Invasive and non-invasive mechanical ventilation

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Abstract

Early recognition of patients who might potentially require ventilatory support is a key goal of critical care outreach programs and an important skill for all hospital medical staff. Decisions about the initiation and timing of invasive ventilation can be difficult and early discussion with critical care colleagues is essential. Appropriateness of invasive ventilatory support may also be an issue requiring advanced discussion with patients and their families. In the past 10–15 years, the role of non-invasive ventilation (NIV) has expanded, not least in an attempt to minimize the complications inherent with invasive ventilation. As such, NIV is now considered first-line therapy in some conditions (chronic obstructive pulmonary disease, pulmonary oedema, mild-to-moderate hypoxaemic respiratory failure in immunocompromised patients), and a 'trial of NIV' is often considered in respiratory failure resulting from an increasingly wide range of causes. When using NIV, the importance of the environment (setting, monitoring and experience of staff) and forward planning cannot be overemphasized. When used for other than the standard indications, NIV should be employed in a high-dependency/intensive care setting only in patients for whom invasive ventilation would be considered.

Keywords intensive care; mechanical ventilation; non-invasive mechanical ventilation; respiratory failure

Introduction

Indications for ventilation

Early identification of critically ill patients, before the occurrence of significant cardio-respiratory decompensation, is one of the major goals of critical care outreach programmes. Patients who require ventilatory support often develop a common pattern of physiological deterioration including:

- increasing respiratory rate
- asynchronous respiratory pattern
- a change in mentation and level of consciousness
- frequent oxygen desaturation despite increasing oxygen concentration
- hypercapnia and respiratory acidosis
- circulatory problems, including hypotension and atrial dysrhythmias.

Modern ventilators

The modern ventilator is a complex computer-driven tool and a detailed description of its modes and use are beyond the scope of this article (see Further reading). In simple terms, it mixes air under pressure with variable oxygen concentrations to provide inspiration and expiration, each 'breath' is characterized by three factors, which can be adjusted by the operator;

- **Trigger:** the ventilator can deliver a breath according to a timer that defines a specific set rate (ventilator initiated/mandatory breaths), or as a result of the patient's own breathing efforts effecting a change in the pressure or flow in the ventilator circuit (patient-initiated/spontaneous breaths).
- **Target:** the flow of air into the lung can be to a specific target flow rate (volume control) or pressure (pressure control; pressure support; bi-level)
- **Termination:** the signal for the ventilator to finish inspiration and allow expiration (passive) may be the achievement of a specific volume (**volume-cycled**: volume control), after a specific time (**time-cycled**: pressure control/bi-level) or following the reduction of inspiratory flow to a preset level (**flow-cycled**: pressure support)

Non-invasive ventilation (NIV)

NIV refers to the provision of respiratory support without direct tracheal intubation. As such, it aims to avoid some of the complications inherent with invasive ventilation, such as the need for sedation with risks of haemodynamic instability and subsequent risk of delirium, nosocomial infection, etc.[1] In a recent worldwide survey, use of NIV increased from 4% to 11% of all episodes of mechanical ventilation between 2001 and 2004 respectively, with even higher rates of use in some European countries.[2] Indeed, for some situations it is considered the first-choice mode of ventilatory support (Table 1: **Evidence for use**). However, it may not be appropriate for all patients, particularly as it is being used increasingly outside of the traditional critical care setting (Table 2 – **Indications/Contraindications for NIV**).

NIV today consists almost exclusively of the delivery of positive pressure ventilation via an external interface. There are six broad types of interface available, each with its own particular benefits and drawbacks (see Further reading):

- total face masks (enclose mouth, nose eyes)
- full face masks (enclose mouth and nose)
- nasal mask (covers nose but not mouth)
- mouthpieces (placed between lips and held in place by lip seal)
- nasal pillows or plugs (inserted into nostrils)
- helmet (covers the whole head/all or part of the neck – no contact with face).

NIV can be delivered using most modern 'intensive care' ventilators. For sicker patients this has several advantages (ability to deliver higher and precise concentrations of oxygen; separate inspiratory/expiratory limbs minimizing re-breathing of CO_2; better monitoring/alarm features; and rapid access to invasive

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Recommendations for use of non-invasive ventilation to treat acute respiratory failure

Recommendations based on levels of evidence[21]

Level 1 evidence

Systematic reviews (with homogeneity) of RCTs and individual RCTs (with narrow CIs)

Evidence of use (favourable)

- COPD exacerbations
- Facilitation of weaning/extubation in patients with COPD
- Cardiogenic pulmonary oedema
- Immunosuppressed patients

Evidence of use (caution)

- None

Level 2

Systematic reviews (with homogeneity) of cohort studies—individual cohort studies (including low-quality RCTs; eg, <80% follow-up)

Evidence of use (favourable)

- Do-not-intubate status
- End-stage patients as palliative measure
- Extubation failure (COPD or congestive heart failure) (prevention)
- Community-acquired pneumonia in COPD
- Postoperative respiratory failure (prevention and treatment)
- Prevention of acute respiratory failure in asthma

Evidence of use (caution)

- Severe community-acquired pneumonia
- Extubation failure (prevention)

Level 3

Systematic reviews (with homogeneity) of case–control studies, individual case–control study

Evidence of use (favourable)

- Neuromuscular disease/kyphoscoliosis
- Upper airway obstruction (partial)
- Thoracic trauma
- Treatment of acute respiratory failure in asthma

Evidence of use (caution)

- Severe acute respiratory syndrome

Level 4

Case series (and poor-quality cohort and case–control studies)

Evidence of use (favourable)

- Very old age, older than age 75 years
- Cystic fibrosis
- Obesity hypoventilation

Evidence of use (caution)

- Idiopathic pulmonary fibrosis

CI, confidence interval; COPD, chronic obstructive pulmonary disease; NIV, non-invasive ventilation; RCTs, randomized controlled trials. (Reprinted from *Lancet*, vol. 374; 250–259. Nava S, Hill N, Non-invasive ventilation in acute respiratory failure. With permission from Elsevier).

Table 1

ventilation). Outside of the ICU, NIV is commonly applied using smaller, 'simpler' but increasingly sophisticated 'non-invasive' ventilators, which can provide a range of respiratory support modes. Pressure-cycled modes are generally preferred (accommodation of leaks), and breaths can be either patient-triggered (pressure support or bi-level positive airway pressure (BiPAP)), or initiated and controlled by the ventilator (pressure control). Indeed, both modes are often used synergistically to provide back up when triggering is poor or if patient respiratory rate is unreliable, and to cover potential apnoeic episodes.

Acute hypercapnic respiratory failure

Patients with acute hypercapnic respiratory acidosis secondary to an acute exacerbation of chronic obstructive pulmonary disease (COPD), represent the most extensively studied group, and the greatest evidence for benefit exists in COPD.[3–6] Numerous studies and meta-analyses have confirmed that use of NIV is associated with reduced risks of treatment failure (RR 0.48), lower intubation rates (RR 0.41) with lower incidence of nosocomial infections, and a reduction in mortality (RR 0.52) with subsequent reduced hospital length of stay and costs.[7] These benefits have been shown predominantly in patients with mild-to-moderate hypercapnic respiratory failure (pH 7.30–7.34). As such, NIV should be considered first-line therapy for this patient group, and can be safely used in appropriately staffed and monitored environments outside of the ICU.[4] This does not preclude the use of NIV in patients with more severe respiratory failure,[8–10] and a pH as low as 7.20 may still be compatible with favourable outcomes. However, such patients should be managed in a high-dependency environment, to allow for rapid escalation to intubation and invasive ventilation if appropriate.

The importance of an established structure for effective NIV delivery cannot be overemphasized. Early initiation by experienced and skilled staff, appropriate environments and monitoring, and protocols to aid patient selection and subsequent decision making are key to the successful and safe application of NIV in all forms of respiratory failure[11] (Figure 1).

Although treatment failure is uncommon in mild-to-moderate respiratory failure, it becomes increasingly frequent in sicker (lower pH and/or significant hypoxaemia) patients (Table 2). Common causes of NIV failure include interface leaks and patient asynchrony with the ventilator (Table 2). In experienced hands, such issues can be recognized early and rapidly remedied; if this is not possible, intubation and invasive ventilation will need to be considered.[11,12]

The appropriateness of invasive ventilation in patients with COPD can be a contentious issue. However, recent evidence suggests more favourable outcomes than predicted, with stable or even improved quality of life in most patients.[13] Decisions about the extent of future intervention should be made by a senior physician, taking into account factors such as functional status, previous pulmonary function tests, existing co-morbidities, body mass index, the need for long-term oxygen therapy and the patient's expressed wishes; ideally before the initiation of NIV. The outcome should be documented in the medical record and communicated to the patient/family as appropriate.

Non-invasive ventilation: indications, contraindications and predictors for failure

Indications

Clinical observation

- Moderate to severe dyspnoea
- Tachypnoea (>25–30 breaths/minute)
- Signs of increased work of breathing (abdominal paradox; accessory muscle use)

Fatigue

- Drowsiness, laboured breathing

Features of CO_2 retention

- Delirium/confusion
- Hypercapnic flap
- Bounding pulse
- Drowsiness

Gas exchange

- Acute-on-chronic respiratory failure: pH <7.35; pCO_2 >6
- Hypoxaemia (use with caution): paO_2/FiO_2 <27 Kpa

Contraindications	**Potential solution**
Facial burns/trauma/recent facial upper airway surgery	Rarely role for NIV – invasive ventilation standard therapy
Vomiting	Treat cause, anti-emetics consider NG tube
Upper gastrointestinal surgery	Varies on type of surgery and also time from surgery
Copious respiratory secretions	Chest physiotherapy, adequate breaks off NIV (if possible) and treatment of infection – consider early IMV
Severe hypoxaemia	HDU/ICU setting – consider early IMV
Haemodynamically instability	HDU/ICU setting – consider early IMV
Severe co-morbidities	Clearly define role of NIV/IMV - palliative care may be more appropriate
Confusion/agitation	HDU/ICU setting – cautious and controlled pharmacological therapy and appropriate interface. Consider early IMV
Low Glasgow coma score	Those with a low Glasgow coma score (<8) due to hypercapnia, can have a good response to NIV: normally seen immediately. **Do not instigate NIV when invasive ventilation is immediately indicated**.
Unable to protect airway	Consider the above. Invasive ventilation likely
Bowel obstruction	NG tube drainage and/or surgery - consider early IMV
Respiratory arrest	No role for NIV; needs invasive ventilation

Predictors of failure of NIV

Hypercapnic respiratory failure

- No improvement or worsening pH within 1–2 hours of effective NIV therapy
- High acuity illness at outset (multi-organ dysfunction; SAPSII score >34)
- Lack of cooperation

Hypoxaemic respiratory failure

- Minimal improvement in oxygenation (PaO_2/FiO_2) after 1–2 hours of effective NIV therapy
- High acuity illness at outset (multi-organ dysfunction; SAPSII score >34; pneumonia with or without sepsis; ARDS)
- Lack of cooperation
- Older age

ARDS, acute respiratory distress syndrome; HDU, high-dependency unit; ICU, intensive care unit; NG, nasogastric; NIV, non-invasive ventilation.

Table 2

Acute pulmonary oedema

The use of NIV (including continuous positive airway pressure (CPAP)) to treat respiratory failure secondary to acute pulmonary oedema is widespread.[14–17] Several meta-analyses have established benefit, including decreased intubation rate (CPAP/bi-level) and mortality (CPAP) compared to standard medical therapy.[18] However, these findings were not borne out in a recent randomized control trial,[19] even though physiological improvements occurred earlier in the NIV arms (CPAP/bi-level). The low rate of intubation (<3%), and the potential for crossover

STAGE 1 (Pre-NIV)

- Diagnose need for NIV (**Fig. 1;2**)
- Inform patient of NIV procedure
- Ensure on Maximal Medical Therapy
- Decide Escalation plan if treatment fails
- Decide area of application of NIV (i.e. Ward/HDU/ICU)

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STAGE 2 (NIV application)

- Size "interface" - hold it in place to familiarise the patient
- Ensure adequate Monitoring
  - Continuous ECG monitoring
  - Continuous Pulse oximetry
- Set up the ventilator – reasonable starting set up:
  - Mode: Spontaneous/timed
  - EPAP (CPAP/PEEP): 5-8 cmH_2O
  - IPAP (PS/ASB): 12-15 cmH_2O
  - Triggers: Max sensitivity
  - Back up rate: 12-15/min
- Once set up, hold the mask in place for the first few minutes and then secure the interface
  - Ensure comfortable fitting
  - Minimise leak
  - Poor tolerance leads to higher incidence of NIV failure/invasive ventilation
- Re-assessment early
  - ABG's after 1 hour minimum (**Early improvement predicts success)**
  - Thereafter minimum at 4 and 12 hourly
- ABG 1 hourly after any ventilator change
- Ensure Maximal Medical therapy continues
- Titrate FiO_2 to target
  - SaO_2 88-92% in hypercapnic respiratory failure

↓

STAGE 3 (Treatment Progress/Adjustment)

- Titrate IPAP rapidly in 2-5 cm increments at a rate of approximately 5cms H2O each 10-20mins
- Review and manage any new complications (example Pneumothroax)
- PaCO2 fails to improve
  - Too much O2 –aim appropriate SaO2
  - Exclude/correct mask leaks
  - Ensure circuit set up properly
  - Check exp valve (i.e. not re-breathing CO2)
  - Is patient triggering appropriately-adjust to maximum trigger if needed
  - Is ventilation adequate -consider increasing IPAP to tolerable levels
- PaO2 remains low
  - Mask leak
  - Increase FiO2
  - Increase EPAP/CPAP

Note, Monitor ABG at least 1 hour after every ventilator change

- If treatment unsuccessful
  - Review stage 3
  - If no room for improvement/ongoing deterioration -***Initiate process for invasive ventilation or palliation as per escalation plan***

Figure 1

between the study arms may have limited the ability to document improvements with NIV. The European Cardiology Task Force[20] for diagnosis and treatment of cardiogenic pulmonary oedema recommends NIV/CPAP as first-line treatments in addition to standard medical therapy when respiratory failure is present.

Hypoxaemic respiratory failure

There is conflicting evidence for the use of NIV in hypoxaemic respiratory failure.[21–24] A recent meta-analysis where NIV in addition to standard therapy was compared to standard therapy alone, in hypoxaemic respiratory failure not related to pulmonary oedema, reported improvements in intubation rate, mortality and hospital length of stay with the use of NIV.[22] However the literature in this area is hampered by marked heterogeneity between the study populations in both cause and severity of respiratory failure – in particular the frequency of pre-existing COPD. Therefore, although some studies suggest benefit, routine use of NIV in severe pneumonia or acute respiratory distress syndrome (ARDS) cannot be recommended. However, in immunocompromised patients, studies have shown early NIV use to be beneficial in the management of hypoxic respiratory failure, particular in patients with solid organ transplantation, haematological malignancies and HIV infection.[25–27] NIV should be considered in such patients, preferably in a high-dependency/ICU environment with rapid access to invasive ventilation and multi-organ support.

NIV in weaning from invasive ventilation

In an attempt to limit exposure to the risks of invasive mechanical ventilation, NIV is being used increasingly to promote earlier extubation and prevent re-intubation. Present evidence suggests it is most likely to be beneficial in COPD patients, medical patients with multiple morbidities who are likely to fail on extubation and those with hypercapnia during spontaneous breathing trials.[28]

NIV in other conditions

With increasing expertize in its use, it is not surprising that clinicians have been keen to exploit the potential benefits of NIV over invasive ventilation in other[29,30] forms of respiratory compromise (Table 1). It is important to recognize that in some conditions the literature represents small series from experienced centres and the importance of the environment and forward planning cannot be overemphasized. In these circumstances we would recommend that NIV should be employed in an intensive care setting only if invasive ventilation would be considered for the patient.

Invasive ventilation

Invasive mechanical ventilation requires access to the trachea, most commonly via an endotracheal tube, and represents the commonest reason for admission to the ICU. Large multinational surveys confirm the common indications for invasive ventilation to be:[2]

- coma 16%
- COPD 13%
- ARDS 11%
- heart failure 11%
- pneumonia 11%
- sepsis 11%
- trauma 11%
- postoperative complications 11%
- neuromuscular disorders 5%.

Initiation of ventilation in the critically ill

Decisions about the initiation and timing of invasive ventilation can be difficult and early discussion with critical care colleagues is essential. Appropriateness of ventilatory support may also be an issue requiring advanced discussion with patients and families. Once a decision to intubate has been made, the transition from an awake and self-ventilating patient to controlled invasive ventilation can be very difficult in the critically ill. Most patients will have evidence of developing or established organ dysfunction, particularly cardiovascular dysfunction (ischaemic heart disease, sepsis), and commonly such patients are hypovolaemic. Both anaesthetic induction agents and positive pressure ventilation (which decreases venous return) produce cardiovascular depression and peri-intubation hypotension is common. In addition, cessation of spontaneous ventilation can lead to very rapid desaturation in such patients, due to their marginal respiratory reserve and circulatory problems. Such consequences need to be anticipated: large-volume cannulae should be in place; access to plasma expanders and inotropes should be immediately available; and following induction of anaesthesia the airway must be rapidly secured by an experienced member of the critical care team – ideally in an appropriately equipped area of the hospital.

Descriptions of individual ventilatory strategies are beyond the scope of this chapter. However, over the past 10–20 years there has been increasing recognition that invasive ventilation, although lifesaving, can be associated with significant complications, such as nosocomial pneumonia, critical illness neuromyopathy syndromes and barotrauma (pneumothoraces); and ventilation itself may be associated with propagation of underlying lung injury and subsequent worsening of multi-organ failure.[31,32] The landmark NIH ARDS network trial[33] confirmed that in patients with acute lung injury, the use of a reduced tidal volume (6 ml/kg) and avoidance of high airway pressures (<30 cmH_2O) were associated with improved mortality (31% vs. 39.8% (NNT ≈ 11)) when compared with a conventional ventilatory approach. Although it is not without controversy,[34] this and subsequent studies form the basis for management of patients with **hypoxaemic respiratory failure**. Although individual patients differ, key concepts include:

Ventilator-specific strategies

- Low tidal volume (6 ml/kg ideal bodyweight) and avoidance of high inspiratory pressures ($P_{plat} < 30$) to minimize the risk of volutrauma[33]
- Reduced oxygenation targets (SaO_2 88–95%; pO_2 7.5–10.5) – 'permissive hypoxia'
- Acceptance of mild–moderate respiratory acidosis – 'permissive hypercapnia'
- Greater use of positive end-expiratory pressure (PEEP), particularly in more severe hypoxaemia[35] (**NB: PEEP should be used cautiously and may be contraindicated in obstructive airways disease**)
- Early use of neuromuscular blockade in severe cases[36]

General strategies

- Avoidance of excessive fluid administration
- Minimizing sedation once acute insult has settled – daily sedation holds (interruption of sedation), use of sedation scores[37]
- Daily trials of spontaneous breathing and protocolized weaning once initial insult has resolved[38]
- Early and appropriate nutritional support
- Deep vein thrombosis prophylaxis
- Stress ulcer prophylaxis

More recently, attention has turned to the use of extracorporeal support in patients with extreme gas exchange abnormalities. In the recent CESAR study,[39] transfer to a centre capable of delivering extracorporeal membrane oxygenation (ECMO) was associated with improved outcome (death or disability) at 6 months. This study and the high-profile success of ECMO in the H1N1[40] influenza pandemic has resulted in a resurgence of interest in this technique. Simpler forms of extracorporeal support exist where hypercapnia is the predominant problem.[41] The development of these and other specialist techniques, along with a recognized volume–outcome relationship for mechanical ventilation,[42] has promoted the concept of advanced respiratory support centres to manage the sickest patients.

Longer term, there is an increased recognition that survivors of critical illness can be left with significant physical, mental and psychological sequelae[43] and early rehabilitation and ICU follow-up programmes have evolved to address these issues. ◆

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FURTHER READING

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