3000®

This is one of the most advanced ventilators used in the ED for both invasive and non-invasive ventilation, and offers both CPAP and BiPAP modalities. It includes an apnea alarm (activated by pressure, flow or CO₂) and displays pressure curves. Electrical autonomy is 90 minutes. It is designed to withstand a fall from a height of 75 cm, and is suitable for air transport, tolerating temperatures from -20 to +50°C. It allows one to establish a VT from 50 to 2,000 ml, an I:E ratio from 1:4 to 3:1, inspiratory time of 0.2 to 10 seconds, inspiration pressure, PEEP, trigger sensitivity, pressure support, gradient, inspiration flow from 0 to 100 L/min, an FR of 2-60 breaths/min and an adjustable concentration of oxygen, from 40 to 100%^{1,5}.

BiPAP Harmony®

These BIPAP devices are very lightweight (2.6 kg), easy to use and versatile (29 x 18 x 14 cm). They allow high flows (greater than 80 l/m) and can provide IPAP (4-30 cm H₂O) and EPAP (4-15 cm H₂O). FR can be set at 4-30 rpm, inspiratory time 0.5-3 seconds with inspiratory trigger and automatic expiratory time, as well as automatic

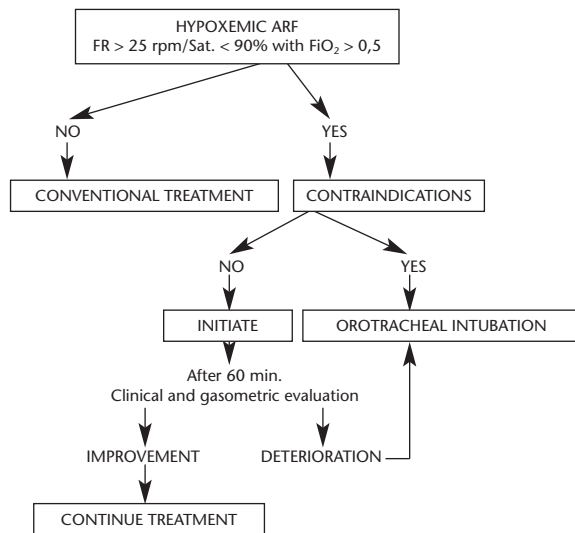


Figure 5. Algorithm for the implementation of CPAP^{1,5,7} (positive pressure in-airway) in the EPES 061 medical teams, Andalusia. FR: respiratory rate. Sat: Saturation of arterial oxygen.

compensation for leaks. The battery is external with operative duration time of 90 minutes^{1,5,7}.

BiPAP Vision®

This a versatile, very reliable non-invasive ventilation system designed with advanced technology, incorporating an automatic sensitivity adjustment system (Auto Trak System) and leak compensation, which adjusts to changes in the breathing pattern. It allows the application of spontaneous/synchronized CPAP or BiPAP, and proportional assisted/synchronised ventilation. It also allows FiO₂ control with total reliability. It has a screen display of flow and pressure curves, and monitoring and adjustment of alarms¹¹.

Exhaustive control of the patients (Table 5)

In this section, fundamental to the success or failure of the technique, the role of nurses is transcendental. Their training should be considered as a priority in ED^{1,5-7,11}. Once the patient is considered to have no contraindications and respiratory parameters indicate that NIV must be used, it is important to follow all the steps listed in Table 5, for optimal adaptation and tolerance of the patient to the NIV device. We must not forget that we face a critical situation where a ventilatory support technique is applied to make respiration more effective, but without losing sight of the risk of an unfavourable evolution (failure of the technique) that must be detected early, in order to

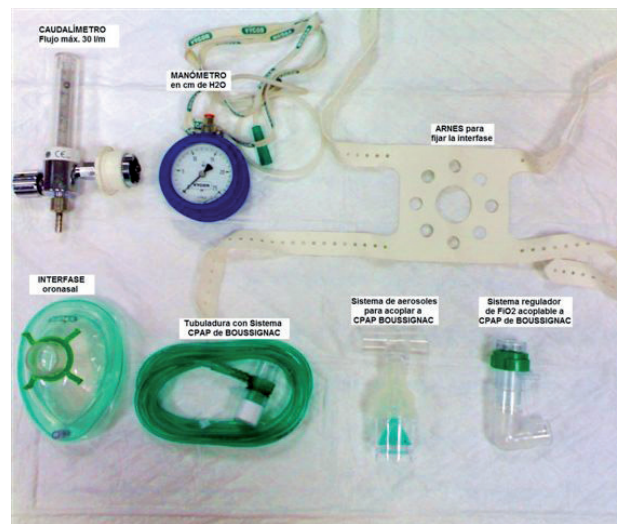


Figure 6. CPAP (continuous positive pressure in the airway) by Boussignac (Vygón®) and its components (interface, harness, CPAP device, pressure gauge, flowmeter, FiO₂ regulator and aerosol device), all being contained in a case.

change the approach or strategy for management of the patient.

Patient-ventilator synchronization

Synchrony between the patient and the mechanical systems supplying NIV is necessary for successful ventilation of the patient, with pressures tailored to their respiratory needs. The success of NIV is determined by a fundamental requirement: the adaptation and tolerance of the patient to the technique^{11,62,63}. It is based on 3 elements that are determinant in the breathing cycle^{11,62}:

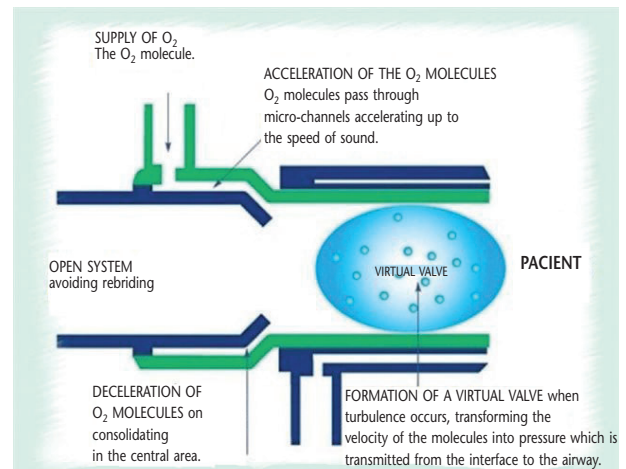


Figure 7. Virtual valvular mechanism of CPAP (continuous positive pressure in the airway) by Boussignac.

a. Trigger. Level of inspiratory effort made by the patient to activate delivery of ventilation from the passive expiratory phase to the inspiratory phase.

b. Ventilator cycling or change of phase from inspiration to expiration, with proper pressurization of the airway to progressively reduce leaks at the same time as obtaining maximum inspiratory pressure. The ventilator detects the end of patient inspiratory effort and interrupts the delivery of air under pressure. The cycling mechanism is deregulated in cases of excessive leakage due to high pressure, making the detection of inspiration impossible, so delivery will continue; the result is maladjustment to the patient's breathing cycle and loss of synchronization, or the ventilator cycle becomes decoupled from the respiratory cycle of the patient.

c. Expiratory phase: the ventilator can cause hyperinflation in patients with shortened expiratory phase, as in many obstructive patients.

Recently, ventilators have appeared on the market offering solutions to these problems, through a system of automatic correction of leakage, which compensates for each of the respiratory cycle phases with ultrasensitive flow triggers, allowing control of inspirational times^{11,62}.

Chain of care of patients with ARF

The proper handling of patients with ARF implies proper attention at any point in the chain of care, including the prehospital phase (primary emergency care and emergency teams) and the hospital phase, and ensuring continuity of NIV if necessary. It is therefore important to establish a consensus in the various health districts of a reference hospital area on the criteria for application of NIV, actively involving the medical teams and equipment in the emergency primary care area, ED observation, pulmonology, radiology, internal medicine, pediatrics, anesthesia and UCI, and establish inter-departmental performance criteria for the management of these patients^{1,5,7,64}.

NIV has been used in the prehospital setting since some years ago, and by the French SAMU and the Emergency Medical System in the USA^{43,45,65-67}. In our country the first experience with NIV was by the Public Health Emergencies Enterprise (EPES) of Andalusia, which since 2005 has equipped all its ground and air mobile with Boussignac CPAP devices. Also noteworthy is the

CPAP protocol initiated in the Emergency Services of the Canary Islands, where an ARF patient can be treated by a nurse after indication by a doctor from the coordination centre.

We found only one study⁶⁸ performed in Spain, in 2002 by Mas et al, referring to the pre-hospital setting. These authors showed that patients admitted to the ICU who had received prehospital NIV required fewer days of hospitalization, shorter NIV duration in both COPD and CPE, significantly less decrease in frequency rate and normalized gasometric parameters (pH and pCO₂) on arrival at ED.

Training of both ED physicians and nurses together with experience in managing patients with respiratory disease, and an adequate selection of patients meeting the criteria for this procedure, will facilitate the achievement of good results^{1,7,11,69}.

Similarly, organizing training programs may increase the number of patients treated with NIV and result in greater success of results⁷⁰.

Table 5. Continuous monitoring of patients undergoing NIV^{1,5-7,11}

1. Maintain close communication between nursing staff and the patient, providing assurance.
2. The patient should be seated, with loose limbs.
3. Application of oxygen with FiO₂ ≥ 0.5 while preparing the NIV.
4. Approach via a peripheral vein to administer drugs and fluid, as well as to extract samples for laboratory tests. Prehospital samples are very useful.
5. Control O₂ saturation by pulse oximetry, with gasometry when possible (measurements obtained in the pre-hospital phase being most useful).
6. Continuous assessment of heart rate and respiratory work.
7. Continuous assessment of heart rate and the frequency by ECG monitoring.
8. Control of hemodynamic status using the temperature and skin color, PAS, capillary filling, diuresis, etc.
9. Continuous assessment of level of consciousness.
10. Ensure that no contra-indications for NIV are present initially or during evolution (failure of NIV).
11. Choose the proper size and model of the interface.
12. Cushion the nose bridge (if this type of interface is needed) with hydrocolloid material, which prevents the occurrence of decubitus ulcers in long periods of treatment.
13. Initially place the facial interface manually, without adjusting the harness until later, regardless of the presence of leaks.
14. Adjust the initial level of CPAP to 5 cm H₂O.
15. Increase levels of CPAP by steps of 2 cm H₂O up to a maximum of 10-12 cmH₂O.
16. Continuous assessment of the synchronization patient-ventilator interface.
17. Application of NGT for feeding, if the patient must stay longer than 48 hours continuously with this therapy, especially in cases of chronic malnutrition. NGT is also useful in the initial treatment if the patient has obvious gastric distension, which could favour bronchoaspiration.
18. Light sedation with midazolam (0.05 mg / kg iv), repeated doses if necessary.

NIV: noninvasive mechanical ventilation; SBP: Systolic blood pressure; NGT: nasogastric tube; CPAP: continuous positive pressure airway.

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Manejo de la insuficiencia respiratoria aguda con ventilación mecánica no invasiva en urgencias y emergencias

Ayuso Baptista F, Jiménez Moral G, Fonseca del Pozo FJ

La ventilación mecánica no invasiva (VMNI) es un instrumento terapéutico que puesto en manos del *urgenciólogo* como apoyo inicial al paciente con insuficiencia respiratoria aguda (IRA) puede marcar de forma definitiva la evolución de ese cuadro clínico. Múltiples ventajas que avalan la VMNI frente a las formas invasivas de ventilación: preserva mecanismos como la tos, permiten al paciente hablar o alimentarse, sin invadir la vía aérea y evita las complicaciones que ello comporta. En los últimos años han aparecido multitud de estudios que apoyan su aplicación precoz en pacientes adecuadamente seleccionados. Tras los documentos de consenso de 2001 de la *American Thoracic Society*, y en 2002 de la *British Thoracic Society* en que consideraban la VMNI como un elemento más en el manejo inicial de la IRA, tanto hipoxémica como hipercápnica, en sus diferentes modos ventilatorios, cada vez se encuentra más extendido su uso en los servicios de urgencias hospitalarios, en los equipos de emergencias, así como su aplicación domiciliaria en pacientes crónicos. En un futuro inmediato el reto es la formación de los profesionales que integran los equipos asistenciales de urgencias y emergencias, adiestrándolos en manejo de la IRA y sus bases fisiopatológicas, sin dejar a un lado el desarrollo y consolidación de la cadena asistencial en ventilación no invasiva, mediante el establecimiento de documentos de consenso interservicios. [Emergencias 2009;21:189-202]

Palabras clave: Ventilación. Insuficiencia respiratoria aguda. Servicio de urgencias.

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– **Evaluation:** The evaluation will be performed exclusively online. Registered users of the program of Continuing Medical Education EMERGENCIAS may complete the evaluation forms that will appear simultaneously with the journal. Each evaluation will correspond to an issue of the journal, starting with number 3, volume 21 (June 2009).

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