Non-invasive ventilation outside the Intensive Care Unit for acute respiratory failure

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Abstract

Non-invasive ventilation (NIV) has been shown to be an effective therapy in selected patients with acute respiratory failure. Due to its benefit and relative ease of use, NIV is frequently used. In addition, the shortage and high cost of intensive care beds have prompted the use of NIV outside the intensive care unit. Choosing the right time and type of patient with acute respiratory failure to improve the chances of success with NIV requires an appropriate environment and monitoring. This review presents and discusses the currently available data regarding NIV success outside the intensive care unit, the optimal ventilatory strategy, possible solutions to the mechanical problems and the minimum monitoring required.

Key words: Respiration, artificial - Ventilation - Emergency service, hospital.
Recently, an interestingly article pointed out some of the major problems with the effectiveness, safety, and technical/organizational aspects of NIV in general wards. The anesthesiologist on duty decided to prescribe NIV. Medical assistance was provided in conjunction with the ward personnel but could not be always be immediate. The ward nurses (medical wards usually have the least experienced nurses) were responsible for daily management of the treatment. They clearly had no experience in critical care and had received no specific training about NIV. They reported a large number of complications and problems, some potentially serious (rapid desaturation, coma, and equipment malfunction). The overall picture suggested that treatments were often prolonged more than necessary. These remarks suggest a situation of “full deregulation” of this effective and promising respiratory assistance procedure. There were several potentially dangerous drawbacks for the patient.

After having done everything to make the ICU bed available, if there is really a shortage of ICU beds, NIV in the ward might be an appropriate response to an acute clinical need. In such cases, patient population and ventilatory techniques must be carefully selected in order to maximize the efficacy (volume of patients treated per year) and minimize the risks of management of patients in respiratory distress.

Evidence of NIV success outside the ICU

The most commonly reported locations for starting NIV outside ICUs and high-dependency units were in the emergency department. More recently, there have been reports in general hospital wards, particularly on respiratory wards staffed by standard caregivers. However, to optimize the efficacy and avoid harm to patients, each hospital should have a specific, designated area staffed by personnel with appropriate experience. There should also be structures to ensure that patients requiring NIV can be transferred to this area with minimum delay.

During a period of one year, Antro et al. found that 200 NIV interventions were delivered to 190 patients admitted for acute respiratory failure. The main indications were cardiogenic pulmonary edema (70%), acute exacerbation of COPD (39%) and pneumonia (48%). The overall success rate was about 60%.

A British survey in 1998 found that NIV was available only in 48% of the 268 hospitals questioned. In particular it was available in 34% of the ICUs and 16% of the general wards. Nowadays, with the growing shortage of intensive care beds and the ease of NIV application, it is becoming increasingly common in clinical practice to start NIV outside the ICU. This was confirmed by Badger et al., who reported that in the period of 1998-99, more than 75% of NIV cases were delivered in an intensive care unit, while in the period 2000-01, 71% were administered in general wards.

Acute cardiogenic pulmonary edema

This is the most common and helpful field of NIV application. Randomized controlled trials (the best level of evidence) have demonstrated physiological improvements. However, they still do not support outcome advantages. These points are unconvincing from a clinical point of view because these studies randomized patients to a conventional medical therapy arm or an NIV arm. Since we have to accept that both arms should be safe, it is obvious that in the study arm there was very little range to demonstrate that instrumental respiratory assistance could add substantially to the medical treatment.

The only studies that give useful information are those which enrolled patients unresponsive to full medical treatment. These studies tested NIV versus invasive ventilation. A prospective trial in emergency departments with non-invasive pressure support ventilation by a mask on acute pulmonary edema patients unresponsive to full medical treatment (morphine, oxygen mask, diuretics, nitrates) showed that 90 min of NIV was enough to restore respiratory competence in the oxygen mask and to avoid the need for ICU admission. This is possible if the mean arterial pressure at emergency department admission is higher than 95 mmHg (heart response to stress reaction) and the patient does not suffer from COPD. All other patients have to be given invasive ventilatory support without delay.

NIV can be considered adjunctive therapy in patients with acute cardiogenic pulmonary edema.
ma who have severe respiratory distress or whose condition does not improve with pharmacologic therapy.

In the recent years, there have been few reports of NIV application in the pre-hospital setting.20-22 It has been applied to patients with presumed severe acute cardiogenic pulmonary edema in order to quickly stabilize vital parameters and to avoid endotracheal intubation before hospital admission. NIV as continuous positive airway pressure (CPAP) was delivered with a face mask, Boussignac circuit or head helmet. These studies demonstrate that administration of non-invasive CPAP is feasible, even in turbulent pre-hospital scenarios. This intervention is good at improving vital signs, reducing the rate of endotracheal intubations and decreasing hospital mortality.20-22

Acute exacerbation of COPD and pneumonia with marginal respiratory insufficiency

From all the available data,11, 17, 23-26 it seems feasible and reasonable to make a short trial of NIV in COPD patients presenting with acute respiratory failure. The targeted population was not severely acidic (mild to moderate acidosis with a pH of 7.25-7.35, carbon dioxide higher than 45 mmHg). The patients were free of dyspnea, tachypnea, or the use of accessory muscles. Patients had preserved neurologic status, no facial abnormality, and were cooperative and able to protect their airway. Furthermore, the patients were those whom conventional therapy did not produce a prompt clinical response. Patients with a pH lower than 7.25 were excluded because the prognosis without invasive mechanical ventilation was considered to be very poor. To not admit these patients directly to the intensive care unit would have been unethical.24

An early NIV trial rapidly separates responders from non-responders (who will have to be admitted to an ICU to continue treatment).

Concerning the clinical predictors for success in patients treated with NIV at hospital admission, Poponick et al. found only an improvement in pH and PaCO₂ during 30-min clinical trials.27 Failure to improve after 30-60 minutes of NIV should be an indication for discontinuation and conversion, if appropriate, to controlled mechanical ventilation.

Considering the strong evidence of efficacy, the shorter length of daily use (compared with other subsets of patients, e.g. hypoxemic acute respiratory failure), and the relatively low rate of failure, the use of NIV to avoid intubation in COPD patients with mild to moderate ARF (i.e. pH <7.35 and >7.25) is strongly suggested and is feasible outside the ICU. Although the need for intubation is significantly reduced (but not entirely abolished) by NIV, it is advisable to manage patients with more severe respiratory failure in the ICU, where endotracheal intubation can be done promptly. It is important to admit patients who deteriorate or do not improve despite NIV.

Postoperative patients in a surgical ward

A single retrospective study reported that NIV was administered to 40% of general surgical patients directly in a surgical ward. The majority received NIV after emergency surgery. The main reasons were chest infection, acute respiratory distress syndrome and heart failure.12

Hematological malignancy and mixed etiology

Especially in immunosuppressed patients, it is fundamental to limit the risk of nosocomial infection as much as possible. Consequently, NIV can play a significant role. Principi et al., in a small group of hypoxemic patients with hematological malignancies, found that NIV delivered directly in the hematology department with a helmet achieved better oxygenation with longer duration of application and higher survival rates than a historical group of patients.28 However, in this study the hematologist and intensivists collaborated closely in treating the patients, illustrating the importance of interdisciplinary collaboration to ensure the efficacy of NIV. They also carefully evaluated the duration of the treatment.

Pros and cons

One advantage of NIV outside the ICU is that it can be started in more patients, including “borderline” ones (old, severe disability) at an earlier stage of acute respiratory failure because it requires less utilization of medical resources. How far can we push the out-of-ICU stay? A significant, pro-
gressive improvement in oxygenation and respiratory mechanics after the first 2-3 hours of treatment probably selects a patient population that is unlikely to need endotracheal intubation. This is the case in acute cardiogenic pulmonary edema or acute lung injury in a general ward or in emergency department. This is also the case in busy locations that cannot be occupied by a single patient for a long time.

The situation presents a challenge for pathologies needing longer treatment to reach autonomy. Generally, these patients have pneumonia and are in a ward. To date, there is little information on this issue. Great care is needed in these cases to avoid delayed (and therefore risky) intubation. Furthermore, a delay in endotracheal intubation can facilitate further lung deterioration, risk of aspiration, cardiac dysfunction and mental deterioration. A crucial point is the planning by supervisory and ward personnel. These people must anticipate the criteria for ICU admission.

Types of NIV and technical problems

One of the main issues related to the most popular techniques is the choice of NIV technique (CPAP for hypoxemic patients; CPAP and pressure support [PSV] for hypercapnic patients). Although simplistic, this scheme should be applicable to the vast majority of patients. One exception that can be easily predicted is acute cardiogenic pulmonary edema. This event is frequently combined with different degrees of hypercapnia that usually respond well to CPAP alone. It can be argued that if CPAP is effective, then CPAP plus PSV should be even better. From a physiological point of view, this is certainly true. The adjunctive unloading of the respiratory muscles provided by PSV should help. However, we have always to take into account the feasibility of such an approach. Non-invasive PSV is often administered using standard intensive care ventilators. However, portable devices that deliver pressure-limited ventilation are used more frequently. These devices are referred to as "bilevel" because they cycle between two different levels of positive pressure. They are also lighter and more compact than standard intensive care ventilators. The performance of these ventilators is quite good.

CPAP can be implemented without a ventilator. A continuous flow system is much easier to install than the demand flow system necessary to provide PSV, and it is much better suited for use outside the ICU. Continuous flow systems have less room for patient-machine interaction issues and the learning time is shorter than for a demand flow system. Continuous flow systems are also cheaper. They should be preferred to demand flow systems whenever clinically indicated (for hypoxemic patients).

Nasal CPAP is mainly employed in neonatology for patients with obstructive sleep apnea. The non-invasive CPAP systems of greatest interest in this paper are the helmet, the traditional CPAP circuit and the Boussignac CPAP.

Helmet CPAP

A helmet requires a high flow of fresh gases to avoid rebreathing. This system becomes unacceptable if the inflow to the helmet drops below 30 L/min. Outside the ICU, the most common sources of fresh gases are different "modified" Venturi systems fed by the conventional hospital oxygen supply lines. These systems are usually very efficient and can provide up to 100 L/min of fresh gas with an oxygen fraction in the range of 0.35-0.45. In order to increase the inspiratory concentration of oxygen, the "modified" Venturi system has an additional source of oxygen (oxygen fraction up to 0.6-0.7). In extreme hypoxemic conditions, the Venturi system can be blocked to administer 100% of oxygen at an adequate flow rate. With such a high flow, adequate pneumatics of the circuit are ensured. There should be no need for a reservoir bag, such as in a traditional CPAP circuit. However, to make sure that the airway pressure is really "continuous and positive," a check must be made that the flow through the PEEP valve is uninterrupted.

It is important to note that a mechanical ventilator must not be used to provide helmet CPAP since it cannot be expected to provide a gas flow high enough to avoid rebreathing.

PEEP can be administered through a traditional water valve or, perhaps more conveniently, through a less cumbersome mechanical valve. In any case, direct measurement of the PEEP administered is recommended since any PEEP system...
can provide extra pressure through its inherent resistive properties. These properties become particularly noticeable at high flow rates. In everyday practice, this can be important when we want to evaluate the effectiveness of helmet CPAP.

We strongly discourage comparison of blood gases with helmet CPAP and the Venturi oxygen mask because of the uncertainty of the oxygen fraction. Helmet CPAP is an oxygen head tent and therefore provides a more predictable oxygen fraction than the Venturi mask. Consequently, we suggest testing the efficacy of helmet CPAP by disconnecting the PEEP valve from the circuit maintaining the unmodified oxygen fraction.

One potential danger with helmet CPAP is inadvertent disconnection from the fresh gas supply, leading to a high degree of rebreathing. Helmets are now fitted with anti-suffocation valves that delay the onset and minimize rebreathing. However, these devices can never substitute for adequate monitoring by skilled personnel.

The helmet is stabilized by cushioned arm braces. This method is simple and efficient, but should not be used continuously for long periods because it can cause the patient discomfort, arm edema and even thrombophlebitis. There is a lack of data specifically addressing this issue. Therefore, we suggest using different anchorage points, such as the bed frame, when treatment is likely to exceed a few hours.

The patient inside the helmet may complain of excessive noise and a reversible reduction in tympanic compliance. To minimize this, we suggest reducing the unnecessarily high flow generated by the Venturi system, positioning an HME filter in the inspiratory limb to act as a muffler and, if appropriate, providing ear plugs for the patient.

**Traditional CPAP circuit**

This comprises a conventional ventilator circuit with a Y-piece, a large balloon reservoir and an interface (usually an oronasal face mask). The reservoir is necessary to minimize the protoinspiratory pressure drop due to elevated initial flow demand. Unlike the helmet, this circuit is rigid with a very low compliance. Therefore, the reservoir chamber should be used. Recently, a simplified circuit fed by the "modified" Venturi system described above has been proposed. The high flow from the Venturi system is used in place of the reservoir. However, we still have to stress that monitoring the uninterrupted flow through the PEEP valve is more important than with the helmet. Once again, the "true" PEEP administered oxygen fraction up to 1 cannot be continually checked.

Unlike the helmet, CPAP can be provided by the mechanical ventilator since rebreathing is not an issue with the conventional circuit. If a full face mask is applied instead of the traditional oronasal one, the problem of increased dead space may arise. For CPAP delivered by the mechanical ventilator, all the limitations inherent to a demand flow system must be taken into consideration.

**Boussignac CPAP**

This system is centered on a very smart "virtual" PEEP generated by the acceleration of oxygen-air injected through several small holes drilled inside a small connector directly connected to the face mask. The PEEP value is related to the oxygen flow. Approximately 22 and 30 L/min are necessary to generate 5 and 10 cmH₂O of PEEP, respectively. The whole system is very handy and particularly easy to manage during transportation inside and outside the hospital. Even if it is not quite as efficient as the helmet, from a pneumatic standpoint, it compares favorably with the demand flow CPAP system. The oxygen fraction cannot be adjusted since it depends on the patient's respiratory drive and PEEP. In fact, the lower the PEEP, the lower the oxygen flow and consequently the lower the oxygen fraction. This is especially true in patients with a high inspiratory flow rate.

**Humidification**

During spontaneous breathing, the inspired air is heated to body temperature. It is then humidified by the upper airways so it is fully saturated at the alveoli. During NIV, the upper airways are not bypassed, so theoretically they should adequately heat and humidify the medical gases. Normally, the gases are drier and colder than normal ambient air. A recent review on NIV concluded that humidification of the medical gases is usually unnecessary during short-term application of
However, the last international consensus conference stated that inadequate humidification may cause patients distress, especially if the gases are supplied through a pipeline or from a cylinder. In addition, there is still no information on the optimal level of humidity for inspired gases during NIV. The American National Standards Institute suggested - although not directly for NIV - that 10 mH₂O/L of absolute humidity is the lowest acceptable level needed to minimize mucosal damage of the upper airways. It was recently shown that the helmet could act as a "mixing chamber" between the heated and humidified expired gases and the dry medical gases entering the helmet. However, the level of humidity was acceptable only with a ventilator CPAP and not with a continuous flow CPAP. Thus, the use of a heated humidifier is probably indicated with continuous flow CPAP and with the face mask. In these two systems, there is insufficient mixing between the expired and inspired gases, especially for a prolonged period of treatment.

Monitoring

The minimum suggested monitoring for NIV patients should include regular assessment of the respiratory, hemodynamic and neurologic functions by adequately trained personnel 24 hours/day. This implies:

1) Monitoring of arterial blood gases after one hour of NIV and at least every two hours thereafter. Continuous monitoring of cutaneous oxygen saturation should occur. Caregivers need to know the factors that can influence this, including anemia, ambient light, motion artifacts, skin pigmentation or skin perfusion.

2) Circulatory assessment should be completed, consisting of non-invasive blood pressure every 5-10 min, skin perfusion, (cold, clammy, cyanotic) and urinary output.

3) EKG with continuous monitoring of rhythm at the second lead should be done. If possible, ST analysis should be completed.

4) Overall continuous clinical evaluation should be completed, including assessment of adequacy of respiratory mechanics, use of accessory muscles, and, above all, neurological status.

5) A standardized supervision system on length of treatment is needed (call if oxygen saturation in 1 hour does not reach 90% or falls below this level). Complete material for emergency intubation should be immediately available.

Personnel and staff implications

The British Thoracic Society suggests that all staff involved in NIV should receive training appropriate to their baseline knowledge and role. This training must include knowledge-based learning supported by clinical experience. The planning must include type of ventilation, setup, and basic monitoring required. Planning by the supervising team with ward personnel is vital. A schedule for visits and clear criteria for unscheduled alerting should be explained and shared with all nursing staff concerned. A beeper or dedicated phone number should be available to the staff for alerting the supervising team in case of emergency.

Hospital experts should do the teaching, and they should be encouraged to share their knowledge and train new instructors, promoting a kind of "chain effect." Refresher courses should be planned. The experts are those who routinely apply these techniques in clinical practice. In Italy, the experts are mainly anesthesiologists. However, depending on the circumstances, it might be a pneumologist, emergency physician, or nurses in the units. These experts (critical-care specialist on duty and a critical-care trained nurse) form the supervising team for 24-hour decision making. This team supports the "normally" trained nurses and specialist ward doctors.

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Received on February 2, 2009. – Accepted for publication on April 6, 2009.

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