

Non-invasive ventilation in acute respiratory failure

British Thoracic Society Standards of Care Committee

Thorax 2002;**57**:192–211

INTRODUCTION

Nomenclature

Non-invasive ventilation (NIV) refers to the provision of ventilatory support through the patient's upper airway using a mask or similar device. This technique is distinguished from those which bypass the upper airway with a tracheal tube, laryngeal mask, or tracheostomy and are therefore considered invasive. In this document NIV refers to non-invasive positive pressure ventilation, and other less commonly used techniques such as external negative pressure or rocking beds will not be discussed. (NIPPV is an alternative abbreviation but it is more cumbersome and involves ambiguity as to whether "N" is for "non-invasive" or "nasal".)

Continuous positive airway pressure (CPAP) in this document refers to the non-invasive application of positive airway pressure, again using a face or nasal mask rather than in conjunction with invasive techniques. Although it might be open to debate as to whether the use of non-invasive CPAP in acute respiratory failure constitutes ventilatory support, it is included in this document because of the confusion which commonly arises between NIV and CPAP in clinical practice.

Background

One of the first descriptions of the use of NIV using nasal masks was for the treatment of hypoventilation at night in patients with neuromuscular disease.^{1,2} This has proved to be so successful that it has become widely accepted as the standard method of non-invasive ventilation used in patients with chronic hypercapnic respiratory failure caused by chest wall deformity, neuromuscular disease, or impaired central respiratory drive. It has largely replaced other modalities such as external negative pressure ventilation and rocking beds.

Within a few years of its introduction, NIV was starting to be used in acute hypercapnic respiratory failure and in patients with abnormal lungs rather than an impaired respiratory pump. Initial anecdotal reports were followed by larger series and then by randomised trials. Analysis of these trials has shown that NIV is a valuable treatment for acute hypercapnic respiratory failure, as will be discussed under the section on Indications. It has a number of potential advantages, particularly the avoidance of tracheal intubation with its associated mortality and morbidity from problems such as pneumonia. Pressure on intensive care unit beds is often high, and NIV can be used in other clinical areas and also at an earlier stage than tracheal intubation. Intermittent ventilatory assistance is possible with NIV, allowing gradual weaning and also normal eating, drinking, and communication. Breaks from ventilatory support can be used for giving nebulised medication, physiotherapy, and expectoration.

A survey of acute admissions in Leeds has suggested that, if NIV was used in all patients with chronic obstructive pulmonary disease (COPD) with a pH of <7.35 (H^+ >45 nmol/l) after initial medical treatment, a typical district general hospital serving a population of 250 000 would expect to treat around 70 patients per year.³

• *Non-invasive ventilation has been shown to be an effective treatment for acute hypercapnic respiratory failure, particularly in chronic obstructive pulmonary disease. Facilities for NIV should be available 24 hours per day in all hospitals likely to admit such patients. [A]*

NIV is not suitable for all patients with respiratory failure. If used indiscriminately, patients who would be managed more appropriately by tracheal intubation will receive suboptimal treatment. Use of NIV in patients in whom it is unlikely to be beneficial is also undesirable. It is essential that NIV is applied in an appropriate clinical area by appropriately trained staff using the optimal ventilator mode, settings, and interface for that patient with adequate monitoring.

• *NIV should not be used as a substitute for tracheal intubation and invasive ventilation when the latter is clearly more appropriate. [B]*

Purpose of this document

The main aims of this document are to:

- Set standards of care for patients receiving NIV in acute respiratory failure based on the available evidence and define minimum standards for the provision of an acute NIV service
- Identify which patients with acute respiratory failure should be considered for NIV or CPAP
- Describe the optimal application of different ventilatory modes and patient interfaces

Abbreviations: AHRF, acute hypercapnic respiratory failure; ARDS, acute respiratory distress syndrome; ASB, assisted spontaneous breathing; BMI, body mass index; CMV, continuous mandatory ventilation; COPD, chronic obstructive pulmonary disease; CPAP, continuous positive airways pressure; EPAP, expiratory positive airways pressure; FiO_2 , fractionated inspired oxygen concentration; FRC, functional residual capacity; HDU, high dependency unit; ICU, intensive care unit; IE, inspiratory/expiratory; IPAP, inspiratory positive airways pressure; IPPV, intermittent positive pressure ventilation; LTOT, long term oxygen therapy; NIV, non-invasive ventilation; OSA, obstructive sleep apnoea; $Paco_2$, partial pressure of arterial carbon dioxide; Pao_2 , partial pressure of arterial oxygen; PAV, proportional assist ventilation; PEEP, positive end expiratory pressure; PEEPi, intrinsic PEEP; PS, pressure support; Spo_2 , oxygen saturation; SIMV, synchronised intermittent mandatory ventilation; S/T, spontaneous/timed; V/Q, ventilation perfusion.

Members of BTS Standards of Care

Committee: S Baudouin, S Blumenthal, B Cooper, C Davidson, A Davison, M Elliott, W Kinnear (Chairman), R Paton, E Sawicka, L Turner (Secretary)

Correspondence to: Dr W Kinnear, University Hospital, Queen's Medical Centre, Nottingham NG7 2UH, UK; William.Kinnear@mail.qmculh-tr.trent.nhs.uk

Key points

- Non-invasive ventilation (NIV) works – an evidence-based verdict
 - NIV can be used in any hospital given the following minimum facilities:
 - A consultant committed to developing an NIV service
 - Nurses on a respiratory ward, high dependency unit, or intensive care unit who are keen to be involved in NIV
 - An intensive care unit to provide back up for patients who do not improve on NIV
 - A non-invasive ventilator and a selection of masks
 - NIV is particularly indicated in:
 - COPD with a respiratory acidosis pH 7.25–7.35 (H^+ 45–56 nmol/l)
 - Hypercapnic respiratory failure secondary to chest wall deformity (scoliosis, thoracoplasty) or neuromuscular diseases
 - Cardiogenic pulmonary oedema unresponsive to CPAP
 - Weaning from tracheal intubation
 - NIV is *not* indicated in:
 - Impaired consciousness
 - Severe hypoxaemia
 - Patients with copious respiratory secretions
 - The benefits of an acute NIV service are likely to be:
 - Fewer patients referred to intensive care for intubation
 - Shorter stays on intensive care
 - Fewer deaths of patients with acute respiratory failure
 - Visit the BTS and ARTP websites (brit-thoracic.org.uk and artp.org.uk) for:
 - The BTS recommendations on NIV
 - An up to date list of non-invasive ventilators
 - Suppliers of equipment for NIV
 - Details of courses and centres offering training in NIV
- Define minimal monitoring requirements and give guidance on what to do in the event of treatment failure
 - Identify which patients should be referred for long term NIV after initial treatment of their acute respiratory failure
 - Provide guidance on setting up and running a NIV service including location, staffing levels, provision and maintenance of equipment, minimisation of cross infection, and training
 - Facilitate collection of data on the use of NIV in acute respiratory failure and provide tools for audit
 - Identify areas requiring further research

This document is aimed at those who wish to set up an acute NIV service. It is also intended to help those who are seeking to expand or consolidate existing facilities, particularly where purchasers require evidence of efficacy. The provision of long term NIV at home is not covered. NIV can be used as a treatment for breathlessness in the terminal stages of progressive neuromuscular disease, but this and other specialised applications will not be discussed further. Although NIV is being introduced into paediatric practice, the published evidence is not yet strong enough for recommendations to be made about its use in children.

Definitions

Respiratory failure is defined as a failure to maintain adequate gas exchange and is characterised by abnormalities of arterial blood gas tensions. *Type 1 failure* is defined by a P_{aO_2} of <8 kPa with a normal or low P_{aCO_2} . *Type 2 failure* is defined by a P_{aO_2} of <8 kPa and a P_{aCO_2} of >6 kPa. Respiratory failure can be

acute, acute-on-chronic, or chronic. Although not always clearcut, this distinction is important in deciding on the location of patient treatment and the most appropriate treatment strategy, particularly in type 2 respiratory failure:

- *Acute* hypercapnic respiratory failure: the patient will have no, or minor, evidence of pre-existing respiratory disease and arterial blood gas tensions will show a high P_{aCO_2} , low pH, and normal bicarbonate.
- *Chronic* hypercapnic respiratory failure: evidence of chronic respiratory disease, high P_{aCO_2} , normal pH, high bicarbonate.
- *Acute-on-chronic* hypercapnic respiratory failure: an acute deterioration in an individual with significant pre-existing hypercapnic respiratory failure, high P_{aCO_2} , low pH, high bicarbonate.

Knowledge of arterial blood gases is essential before making a decision as to whether NIV is indicated. The patient should first be established on appropriate oxygen therapy and the arterial blood gases interpreted in light of the F_{iO_2} . A proportion of patients who fulfil arterial blood gas criteria for NIV (see below) at the time of admission to hospital improve rapidly with initial medical treatment with an appropriate F_{iO_2} .³ It will usually then be necessary to repeat measurement of arterial blood gas tensions to see if NIV is still needed.

Measurement of arterial blood gas tensions should be considered in all individuals with breathlessness of sufficient severity to warrant admission to hospital. In certain subgroups of patients—for example, asthmatic patients with no features of a severe attack—oxygen saturation can be used as an initial screen, proceeding to arterial blood gas analysis in those with a S_{pO_2} of <92%. However, it is important to note that oximetry alone may provide false reassurance in patients on supplemental oxygen in whom oxygenation is well maintained in the face of dangerous hypercapnia.

It should also be appreciated that there is a subgroup of patients with acute-on-chronic hypercapnic respiratory failure who have few symptoms despite severely deranged arterial blood gas tensions. In certain patients, particularly those with chest wall deformity or neuromuscular disease, breathlessness may not be a prominent symptom because exercise is limited by other factors; there should be a low threshold for performing arterial blood gas measurements in patients with these diseases who complain of morning headaches, excessive daytime sleepiness, general tiredness, malaise, or ankle oedema. Respiratory failure may occasionally present as confusion, delirium or dementia, and arterial blood gas tensions should always be considered in such patients.

- *The beneficial effects of NIV have mainly been demonstrated in patients with a respiratory acidosis (pH <7.35 (H^+ >45 nmol/l)). Knowledge of arterial blood gas tensions is therefore critical to its application. Arterial blood gas tensions should be measured in most patients with acute breathlessness. [B]*
- *Arterial blood gas tensions improve rapidly in many patients with acute hypercapnic respiratory failure when they receive maximum medical treatment and appropriate supplementary oxygen. A repeat sample should usually be taken after a short interval to see if NIV is still indicated. [B]*
- *There should be a low threshold for measuring arterial blood gas tensions in patients with neuromuscular diseases, chest wall deformity, obesity, or acute confusional states who may be in respiratory failure without significant breathlessness. [B]*

Critical care facilities are in the process of being redefined, with dependency levels ranging from 0–3.⁴ However, for the purpose of this document, a *high dependency unit* (HDU) is defined as a clinical area staffed by appropriately trained nurses at a level higher than that of a general ward, usually one member of staff for every two patients (level 2 care). An

SUMMARY OF RECOMMENDATIONS

Introduction

- NIV has been shown to be an effective treatment for acute hypercapnic respiratory failure (AHRF), particularly in chronic obstructive pulmonary disease (COPD). Facilities for NIV should be available 24 hours per day in all hospitals likely to admit such patients. [A]
- NIV should not be used as a substitute for tracheal intubation and invasive ventilation when the latter is clearly more appropriate. [B]
- The beneficial effects of NIV have mainly been demonstrated in patients with a respiratory acidosis ($\text{pH} < 7.35$, $\text{H}^+ > 45$ nmol/l). Knowledge of arterial blood gas tensions is therefore critical to its application. Arterial blood gas tensions should be measured in most patients with acute breathlessness. [B]
- Arterial blood gas tensions improve rapidly in many patients with AHRF when they receive maximum medical treatment and appropriate supplementary oxygen. A repeat sample should usually be taken after a short interval to see if NIV is still indicated. [B]
- There should be a low threshold for measuring arterial blood gas tensions in patients with neuromuscular diseases, chest wall deformity, obesity, or acute confusional states who may be in respiratory failure without significant breathlessness. [B]

Ventilators

- Many different types of ventilator have been used successfully to provide NIV in AHRF; local expertise will influence the choice of ventilator used. If possible, a single model of ventilator should be used in any one clinical area for ease of training and familiarity of staff with the equipment. [D]
- Bi-level pressure support ventilators are simpler to use, cheaper, and more flexible than other types of ventilator currently available; they have been used in the majority of randomised controlled trials of NIV and are recommended when setting up an acute NIV service. [C]
- Volume controlled ventilators should be available in units wishing to provide a comprehensive acute NIV service. [C]

Interfaces

- A selection of different sizes of nasal masks, full-face masks, and nasal pillows should be available for NIV. [C]
- Both nasal and full-face masks have been used successfully for NIV in AHRF. In the acute setting, a full-face mask should be used initially, changing to a nasal mask after 24 hours as the patient improves. [D]

Indications

- NIV may be undertaken as a therapeutic trial with a view to tracheal intubation if it fails, or as the ceiling of treatment in patients who are not candidates for intubation. A decision about tracheal intubation should be made before commencing NIV in every patient. This should be verified as soon as possible with senior medical staff and documented in the case notes. [D]
- NIV should be considered in patients with an acute exacerbation of COPD in whom a respiratory acidosis ($\text{pH} < 7.35$, $\text{H}^+ > 45$ nmol/l) persists despite maximum medical treatment on controlled oxygen therapy. [A]
- Continuous positive airway pressure (CPAP) has been shown to be effective in patients with cardiogenic pulmonary oedema who remain hypoxic despite maximal medical treatment. NIV should be reserved for patients in whom CPAP is unsuccessful. [B]
- NIV is indicated in acute or acute-on-chronic hypercapnic respiratory failure due to chest wall deformity or neuromuscular disease. [C]
- Both CPAP and NIV have been used successfully in patients with decompensated obstructive sleep apnoea. Although no direct comparison is available, NIV (in the form of bi-level pressure support) should be used for these patients if a respiratory acidosis is present. [C]
- CPAP should be used in patients with chest wall trauma who remain hypoxic despite adequate regional anaesthesia and high flow oxygen. [C] NIV should not be used routinely. [D]
- In view of the risk of pneumothorax, patients with chest wall trauma who are treated with CPAP or NIV should be monitored on the ICU. [D]
- Many patients with acute pneumonia and hypoxaemia resistant to high flow oxygen will require intubation. In this context, trials of CPAP or NIV should only occur in HDU or ICU settings. [D]
- CPAP improves oxygenation in patients with diffuse pneumonia who remain hypoxic despite maximum medical treatment. NIV can be used as an alternative to tracheal intubation if the patient becomes hypercapnic. [C] In this context, patients who would be candidates for intubation if NIV fails should only receive NIV in an ICU. [D]
- NIV should not be used routinely in acute asthma. [C]
- A trial of NIV may be undertaken in patients with a respiratory acidosis ($\text{pH} < 7.35$, $\text{H}^+ > 45$ nmol/l) secondary to an acute exacerbation of bronchiectasis, but excessive secretions are likely to limit its effectiveness and it should not be used routinely in bronchiectasis. [C]
- NIV has been used in a variety of other conditions (such as acute respiratory distress syndrome, postoperative and post-transplantation respiratory failure) with reduced intubation rates, ICU stay and mortality. In this context, patients who would be considered for intubation if NIV fails should only receive NIV in ICU. [D]
- NIV has been used successfully to wean patients from invasive ventilation, and should be used when conventional weaning strategies fail. [B]

SUMMARY OF RECOMMENDATIONS (Continued)**Contraindications**

- NIV should not be used in patients after recent facial or upper airway surgery, in the presence of facial abnormalities such as burns or trauma, if there is fixed obstruction of the upper airway, or if the patient is vomiting. [D]
- Contraindications to NIV include recent upper gastrointestinal surgery, inability to protect the airway, copious respiratory secretions, life threatening hypoxaemia, severe co-morbidity, confusion/agitation, or bowel obstruction. NIV can be used in the presence of these contraindications provided contingency plans for tracheal intubation have been made, or if a decision has been made not to proceed to invasive ventilation. [C]
- Although NIV has been used successfully in the presence of a pneumothorax, in most patients with a pneumothorax an intercostal drain should be inserted before commencing NIV. [C]

Monitoring

- Clinical evaluation of the patient should include assessment of patient comfort, conscious level, chest wall motion, accessory muscle recruitment, coordination of respiratory effort with the ventilator, respiratory rate and heart rate. Patients receiving NIV should be reviewed regularly to assess their response to treatment and to optimise the ventilator settings. [D]
- The need for arterial blood gas analysis will be governed by the patient's clinical progress but should be measured in most patients after 1–2 hours of NIV and after 4–6 hours if the earlier sample showed little improvement. If there has been no improvement in PaCO_2 and pH after this period, despite optimal ventilator settings, NIV should be discontinued and invasive ventilation considered. [B]
- Oxygen saturation should be monitored continuously for at least 24 hours after commencing NIV and supplementary oxygen administered to maintain saturations between 85% and 90%. [C]
- Breaks from NIV should be made for drugs, physiotherapy, meals, etc. Patients who show benefit from NIV in the first few hours should be ventilated for as much as possible during the first 24 hours, or until improving. [B]
- All patients who have been treated with NIV for AHRF should undergo spirometric testing and arterial blood gas analysis while breathing air before discharge. [C]
- All patients with spinal cord lesions, neuromuscular disease, chest wall deformity, or morbid obesity who develop AHRF should be referred for assessment to a centre providing long term ventilation at home. [C]

Setting up an acute NIV service

- A named consultant with appropriate training should have overall responsibility for the NIV service. This will usually be a consultant respiratory physician. [D]
- NIV can be provided in a number of locations including the ICU, a high dependency unit (HDU), or a respiratory ward. However, each hospital should have a specific designated area with an available cohort of staff with appropriate experience, together with structures to ensure that patients requiring NIV can be transferred to this area with the minimum of delay. [C]
- The clinical area in which a patient is treated with NIV will be influenced by several factors including their clinical state, whether they will be intubated if NIV fails, and the availability of beds. Taking into account the overall clinical picture, patients with more severe acidosis ($\text{pH} < 7.30$, $\text{H}^+ > 50 \text{ nmol/l}$) should be managed in a higher dependency area such as an HDU or ICU, as should those in whom improvement in clinical state and arterial blood gas tensions is not seen after 1–2 hours of NIV on a respiratory ward. [C]
- Patients with AHRF from a cause where the role of NIV is not yet clearly established (such as pneumonia, ARDS, asthma) should only receive NIV in an HDU or ICU where facilities for immediate tracheal intubation are available. [C]
- There should be a clear protocol for the on-call medical staff as to the indications for NIV, how to initiate treatment, and who has continuing responsibility for supervision of the patient. [D]
- Trained ICU staff, doctors, physiotherapists, lung function technicians, and nurses can successfully set up and maintain NIV. When setting up an acute NIV service, it is recommended that NIV be initiated and run by nursing staff. [C]
- All staff involved in an acute NIV service should receive training appropriate to their baseline knowledge and role in providing the service. Training in NIV should be available for consultants in respiratory medicine and should be included in all specialist registrar training programmes. [D]
- A training programme for the provision of an NIV service should provide a combination of knowledge based learning supported by clinical experience in the workplace. [D]
- The use of NIV in acute respiratory failure should be the subject of regular audit. In addition to collection of data on patients receiving NIV, details of the number of patients admitted with acute hypercapnic respiratory failure will be required, together with the use of invasive ventilation in these patients. [D]

Infection control and equipment safety

- Reusable masks and exhalation valves should be reprocessed in an automated washer/disinfector/drier machine after disassembly into their component parts. [C]
- A bacterial filter should be attached to the ventilator outlet during NIV and the external surface of the ventilator cleaned between patients. [C]
- Maintenance and electrical safety checks on ventilators should be undertaken according to the manufacturers' recommendations, and at least annually. [D]

intensive care unit (ICU) is defined as a unit with facilities for the management of the intubated patient, usually with a nurse:patient ratio of 1:1 (level 3 care). A general *respiratory ward* is defined as a ward admitting unselected medical, but mainly respiratory, patients.

Methodology

The Standards of Care Committee of the British Thoracic Society (BTS) selected the topic as the subject for preparation of a guideline and a subcommittee was convened. This was a multidisciplinary group including clinical experts, medical, nursing, physiotherapy, and lung function staff. Every subcommittee member completed a form declaring any potential conflicts of interest; these forms were held at the BTS offices and were tabled at meetings of the subcommittee.

A literature search was conducted on Medline, Embase and the Cochrane database covering 1966–2000, and further papers were obtained from the resulting reference lists and from the personal collections of members of the subcommittee. Keywords used were “non-invasive ventilation”, “mechanical ventilation”, “positive pressure ventilation”, “non-invasive positive pressure ventilation”, “nasal intermittent positive pressure ventilation”, “bi-level positive airway pressure”, “pressure-controlled ventilation”, “volume-controlled ventilation”, “ventilatory support”, “continuous positive airway pressure”, and “CPAP”. Searches were limited to human studies and English language.

All abstracts were reviewed and articles were selected for inclusion on the basis of containing original patient data on the use of NIV or CPAP in adults with acute respiratory failure. Evidence tables were constructed and the recommendations were graded by at least two members of the subcommittee according to the 2000 version of the Scottish Intercollegiate Guideline Network (SIGN) criteria (appendix 1). After the members had prepared their sections of this document, it was reviewed at two whole day meetings of the subcommittee and the grading for each recommendation was agreed. Further expert opinions were obtained (listed at the end of the document) and, after revision, the recommendations were presented to a national meeting of the BTS. A draft of the guideline was available on the BTS website for a period of 3 months for comment. The guidelines were reviewed by the members of the Standards of Care Committee, the Clinical Effectiveness and Evaluation Unit of the Royal College of Physicians of London, the Intensive Care Society, the Faculty of Accident and Emergency Medicine, the UK Home Mechanical Ventilation Providers Group, and the Association of Respiratory Technicians and Physiologists.

Further editorial changes were made in the light of comments received during the above process and from reviewers for *Thorax*; editorial control remained independent of all sources of funding for the guideline. The guideline group will be reconvened every 2 years to update the document and an updated version will be available on the BTS website (brit-thoracic.org.uk).

MODES OF NON-INVASIVE VENTILATION

The terminology used to describe different modes of NIV can be confusing. The following section describes the principal modes. There is no standardisation between manufacturers, and unfortunately each mode may be called by different names on different ventilators.

Controlled mechanical ventilation

In the mandatory controlled mechanical ventilation (CMV) mode, full ventilatory support is provided and no patient effort is required. Inflation pressure or tidal volume is set, as is frequency and the timing of each breath. In pressure control, the resulting tidal volume depends upon the resistance to flow of ventilator tubing, any airflow limitation, and the compliance

of the lungs and chest wall. In volume control, tidal volume is set and the resulting pressure required to deliver this volume is determined by circuit compliance and thoracic mechanics. On NIV machines CMV may be referred to as timed ventilation (T). Some ventilators allow the rise time to be ramped from a slow to a rapid increase. This facility is provided for patient comfort. The ventilator may, however, fail to reach the target pressure when the inspiratory period is short and a prolonged rise time is selected, resulting in a smaller tidal volume.

Assist/control ventilation

In assist/control mode (ACV) a preset number of mandatory breaths per minute will be delivered in the absence of patient effort. As with CMV, ventilator delivered breaths are determined by setting volume or pressure and the inspiration and expiration durations. Patient triggering is permitted but the machine delivers an identical breath to mandatory breaths. To avoid excessive inflation through breath stacking, the ventilator is programmed to fail to deliver within a variable “lock out” period. As respiratory rate is increased, the lock out period must shorten. On some ventilators, setting a long expiratory time also sets a long lock out and may lead to poor patient tolerance. Triggered breaths delay the next machine determined breath so that there is said to be synchronisation between patient triggered and machine delivered breaths (SIMV). This mode is sometimes referred to as spontaneous/timed (S/T) or IE mode on NIV machines.

Assisted spontaneous breathing (pressure support)

In assisted spontaneous breathing (ASB) the patient's respiratory effort triggers the ventilator both on and off. Respiratory frequency and the timing of each breath are therefore determined by the patient. As this mode usually involves setting pressure, it is often termed pressure support (PS). If the patient fails to make respiratory effort, no respiratory assistance will occur, although many manufacturers now incorporate a back up rate of 6–8 breaths per minute.

Continuous positive airway pressure

CPAP is employed in patients with acute respiratory failure to correct hypoxaemia. It permits a higher inspired oxygen content than other methods of oxygen supplementation, increases mean airway pressure, and will improve ventilation to collapsed areas of the lung. The recruitment of underventilated lung is similar to the use of positive end expiratory pressure (PEEP) in the intubated mechanically ventilated patient.

CPAP also unloads the inspiratory muscles and thereby reduces inspiratory work, although in hyperinflated patients with airflow obstruction any further increase in lung volume produced by CPAP may have an adverse effect on the function of the inspiratory muscles. In cases of respiratory failure due to exacerbations of COPD, the offsetting of intrinsic PEEP by CPAP (see below) may reduce ventilatory work resulting in a slowing of respiratory rate, an increase in alveolar ventilation, and a fall in P_{aCO_2} . Although this might be considered the result of respiratory assistance, conventionally CPAP is not considered respiratory support and its main indication is to correct hypoxaemia.

Flow generators employed in CPAP need to be capable of maintaining the desired pressure throughout the respiratory cycle. In domiciliary practice, as in the treatment of obstructive sleep apnoea (OSA), generators capable of low flows are sufficient as minute ventilation and peak inspiratory flow are low. In the distressed COPD patient the increased minute ventilation, high frequency, and short inspiratory time may result in peak inspiratory flow rates in excess of 60 l/min. High flows are therefore required to prevent a fall in applied pressure. Some of the newer non-invasive ventilators have a CPAP mode capable of delivering adequate flow rates. Other CPAP generators require a high pressure oxygen supply. Whisper flow systems entrain room air by the Venturi effect and

have a F_{iO_2} adjustable above a minimum 40%. The Draeger system provides for a lower F_{iO_2} as air and oxygen is independently set. A reservoir prevents a fall in mask pressure during inspiration. CPAP masks are usually pressurised by inserting a one way exhalation valve.

Bi-level pressure support

In NIV, pressure support and CPAP are often used in combination as bi-level pressure support. Ventilation is produced by the inspiratory positive airway pressure (IPAP), while the expiratory positive airway pressure (EPAP) recruits underventilated lung and offsets intrinsic PEEP (with beneficial effects on triggering). The EPAP also serves to vent exhaled gas through the exhaust port (see below).

Proportional assist ventilation

Proportional assist ventilation (PAV) is an alternative technique in which both flow—to counter resistance—and volume—to counter compliance—are independently adjusted. It may improve patient comfort and so improve success and compliance with acute NIV.⁵

NON-INVASIVE VENTILATORS

Ventilators employed in NIV range from ICU ventilators with full monitoring and alarm systems normally employed in the intubated patient, to light weight, free standing devices with limited alarm systems specifically designed for non-invasive respiratory support. Life support ICU ventilators separate the inspiratory and expiratory gas mixtures. This prevents rebreathing and allows monitoring of inspiratory pressure and exhaled minute ventilation on which monitoring and alarm limits are based. In NIV single tubing is usually employed, and exhalation is either active (the ventilator opens an exhalation valve—for example, NIPPY 1 or Breas PV 401) or passive (exhaled air is encouraged to exit an exhaust valve or port by continuous bias flow (EPAP) from the ventilator). Exhalation valves may increase work of breathing, and normally used EPAP levels (3–5 cm H_2O) do not completely eliminate rebreathing during bi-level pressure support, especially when respiratory frequency increases.⁶ This therefore needs to be considered in the tachypnoeic anxious individual who fails to improve or develops worsening hypercapnia. It is important that exhalation ports or valves are fitted and functioning properly. Occlusion of the exhaust port—for instance, by sputum—can exacerbate hypercapnia through rebreathing.⁷

Volume assist-control ventilators

Volume controlled ventilators predominated in the past but have largely been replaced by pressure devices. Some air leak is invariable with NIV, either from the mask or through the mouth, and with a volume controlled ventilator tidal volumes must be arbitrarily increased to compensate for this. Volume and pressure control modes have both been shown to be effective in COPD but few comparative studies have been reported. Vittaca *et al*⁸ found no difference in outcome whether volume or pressure ventilators were used in AHRF. Girault *et al* found greater respiratory muscle rest with volume assist, but at the cost of greater patient discomfort compared with PS.⁹ The addition of PEEP to PS was not investigated, however, which might have reduced work of breathing. Some experts would wish to use a volume ventilator for the more difficult patient and Schoenhofer *et al* reported that some patients failed to be managed with pressure timed support but were successfully treated by volume control.¹⁰ One explanation might be that volume control is better at ensuring alveolar ventilation when compliance or airway resistance changes. This is probably not important in acute NIV as patient monitoring would detect failure to correct hypercapnia. Similarly, glottic narrowing, which may limit the effectiveness of the

timed mode as the glottic aperture will not be in phase with mechanical breaths,^{11 12} is probably only of relevance to domiciliary practice.

Pressure assist-control ventilators

Technical developments such as microprocessor controlled valves have led to most NIV ventilators now being pressure controlled flow generators. Smith and Shneerson carried out a bench comparison of ventilators and showed the expected better leak compensation of pressure control.¹³ The decelerating flow profile of a pressure controlled breath may result in better distribution of ventilation while, in the ICU, recognition of subtle forms of ventilator associated lung damage has resulted in a move to pressure limited small volume ventilation. This is typified by the recruiting “permissive” hypercapnia ventilation strategies now recommended in acute lung injury.¹⁴

Bi-level assisted spontaneous breathing ventilators

Ventilators used for non-invasive assisted spontaneous breathing (pressure support) usually use two different pressures: inspiratory positive airway pressure (IPAP) to assist inspiration, and a lower expiratory positive airway pressure (EPAP). As with other pressure controlled ventilators, compensation is made for air leakage. EPAP eliminates exhaled air through the expiratory port, thus reducing re-breathing, encourages lung recruitment, and stents open the upper airway. Most recent randomised controlled trials of NIV in AHRF have used this mode of ventilation. One study in patients with acute COPD failed to demonstrate significant benefit with bi-level over pressure support¹⁵ while, in patients with stable neuromuscular disease, the addition of PEEP to PS increased overnight oxygenation.¹⁶ Appendini *et al* also found greater reduction in work of breathing with the addition of PEEP in acute COPD.¹⁷ In patients with COPD, EPAP overcomes the effects of intrinsic PEEP (see below). The significant re-breathing potential of these ventilators has been reported, only eliminated by excessively high expiratory pressure (EPAP). Machines were also variable in their speed of response and in the time to reach set pressure.⁶

- *Many different types of ventilator have been used successfully to provide NIV in AHRF; local expertise will influence the choice of ventilator used. If possible, a single model of ventilator should be used in any one clinical area for ease of training and familiarity of staff with the equipment. [D]*
- *Bi-level pressure support ventilators are simpler to use, cheaper, and more flexible than other types of ventilator currently available; they have been used in the majority of randomised controlled trials of NIV and are recommended when setting up an acute NIV service. [C]*
- *Volume controlled ventilators should be available in units wishing to provide a comprehensive acute NIV service. [C]*

Triggering

Ventilator triggering is critical to the success of NIV in both spontaneous and assist/control modes.¹⁸ It is a complex field and involves both sensing inspiratory effort as well as determining the end of inspiration. In assist/control mode, inspiratory support is given for a predetermined set period—for instance, a pressure setting of 20 cm H_2O for 1.2 seconds (Nippy 1 and 2, Sullivan VPAP). On other machines the sensing of the end of inspiration may be varied by setting the ventilator to switch to expiration at 20–80% of the maximum inspiratory flow (Breas PV 401, Puritan Bennett). In others the triggers are preset by the manufacturer (Respironics BiPAP) or only the inspiratory trigger is adjustable. Trigger sensitivity and ventilator response times are generally good with NIV machines,¹⁹ although some ventilators tested showed poor trigger sensitivity when simulated inspiratory effort was small.

Bi-level ventilators employ flow sensors which detect a change in the machine produced bias flow. Improved patient comfort probably explains the widespread adoption of bi-level ventilators. Patient-ventilator asynchrony may still result from undetected inspiratory effort, a delay in response to the start of inspiration or in the detection of the end of a breath, especially in the presence of excessive leakage.^{9 11 17 20} These differential causes may be difficult to resolve. An alternative is to employ the timed or ACV mode which may be set up to provide mandatory breaths similar to the patient's unsupported ventilatory pattern. The timed mode is particularly important in patients with advanced acute respiratory failure who may cease making spontaneous effort when "captured", or in patients who are normally dependent on hypoxic respiratory drive. The patient with neuromuscular disease may also require timed support as respiratory effort may be insufficient to trigger a breath, particularly during sleep.¹²

Intrinsic positive end expiratory positive pressure (PEEPi) is commonly observed in patients with airflow limitation. In the intubated paralysed individual it can be measured by transient occlusion of the airway and reflects the recoil pressure of the overinflated lung. In the spontaneously breathing patient PEEPi may be overestimated as abdominal muscle contraction contributes to the positive intrathoracic pressure at end expiration.¹⁷ PEEPi is overcome by isometric respiratory muscle contraction before airflow can begin and, for the patient receiving NIV, a triggered breath initiated. By offsetting intrinsic PEEP, EPAP therefore helps triggering^{17 19} and, by reducing perceived effort, it improves comfort. Although PEEPi may be 10–15 cm H₂O in patients with severe acute COPD, levels of EPAP of >5 cm H₂O are rarely tolerated.¹⁷

Oxygen

NIV ventilators entrain room air and, on most machines, oxygen enrichment requires oxygen to be fed proximally into the circuit or directly into the mask. An Fio₂ of about 35% can be achieved, but the flow rate of oxygen required will vary depending on the flow rate of air from the ventilator as it attempts to reach the set pressure, and the magnitude of any leaks in the circuit. An oxygen analyser inserted into the ventilator tubing gives unreliable information and an oximeter to guide oxygen enrichment is more reliable. Higher enrichment requires premixing which necessitates a high pressure oxygen supply. This is only available with ventilators designed for ICU use such as the Respironics Vision or volume control machines.

Humidification

Humidification is not normally necessary during NIV. Use of heated humidifiers or heat/moisture exchangers significantly alters the compliance and resistance of the circuit and, in particular, can impair the function of inspiratory and expiratory triggers.

Alarms

Alarms on NIV ventilators are based on pressure, flow, or volume. A low pressure alarm detects disconnection or excessive leakage which prevents the ventilator achieving the set pressure. High pressure alarms may be set on volume controlled ventilators to warn of excessively high pressures (which may arise if the patient's condition changes and they become more difficult to inflate, or when a large tidal volume is set with a short inspiratory time). Flow alarms are more informative and can warn of changing leakage, worsening airflow obstruction, or partially occluded ventilator tubing. By measuring flow and assuming constant leakage, some devices compute tidal volume and hence minute volume; alarm limits can then be set and this type of ventilator offers greater monitoring potential. Volume controlled ventilators may have

Box 1 Features of a ventilator suitable for NIV in hospital

Essential

- Pressure controlled
- Pressure capability of at least 30 cm H₂O
- Capable of supporting inspiratory flows of at least 60 l/min
- Assist-control and bi-level pressure support modes
- Rate capability of at least 40 breaths/min
- Sensitive flow triggers
- Disconnection alarm

Desirable

- Short pressure rise time capability
- Adjustable pressure rise time
- Adjustable inspiratory trigger
- Adjustable expiratory trigger
- Adjustable inspiratory-expiratory ratio in assist-control mode
- Temporary alarm cancellation facility
- Internal battery with power for at least 1 hour
- Accessible control panel with cover or lock-out facility
- Simple control knobs
- LED/LCD displays

alarms that indicate settings which cannot be achieved by the machine settings such as a larger tidal volume and short inspiratory time. External alarms can be added to the ventilator circuit; these are particularly important for ventilator dependent patients.

Minimum specifications for NIV ventilators

There is a bewildering choice of ventilators from which to choose when setting up an NIV service. In the setting of acute respiratory failure a significant proportion of the patients will have COPD. Most studies which have shown improved survival in COPD with NIV have used ventilators where inspiratory pressure is the controlled variable, and a bi-level device is probably the preferred mode for this group of patients. An assist/control mode will also be necessary for some of these patients, and also for those with other diseases who are likely to make little respiratory effort once established on NIV. These requirements can be provided by two different devices or combined in a single ventilator. Features of a ventilator suitable for NIV in hospital are shown in box 1.

Different ventilatory modes, the ability to change trigger sensitivity, to vary rise time to the set pressure, and to adjust the sensing of the end of inspiration are just some of the features of newer ventilators. It must be borne in mind that these sophisticated options require more operator understanding than is often available, although by increasing comfort they may increase tolerance. Use of a single model of ventilator (or at least a small number of different types) in any one hospital is advisable for ease of training staff.

An updated list of the features of non-invasive ventilators is available on the ARTP website (artp.org.uk).

PATIENT-VENTILATOR INTERFACES

The sophistication and variety of interfaces reflects how problematic this aspect of NIV can be. Approximately 20–30% of patients with acute respiratory failure cannot be managed by NIV.^{21 22} In some, asynchrony between patient and ventilator is the cause and this may result from poor mask fit. In these circumstances, inspiratory effort and end inspiration may fail to be detected. After semi-continuous use over several days skin ulceration, particularly over the nasal bridge, occurs. A barrier dressing may be used from the outset to reduce the risk of this complication. Overtightening the head gear in an attempt to reduce leakage exacerbates skin damage with resulting poor compliance. Mask fit is therefore important for comfort and to

ensure effective ventilatory support. Training is required for any therapist involved with NIV. More sophisticated “off the shelf” masks are available with cushioned gel surrounding the nasal interface (Gold Seal, Respironics) or comfort flaps that limit leakage. Alternatively, horizontal rather than vertical catheter mounts (Blue Horizon, Tiara Medical), nasal plugs (Adams circuit, Nellcor Puritan Bennett or Mallinkrodt), or nasal slings (Monarch, Respironics) are available. Although the latter may be more comfortable, they leak and are more easily displaced, particularly during sleep. Individually moulded masks are popular in some centres and heat sensitive plastics that mould to the face are now commercially produced (Profile, Respironics). Laser scanning to produce individual interfaces may become available. At present, the cost of these alternative designs restricts them to patients requiring long term NIV.

A degree of air leakage through the mouth is common and may be significant during sleep.²³ If chin straps are ineffective in reducing leakage, a full face mask must be employed. Acrylic masks for CPAP can be used but these often produce skin ulceration and leakage is severe in edentulous subjects. As with nasal masks, a better fit is obtained if dentures are left in place. Full-face masks may be useful in the uncooperative patient, but nasal masks are generally preferable because they are less claustrophobic and allow eating, drinking, and speech. Air swallowing is also more problematic with a full-face mask and sometimes produces severe abdominal distension. This may limit their use in patients with recent abdominal surgery. Occasional patients are unable to tolerate any mask. Oral interfaces based on a snorkel design are available but require determination on the part of the patient. In patients who are intolerant of NIV because of nasal obstruction, nasal stents can be inserted to restore the patency of the upper airway.²⁴ An updated list of the features of interfaces is available on the ARTP website (artp.org.uk).

- A selection of different sizes of nasal masks, full-face masks, and nasal pillows should be available for NIV. [C]
- Both nasal and full-face masks have been used successfully for NIV in AHRF. In the acute setting, a full-face mask should be used initially, changing to a nasal mask after 24 hours as the patient improves. [D]

INDICATIONS FOR NIV

There have been a number of uncontrolled studies describing the use of NIV in a wide range of different conditions. Controlled trials have predominantly, but not exclusively, been carried out in patients with COPD. None of these trials has used “sham” NIV as control therapy. Reservations have been expressed that some of the benefit seen with NIV could reflect the attention given to the patients during the administration of NIV. A further possibility is that the discomfort of the mask merely prevents the patient from falling asleep; gas exchange deteriorates during sleep and supplementary oxygen is more likely to produce rises in P_{aCO_2} than when the patient is awake. Double blind, placebo controlled trials of NIV in AHRF are unlikely ever to be performed, and conclusions about the indications for NIV from the evidence available must therefore be made with caution.

There are very few randomised control trials of CPAP in acute respiratory failure, and most have focused on the treatment of cardiogenic pulmonary oedema. There is also a lack of trials comparing CPAP with both NIV and best medical therapy. Only one randomised controlled trial, again in cardiogenic pulmonary oedema, is available which compares all three treatments.

There are three levels at which NIV may be used:

(1) As a holding measure to assist ventilation in patients at an earlier stage than that at which tracheal intubation would be considered.

(2) As a trial with a view to intubation if NIV fails.

(3) As the ceiling of treatment in patients who are not candidates for intubation.

A decision about intubation if NIV fails should be made early in each patient, taking into consideration the severity of the underlying disease and previous level of disability, and documented in the notes. The wishes of the patients and their carers should also be taken into account. This decision should be verified by senior medical staff and, if appropriate, consultation with ICU staff should be made at an early stage.

- NIV may be undertaken as a therapeutic trial with a view to tracheal intubation if it fails, or as the ceiling of treatment in patients who are not candidates for intubation. A decision about tracheal intubation should be made before commencing NIV in every patient. This should be verified as soon as possible with senior medical staff and documented in the case notes. [D]

COPD NIV

A number of prospective randomised controlled trials of NIV have been published, predominantly in patients with acute exacerbations of COPD. The studies performed in the ICU^{21 22 25 26} show that NIV is feasible and that the tracheal intubation rate is substantially reduced. In the study by Brochard *et al*²¹ most of the excess mortality and complications, particularly pneumonia, were attributed to intubation. These data suggest that NIV may be superior to mechanical ventilation but, importantly, this was a highly selected group of patients with the majority being excluded from the study. Kramer *et al*²² also noted a reduction in intubation rate, particularly in the subgroup with COPD, but with no difference in mortality. The study by Celiak *et al*²⁵ showed a more rapid improvement in various physiological parameters but there was no difference in intubation rate or survival. However, a number of patients in the conventionally treated group also received NIV because of clinical deterioration. Martin *et al*²⁶ have recently reported a prospective randomised controlled trial comparing NIV with usual medical care in 61 patients including 23 with COPD. In common with other studies there was a significant reduction in intubation rate, but there was no difference in mortality. However, generalisation of these results to the UK, where NIV is usually performed on general wards, is uncertain.

Prospective randomised controlled trials of NIV outside the ICU²⁷⁻³⁰ have shown varying results. In the trial by Bott *et al*²⁹ research staff supernumerary to the normal ward complement initiated NIV. On an intention to treat analysis there was no difference between the two groups, but when those unable to tolerate NIV were excluded a significant survival benefit was seen in the NIV group. In the study by Barbe *et al*²⁸ the lack of difference between the two groups is not surprising as, given the modest level of acidosis at presentation, the majority were likely to improve with standard treatment. Wood *et al*²⁷ found a non-significant trend towards increased mortality in those given NIV (4/16 v 0/11, $p=0.123$) which was attributed to delays in intubation. It is difficult to draw many conclusions from this study as the two groups were poorly matched and the numbers small. In particular, there were more patients with pneumonia in the NIV group.

A multicentre randomised controlled trial of NIV in acute exacerbations of COPD ($n=236$) on general respiratory wards in 13 centres has recently been reported.³⁰ NIV was applied by the usual ward staff according to a simple protocol. “Treatment failure”, a surrogate for the need for intubation defined by a priori criteria, was reduced from 27% to 15% by NIV ($p<0.05$). In-hospital mortality was also reduced from 20% to 10% ($p<0.05$). Subgroup analysis suggested that the outcome in patients with $pH < 7.30$ ($H^+ > 50$ nmol/l) after initial treatment was inferior to that in the studies performed in

the ICU; these patients are probably best managed in a higher dependency setting with individually tailored ventilation. Staff training and support are crucial wherever NIV is performed, and operator expertise more than any other factor is likely to determine the success or otherwise of NIV.

It is important to note that all the randomised controlled trials have excluded patients deemed to warrant immediate intubation and mechanical ventilation and there has been no direct comparison between NIV and invasive ventilation from the outset in COPD.

In addition to these prospective randomised controlled trials, there have been two studies comparing patients treated with NIV with historical controls treated conventionally or with invasive mechanical ventilation. These have shown a reduction in intubation rate,³¹ no difference in hospital mortality, but a survival advantage for non-invasively ventilated patients becoming apparent after discharge at 3 months and 1 year.^{31 32}

CPAP

There are no randomised controlled trials of CPAP in the treatment of respiratory failure in COPD. A number of case series have reported beneficial effects of CPAP, including an increase in P_{aO_2} , decrease in P_{aCO_2} , and a fall in respiratory rate.^{17 33–36} Two of the series^{35 36} reported an intubation rate of 10–30% despite CPAP. The trials of NIV in COPD suggest that CPAP may now be an irrelevant treatment in patients with COPD. However, CPAP remains more readily available, is cheaper, and requires less training for use. There is some evidence for the use of CPAP in COPD and randomised controlled trials comparing CPAP with NIV could be justified. Studies on the benefits or risks of EPAP in NIV are also needed.

Doxapram

Angus *et al*³⁷ compared doxapram with NIV; NIV was found to be more effective and the protocol had to be changed to allow the introduction of ventilatory support following three deaths in the doxapram group. Doxapram may be used while the patient is transferred to an area where NIV can be started, if NIV is not available, or if it cannot be tolerated by the patient. In some patients who remain drowsy on NIV or who are particularly prone to carbon dioxide retention it may be necessary to combine NIV and doxapram.

- *NIV should be considered in patients with an acute exacerbation of COPD in whom a respiratory acidosis ($pH < 7.35$, $H^+ > 45$ nmol/l) persists despite maximum medical treatment on controlled oxygen therapy. [A]*

Cardiogenic pulmonary oedema

CPAP

The best evidence for the efficacy of CPAP in any type of respiratory failure comes from four randomised controlled trials^{38–41} and a systematic review with meta-analysis⁴² in cardiogenic pulmonary oedema.

Three trials^{39–41} compared CPAP with medical treatment alone. Important exclusions from the trials included patients unresponsive to speech or who were unable to maintain their own airways. A number of patients were hypercapnic upon entry. A total of 180 patients were entered into the three studies and primary end points were the need for intubation and hospital mortality. Two of the studies^{39 41} applied a fixed CPAP of 10 cm H_2O while the third⁴⁰ titrated CPAP from 2.5 to 12.5 cm H_2O . All three studies found a survival benefit with CPAP although individual trial 95% confidence intervals included zero effect. All three also found a reduction in the need for intubation with CPAP. The systematic review by Pang *et al*⁴² concluded that all three trials were well conducted. Pooled data showed a decreased need for intubation with CPAP (risk difference –26%, 95% CI –13 to –38) and a trend to decreased hospital mortality (risk difference –6.6%; 95% CI 3 to –16).

NIV

Several case reports and series^{43–51} have described the use of NIV in pulmonary oedema. Mortality in the series varied from 0% to 22% and intubation rates from 0% to 44%. Two recent randomised controlled trials have given conflicting results. Masip *et al*⁵² showed a more rapid clinical improvement when NIV was compared with oxygen therapy in acute cardiogenic pulmonary oedema, with reduced intubation rates but no overall difference in mortality, whereas Sharon *et al*⁵³ found a worse outcome than with intravenous nitrate infusion.

CPAP v NIV

One randomised controlled trial of 27 patients compared CPAP with NIV.³⁸ The study was prematurely terminated due to an increased incidence of myocardial infarction in the NIV group. The interim analysis found no difference in hospital mortality (one death in the NIV group, two deaths in the CPAP group) or need for intubation (one in each group). Comparison of the two groups at entry showed that more patients with chest pain were entered into the NIV limb, raising the possibility of entry mismatch as an explanation for the higher number of myocardial infarctions in the NIV treated group.

- *CPAP has been shown to be effective in patients with cardiogenic pulmonary oedema who remain hypoxic despite maximal medical treatment. NIV should be reserved for patients in whom CPAP is unsuccessful. [B]*

Chest wall deformity/neuromuscular disease

Successful NIV has been described⁵⁴ and, given the success in chronic ventilatory failure, NIV should be considered the treatment of choice in decompensated ventilatory failure due to chest wall deformity and neuromuscular disease. There are no randomised controlled trials and very few case reports of NIV in these patient groups, and it is now very unlikely that a randomised controlled trial will ever be performed. There is good evidence of long term survival benefit with home ventilation, with 5 year survival of around 80%.⁵⁵ The decision to use NIV will, however, depend upon the severity of the ventilatory failure, the presence or absence of bulbar involvement, and the availability of other effective treatments—for example, in myasthenia gravis and Guillain-Barré syndrome.

- *NIV is indicated in acute or acute-on-chronic hypercapnic respiratory failure due to chest wall deformity or neuromuscular disease. [C]*

Decompensated obstructive sleep apnoea

NIV has been used successfully in this condition⁵⁶ and patients admitted acutely with hypercapnic respiratory failure should be given a trial of NIV. CPAP has also been used in the treatment of patients with severe decompensated OSA.^{57 58}

- *Both CPAP and NIV have been used successfully in patients with decompensated obstructive sleep apnoea. Although no direct comparison is available, NIV (in the form of bi-level pressure support) should be used for these patients if a respiratory acidosis is present. [C]*

Chest trauma

One randomised controlled trial⁵⁹ and two case series^{60 61} support the use of CPAP in isolated chest trauma. A trial was performed on 69 patients with more than two rib fractures and hypoxaemia.⁵⁹ CPAP and regional analgesia were compared with immediate intubation followed by intermittent positive pressure ventilation (IPPV) with PEEP. The randomisation method was not described in the study and it was clearly impossible to blind treatment. The injury severity score was also higher in the intubated group. CPAP resulted in fewer treatment days (mean 4.5 v 7.3), mean ICU days (5.3 v 9.5), and hospital days (8.4 v 14.6). Both deaths occurred in the intubated group. It should be noted that patients with greater than moderate lung injury, as defined by a P_{aO_2} of <8 kPa on

an F_{iO_2} of 40% or greater, were excluded from the study. The use of IPPV in the control group, with relatively mild gas exchange problems, could be challenged in view of more recent evidence of adverse effects associated with barotrauma. When CPAP is used in patients with rib fractures it is important to realise that there is the risk of developing a pneumothorax similar to that with invasive ventilation.

- CPAP should be used in patients with chest wall trauma who remain hypoxic despite adequate regional anaesthesia and high flow oxygen. [C] NIV should not be used routinely. [D]
- In view of the risk of pneumothorax, patients with chest wall trauma who are treated with CPAP or NIV should be monitored on the ICU. [D]

Pneumonia

Confalonieri *et al*⁶² have reported a prospective randomised controlled trial of 56 consecutive patients with community acquired pneumonia randomised to receive conventional treatment alone or with the addition of NIV. NIV was well tolerated, safe, and associated with a significant reduction in respiratory rate, need for tracheal intubation (21% *v* 50%; $p=0.03$), and mean (SD) duration of ICU stay (1.8 (0.7) days *v* 6.0 (1.8) days; $p=0.04$). There was no difference in hospital mortality, but in the subgroup with co-existing COPD those randomised to NIV had an improved 2 month survival (88.9% *v* 37.5%; $p=0.05$).

CPAP has been used in the treatment of severe community acquired pneumonia,⁶³ varicella pneumonia,⁶³ and has become standard treatment for the treatment of pneumocystis pneumonia in immunosuppressed patients (particularly those who are HIV positive). Numerous case series and reports⁶⁴⁻⁶⁹ have shown that CPAP improves oxygenation, reduces respiratory rate, and lessens dyspnoea in this situation. In a randomised controlled trial of CPAP in 123 patients with non-hypercapnic acute respiratory failure, 51 of whom had pneumonia, oxygenation and dyspnoea scores were better in the CPAP group after 1 hour; however, there were no significant differences in intubation rates, mortality, or length of ICU stay.⁷⁰ There were more adverse effects in the CPAP group, including four cardiorespiratory arrests, presumably secondary to delayed intubation.

- CPAP improves oxygenation in patients with diffuse pneumonia who remain hypoxic despite maximum medical treatment. NIV can be used as an alternative to tracheal intubation if the patient becomes hypercapnic. [C] In this context, patients who would be candidates for intubation if NIV fails should only receive NIV in an ICU. [D]

Asthma

Meduri *et al*⁷¹ reported successful use of NIV in 17 episodes of status asthmaticus. Mean pH was 7.25 (H^+ 56 nmol/l) confirming severe acute respiratory failure, and NIV resulted in a rapid improvement in physiological variables; only two patients required intubation. Although NIV has been used successfully in patients with acute asthma, there is insufficient evidence to recommend its use in this context. There is also insufficient evidence to recommend CPAP in acute asthma.

- NIV should not be used routinely in acute asthma. [C]

Cystic fibrosis/bronchiectasis

There are no randomised controlled trials of NIV versus conventional treatment in these patient groups. Physiologically, they are similar to patients with COPD with evidence of severe airflow obstruction. However, in addition, secretions are often excessive and this may limit the applicability of NIV. NIV can be used as an adjunct to physiotherapy, but evidence for its effectiveness in clearing secretions is lacking. NIV has been used successfully as a bridge to transplantation in patients

with cystic fibrosis⁷² where invasive ventilation produces a uniformly poor outcome. There is insufficient evidence to recommend its routine use in these patients.

- A trial of NIV may be undertaken in patients with a respiratory acidosis ($pH < 7.35$) secondary to an acute exacerbation of bronchiectasis, but excessive secretions are likely to limit its effectiveness and it should not be used routinely in bronchiectasis. [C]

Other conditions

Case series have reported success with NIV in a variety of other conditions such as adult respiratory distress syndrome.⁷³ Two randomised trials of NIV have included patients with a wide range of conditions other than COPD, although pneumonia and cardiogenic pulmonary oedema were the most common diagnoses in both. Wysocki *et al*⁷⁴ randomised 41 patients to NIV or conventional treatment and found no difference in intubation rate, length of ICU stay, or mortality, with benefit experienced only by the subgroup with hypercapnia. In a more recent study Antonelli *et al*⁷⁵ conducted a prospective randomised controlled trial of NIV against tracheal intubation with conventional mechanical ventilation in 64 patients with hypoxaemic acute respiratory failure who required mechanical ventilation. There was no statistically significant difference in survival but more patients in the conventional ventilation group had serious complications (66% *v* 38%, $p=0.02$) and had pneumonia or sinusitis related to the tracheal tube (31% *v* 3%, $p=0.003$). Among the survivors, patients in the NIV group had shorter periods of ventilation ($p=0.006$) and shorter stays in the ICU ($p=0.002$). They concluded that, in patients with acute respiratory failure, NIV was as effective as conventional ventilation in improving gas exchange and was associated with fewer serious complications and a shorter stay in the ICU.

More recently, Antonelli *et al*⁷⁶ have reported the results of a randomised controlled trial of NIV in solid organ transplant recipients who developed type 1 respiratory failure. A more rapid improvement in oxygenation and a reduction in intubation rate was found with NIV. Hilbert *et al*⁷⁷ have shown a reduction not only in intubation rate but also in mortality in a randomised controlled trial of NIV in immunosuppressed patients with type 1 respiratory failure.

- NIV has been used in a variety of other conditions (such as acute respiratory distress syndrome, postoperative or post-transplantation respiratory failure) with reduced intubation rates, ICU stay, and mortality. In this context, patients who would be considered for intubation if NIV fails should only receive NIV in an ICU. [D]

Weaning in the ICU

Nava *et al*⁷⁸ compared weaning using NIV or continued invasive ventilation in 50 patients who had been intubated and ventilated either from the outset or following a failed trial of NIV. After 48 hours patients on invasive ventilation were subjected to a 2 hour T piece trial; those who failed were randomised to extubation onto a non-invasive ventilator or continued invasive ventilation. Similar weaning strategies were employed in the two groups and there was a clear advantage for the non-invasive approach in the percentage of patients successfully weaned, duration of need for assisted ventilation, ICU stay, survival, and incidence of ventilator associated pneumonia. This suggests a role for NIV in patients who initially have had to be ventilated invasively.

Girault *et al*⁷⁹ compared NIV with continued invasive ventilation in a randomised study on 33 patients who failed a T-piece trial. The patients who received NIV could be extubated earlier, but there was no difference in the number who could be weaned, the length of ICU stay, or survival at 3 months.

NIV can be used through the upper airway while a tracheostomy tube is in place. The tube can be capped off provided the cuff is deflated. It is sometimes not possible to achieve effective ventilation with NIV despite deflating the cuff

Table 1 Factors associated with success or failure in NIV

Success	Failure
High Paco_2 with low A-a oxygen gradient pH 7.25–7.35 (H^+ 56–45 nmol/l)	High APACHE score Pneumonia on chest radiography
Improvement in pH, Paco_2 , and respiratory rate after 1 hour of NIV	Copious respiratory secretions
Good level of consciousness	Edentulous Poor nutritional status Confusion or impaired consciousness

because there is insufficient gap between the tracheostomy tube and the tracheal wall. NIV is easier with a smaller uncuffed fenestrated tracheostomy tube in place. This can be changed to a mini-tracheostomy tube for a few days if access to the lower respiratory tract is still required for aspiration of secretions.

- NIV has been used successfully to wean patients from invasive ventilation and should be used when conventional weaning strategies fail. [B]

Predictors of outcome of NIV in acute respiratory failure

An improvement in pH^{22, 29} and a reduction in respiratory rate²² after 1 hour has been shown to be associated with a successful outcome from NIV. Soo Hoo *et al*⁸⁰ in a small study (14 episodes in 12 patients), in which NIV was successful in 50% of cases, found that there were no differences in age, prior pulmonary function, baseline arterial blood gas tensions, admission arterial blood gas tensions, or respiratory rate between those patients successfully treated and those who failed NIV. Unsuccessfully treated patients had more severe illness than successfully treated patients, as indicated by a higher Acute Physiology and Chronic Health Evaluation (APACHE) II score, and had pneumonia or excess secretions. In addition, they were edentulous and had pursed lip breathing—factors that prevented adequate mouth seal and contributed to greater mouth leaks than in successfully treated patients. Successfully treated patients were able to adapt more rapidly to the nasal mask and ventilator, with greater and more rapid reduction in Paco_2 , correction of pH, and reduction in respiratory rate. In a study of NIV in 17 consecutive patients with respiratory failure of various causes,⁸¹ NIV was successful in 47%; patients successfully ventilated with NIV had a higher Paco_2 , a lower pH (7.33 (0.03) *v* 7.45 (0.08); $p=0.02$), and a lower alveolar–arterial oxygen difference ($\text{P(A-a)}\text{o}_2$) (144 (46) mm Hg *v* 265 (18) mm Hg; $p=0.01$), suggesting that CO_2 retention without major hypoxaemia is a better indication for NIV than severe hypoxaemia alone. In both groups of patients gas exchange improved after 1 hour on NIV, but such values were not improved on the first day in patients who failed with NIV.

Ambrosino *et al*⁸² in a larger study of 59 episodes in 47 patients of which 78% were successfully treated with NIV found that success was more likely with less severely abnormal baseline clinical and functional parameters and with less severe levels of acidosis. Pneumonia was associated with a worse outcome. However, Confalonieri *et al*⁸² in a study of NIV in community acquired pneumonia found that NIV reduced the tracheal intubation rate overall but only improved 2 month survival in the subgroup with COPD. This suggests that there is still a role for NIV in patients with radiological consolidation.

Taken together, these data suggest that NIV is more likely to be successful in patients with a less severe physiological derangement at baseline in whom there is a rapid improvement in pH and respiratory rate with NIV and in whom it is possible to achieve a reasonable fit between the mask and the patient's face. However, it is not possible at the outset to predict who will derive benefit from NIV.

Factors associated with the success or failure of NIV are shown in table 1.

CONTRAINDICATIONS

The boundaries for the use of NIV continue to expand. However, intubation and conventional ventilation remain the “gold standard” in the management of many patients with acute respiratory failure. Local protocols need to be developed in order to avoid inappropriate trials of NIV in patients who require urgent intubation. NIV is not appropriate in well documented end stage disease or when several co-morbidities are present. There are no absolute contraindications although a number have been suggested.^{80, 82} These include coma or confusion, inability to protect the airway, severe acidosis at presentation, significant co-morbidity, vomiting, obstructed bowel, haemodynamic instability (two studies have shown only small changes in cardiac output when NIV is initiated^{62, 82} but haemodynamic collapse comparable to that often seen when patients are intubated is seldom seen), radiological evidence of consolidation, and orofacial abnormalities which interfere with the mask/face interface. In part, these “contraindications” have been determined by the fact that they were exclusion criteria for the controlled trials. It is therefore more correct to state that NIV is not proven in these circumstances rather than that it is contraindicated. Other “contraindications” such as failure of pH to improve within one hour⁸² are a self-fulfilling prophecy if they have been determined from the outset as indicating a failure of treatment. Whether NIV is contraindicated or not must depend on individual circumstances. For instance, if invasive ventilation is not considered appropriate but NIV would be acceptable, there is nothing to be lost by a trial of NIV and there are no contraindications. By contrast, in an individual moribund with life threatening asthma who may be very difficult to ventilate non-invasively but in whom no problems with weaning would be anticipated, there is little to be gained and much to be lost by attempting NIV.

NIV has been used in patients with an undrained pneumothorax without apparently causing the pneumothorax to increase in size.⁸³ However, in most patients with a pneumothorax it will be appropriate to insert an intercostal drain before commencing NIV.

Contraindications to the use of NIV are listed in box 2.

Box 2 Contraindications to NIV

- Facial trauma/burns
- Recent facial, upper airway, or upper gastrointestinal tract* surgery
- Fixed obstruction of the upper airway
- Inability to protect airway*
- Life threatening hypoxaemia*
- Haemodynamic instability*
- Severe co-morbidity*
- Impaired consciousness*
- Confusion/agitation*
- Vomiting
- Bowel obstruction*
- Copious respiratory secretions*
- Focal consolidation on chest radiograph*
- Undrained pneumothorax*

*NIV may be used, despite the presence of these contraindications, if it is to be the “ceiling” of treatment.

- *NIV should not be used in patients after recent facial or upper airway surgery, in the presence of facial abnormalities such as burns or trauma, if there is fixed obstruction of the upper airway, or if the patient is vomiting. [D]*
- *Contraindications to NIV include recent upper gastrointestinal surgery, inability to protect the airway, copious respiratory secretions, life threatening hypoxaemia, severe co-morbidity, confusion/agitation, or bowel obstruction. NIV can be used in the presence of these contraindications provided contingency plans for tracheal intubation have been made, or if a decision has been made not to proceed to invasive ventilation. [C]*
- *Although NIV has been used successfully in the presence of a pneumothorax, in most patients with a pneumothorax an intercostal drain should be inserted before commencing NIV. [C]*

MONITORING

Monitoring of patients on NIV should include clinical assessment combined with pulse oximetry and arterial blood gas tensions. The actual monitoring will vary depending on the location in which they receive treatment and therefore, to some extent, the underlying aetiology of respiratory failure, whether the patient is a candidate for ventilation, and whether there is other co-morbidity. Patients in the ICU or HDU are likely to be monitored according to the routines adopted in those environments.

Clinical evaluation

Physiological monitoring is not a substitute for clinical assessment and observation of the patient on the ventilator should be made regularly. Clinical features that should be assessed are:

- Chest wall movement
- Coordination of respiratory effort with the ventilator
- Accessory muscle recruitment
- Heart rate
- Respiratory rate
- Patient comfort
- Mental state

When initiating NIV it is important that the therapist observes the effect of treatment in enhancing chest wall movement. Lack of an improvement indicates that alveolar ventilation is not increasing and causes should be sought. These include inappropriate ventilator settings leading to patient intolerance, inadequate tidal volume or inflation pressure, and leaks around the mask or through the open mouth. Monitoring of heart and respiratory rate is essential and can be helpful in determining the response to treatment early on, before other physiological measurements are made.^{9 21 51 52 84-87} Improvement in breathlessness is usually seen within 1–2 hours^{21 51 87 88} and is usually accompanied by improvement in the neurological state.^{32 74 89}

Oxygen saturation and arterial blood gas tensions

In published studies of NIV, data on oxygen saturation or transcutaneous CO₂ have seldom been reported. However, several studies have shown that oxygen levels improve early with NIV^{21 49 85 86 88 89} and, on this basis, SpO₂ monitoring is likely to be helpful, although does not replace the need for frequent measurements of arterial blood gas tensions in the early stages of treatment. Ideally, there should be continuous monitoring of SpO₂ for the first 24 hours of treatment, aiming to keep saturation above 85%, with supplemental oxygen if necessary. Transcutaneous CO₂ monitoring may also be used where it is available.

Arterial or arterialised capillary blood gas analysis of pH, PaCO₂, and PaO₂ are critically important in the assessment of patients on NIV and, ideally, staff providing NIV should

be able to carry out these measurements rather than relying on the duty doctor. Timing of arterial blood gas measurement will depend on the patient's condition and response to treatment. In most studies workers have made measurements at 0, 1 hour, 4 hours, and varying intervals thereafter. During the first 24 hours the use of an indwelling arterial line should be considered and this is more likely in an ICU/HDU.

All patients must routinely have a clinical re-assessment approximately 1 hour after being established on NIV, together with blood gas analysis. Frequency of subsequent measurements will depend on the patient's progress. In cases where the patient's clinical condition is rapidly improving, blood samples should not be taken frequently as these patients are often sleep deprived and need to correct this. When there is no improvement or it is very slow, more frequent assessment should be made to guide FiO₂, ventilator setting, or interface adjustments. A further assessment (with or without blood gas analysis) should be taken within 1 hour of any change in FiO₂ or ventilator setting.

It is important to realise that failure of improvement in arterial blood gas tensions is not an indication for simply increasing the FiO₂ but for clinical re-evaluation of the patient. Any changes in oxygenation cannot be assessed in the absence of information regarding the inspired oxygen concentration, and it is vital that the metered flow rate and the mode of supplementation are clearly recorded.

- *Clinical evaluation of the patient should include assessment of patient comfort, conscious level, chest wall motion, accessory muscle recruitment, coordination of respiratory effort with the ventilator, respiratory rate, and heart rate. Patients receiving NIV should be reviewed regularly to assess their response to treatment and to optimise the ventilator settings. [D]*
- *The need for arterial blood gas analysis will be governed by the patient's clinical progress, but should be measured in most patients after 1–2 hours of NIV and after 4–6 hours if the earlier sample showed little improvement. If there has been no improvement in PaCO₂ and pH after this period, NIV should be discontinued and invasive ventilation considered. [B]*
- *Oxygen saturation should be monitored continuously for at least 24 hours after commencing NIV and supplementary oxygen administered to maintain saturations between 85% and 90%. [C]*

Treatment failure

Assessment and definition of treatment failure will depend on the role of NIV in individual patients which should be established before the trial of NIV. However, factors to take into account are:

- Deterioration in patient's condition
- Failure to improve or deterioration in arterial blood gas tensions
- Development of new symptoms or complications such as pneumothorax, sputum retention, nasal bridge erosion
- Intolerance or failure of coordination with the ventilator
- Failure to alleviate symptoms
- Deteriorating conscious level
- Patient and carer wish to withdraw treatment

Some of the alterations to NIV which can be made if arterial blood gases fail to improve are shown in box 3. A management plan of what to do if NIV fails should be made early, ideally by a respiratory physician. Likewise, the decision to progress to intubation should be made by an experienced clinician in consultation with ICU staff.

The expected improvement in arterial blood gas tensions with NIV varies and is affected by the underlying pathology

Box 3 Treatment failure in NIV**Is the treatment of the underlying condition optimal?**

- Check medical treatment prescribed and that it has been given
- Consider physiotherapy for sputum retention

Have any complications developed?

- Consider a pneumothorax, aspiration pneumonia, etc

Paco₂ remains elevated

- Is the patient on too much oxygen?
 - Adjust FiO₂ to maintain SpO₂ between 85% and 90%
- Is there excessive leakage?
 - Check mask fit
 - If using nasal mask, consider chin strap or full-face mask
- Is the circuit set up correctly?
 - Check connections have been made correctly
 - Check circuit for leaks
- Is re-breathing occurring?
 - Check patency of expiratory valve (if fitted)
 - Consider increasing EPAP (if bi-level pressure support)
- Is the patient synchronising with the ventilator?
 - Observe patient
 - Adjust rate and/or IE ratio (with assist/control)
 - Check inspiratory trigger (if adjustable)
 - Check expiratory trigger (if adjustable)
 - Consider increasing EPAP (with bi-level pressure support in COPD)
- Is ventilation inadequate?
 - Observe chest expansion
 - Increase target pressure (or IPAP) or volume
 - Consider increasing inspiratory time
 - Consider increasing respiratory rate (to increase minute ventilation)
 - Consider a different mode of ventilation/ventilator, if available

Paco₂ improves but Pao₂ remains low

- Increase FiO₂
- Consider increasing EPAP (with bi-level pressure support)

and severity of respiratory decompensation. Most trials which describe a positive response to treatment, including randomised controlled trials, have noted an early improvement in Pao₂, pH, and Paco₂. This is usually evident at 1 hour and certainly at 4–6 hours. Lack of progress towards correction of disturbance of these parameters has been associated with failure of NIV.^{21–50} A degree of stability should be reached by 4–6 hours.

The point at which NIV should be abandoned and the patient intubated will vary with each individual, but will include considerations such as severity of ventilatory failure, likelihood of difficulty weaning from invasive ventilation, the patient's wishes, and whether there are factors such as excessive secretions which could be better managed if the patient was intubated. If NIV is clearly failing to palliate a patient's symptoms and they are not candidates for intubation, NIV should be stopped and alternative treatment considered.

Withdrawal of NIV

The duration of NIV required is very variable. However, unlike IPPV, it is not mandatory or continuous even in the acute phases of treatment, with patients having periods off the ventilator for other treatment such as nebulisers or for meals. Studies vary considerably in the extent of treatment in the first 24 hours (4–20 hours/day) as well as the total duration of

NIV (1–21 days).⁹⁰ Many workers in this field believe that, in the early phase of treatment (the first 24 hours or until improving), the patient should be ventilated for as many hours as possible as clinically indicated and can be tolerated, and this is borne out by one randomised controlled trial.²¹

Clinical improvement and stability of the patient's condition are the most important factors in determining when NIV may be safely withdrawn. It is often recognised by patients who independently decide to cease use of the machine. One study indicated that the mode of weaning is to reduce periods of ventilation according to clinical criteria, reducing diurnal ventilation before nocturnal.⁹¹ Another study has suggested a respiratory rate of <24 breaths/min, heart rate <110 beats/min, compensated pH >7.35 (H⁺ <45 nmol/l), and Spo₂ >90% on FiO₂ <4 l/min.²¹

- *Breaks from NIV should be made for drugs, physiotherapy, meals, etc. Patients who show benefit from NIV in the first few hours should be ventilated for as much as possible during the first 24 hours, or until improving. [B]*

Indications for referral for domiciliary NIV

Most patients treated with NIV for acute respiratory failure can be weaned from ventilatory support within a few days. If NIV is still needed more than one week after the acute episode, this may be an indication that longer term NIV will be necessary and consideration should be given to referring the patient to a centre providing home NIV.

On recovery, all patients who have been treated with NIV should undergo spirometric testing and arterial blood gas analysis while breathing air before discharge from hospital. In accordance with RCP guidelines,⁹² if the pre-discharge arterial blood gas measurement shows a Pao₂ of <7.3 kPa in patients with COPD, a repeat measurement should be made after an interval of at least 3 weeks. If hypoxaemia persists, a trial of oxygen will normally be warranted and, at this stage, nocturnal NIV can be considered if the patient is hypercapnic while breathing air or if the Paco₂ rises significantly with administration of sufficient supplementary oxygen to correct the hypoxaemia. It has also been suggested that long term domiciliary NIV should be considered in patients with COPD who have had three or more episodes of acute hypercapnic respiratory failure in the previous year. The role of long term nocturnal NIV in COPD is not yet clearly established.

Nocturnal NIV in patients with chronic respiratory failure secondary to restrictive chest wall abnormalities is associated with prolonged survival. Any patient with neuromuscular disease or chest wall deformity who has an episode of hypercapnic respiratory failure must be referred to a specialist unit for assessment of long term domiciliary therapy.⁹³ Similarly, patients with cervical cord lesions who have an episode of acute respiratory failure should be referred to a spinal injuries unit for assessment.

Many patients with respiratory failure are overweight and it can be difficult to quantify the contribution of obesity to their respiratory problems. Patients with morbid obesity (BMI >30) who develop hypercapnic respiratory failure may have a central respiratory drive problem or decompensated obstructive sleep apnoea, and on recovery and they should also be referred for further investigation.

Indications for referral for consideration of long term NIV are shown in box 4.

- *All patients who have been treated with NIV for acute hypercapnic respiratory failure should undergo spirometric testing and arterial blood gas analysis while breathing air prior to discharge. [C]*
- *All patients with spinal cord lesions, neuromuscular disease, chest wall deformity, or morbid obesity who develop acute hypercapnic respiratory failure should be referred for assessment to a centre providing long term ventilation at home. [C]*

Box 4 Indications for referral for consideration of long term NIV

- Failure to wean from NIV
- Acute hypercapnic respiratory failure secondary to:
 - Spinal cord lesion
 - Neuromuscular diseases
 - Chest wall deformity (e.g. scoliosis, thoracoplasty)
 - Morbid obesity (BMI >30)
- COPD with:
 - Recurrent AHRF (>3 episodes) requiring treatment with NIV
 - Intolerance of supplementary oxygen (because of CO₂ retention) with symptomatic sleep disturbance

USING NIV IN THE HOSPITAL SETTING

Why set up an acute NIV service?

NIV is becoming established as an important modality in the management of acute respiratory failure. The skills required are easily learnt and the equipment required is relatively inexpensive. If an acute NIV service is not provided, the shortage of ICU beds means that some patients will die because facilities to ventilate them invasively are not available. Even if they are intubated, some patients will die unnecessarily from complications such as pneumonia which they would not have developed if they had been ventilated non-invasively. These factors must be weighed against the potential disadvantages of an acute NIV service, the most important of which is that severely ill patients might receive NIV when intubation and invasive ventilation would be more appropriate.

Who should be responsible for the NIV service?

There should be a named consultant who has overall responsibility for the acute NIV service. This will usually be a respiratory physician, but might also be a consultant nurse specialist or clinical scientist. This person will have responsibility for identifying an area where NIV is to be based, and ensuring that the appropriate equipment is available and maintained. They will be responsible for the protocols used, which must be kept up to date. They must organise training for staff and ensure that audit is undertaken on a regular basis.

- *A named consultant should have overall responsibility for the NIV service. This will usually be a consultant respiratory physician. [D]*

Where should this be done?

Prospective randomised controlled trials of the use of NIV have shown that NIV can be set up and successfully used on ICU, HDU, respiratory wards, and general wards. These have been formal studies with funding and manpower support, often conducted in university hospitals. Other observation studies in district general hospitals in the UK have shown successful use of NIV on a general medical and specialist respiratory ward.⁸⁸ The largest study in a variety of hospitals was done in Yorkshire and this showed that NIV could be used on general and respiratory wards.³⁰ There have been no studies comparing the efficiency of NIV between ICU, HDU, general wards, and respiratory wards.

A survey of hospitals in the UK in 1997 showed that, where it was being used, NIV was being undertaken on a general ward in 16%, on a respiratory ward in 24%, on HDU in 12%, on ICU in 13%, and on a combination in 34%.⁹⁴ There are early data suggesting that a low pH (<7.3, H⁺ >50 nmol/l) and a high Paco₂ following initial resuscitation increases the rate of failure with NIV, as does a failure of pH change at 4 hours in ward based NIV.³ It is possible that success would be improved for these patients by more aggressive ventilation in a higher dependency setting.

Hence, NIV can be used in a variety of “high dependency” locations where it has been shown to be effective. Location will be dependent on the degree of acidosis on arterial blood gas analysis, the predetermined role of NIV in individual patients, and the available cohort of staff with experience. There should be a designated place in each hospital, together with structures to ensure that patients are transferred to this area with the minimum of delay. At present this is unlikely to be in the medical admissions unit or accident and emergency setting. The studies vary greatly in time from admission to when NIV is started and there is, as yet, little evidence of benefit from starting NIV early. The exception is cardiac failure where evidence suggests that CPAP should be started as early as possible following the decision to use it.

- *NIV can be provided in a number of locations including the intensive care unit, a high dependency unit, or a respiratory ward. However, each hospital should have a specific designated area with an available cohort of staff with appropriate experience, together with structures to ensure that patients requiring NIV can be transferred to this area with the minimum of delay. [C]*
- *The clinical area in which a patient is treated with NIV will be influenced by several factors including their clinical state, whether they will be intubated if NIV fails, and the availability of beds. Taking into account the overall clinical picture, patients with more severe acidosis (pH <7.30, H⁺ >50 nmol/l) should be managed in a higher dependency area such as an HDU or ICU, as should those in whom improvement in clinical state and arterial blood gas tensions is not seen after 1–2 hours of NIV on a respiratory ward. [C]*
- *Patients with acute hypercapnic respiratory failure from a cause where the role of NIV is not yet clearly established (such as pneumonia, ARDS, asthma) should only receive NIV in an HDU or ICU where facilities for immediate tracheal intubation are available. [C]*

Who should decide to start NIV?

In most hospitals in the UK the acute take is managed by general physicians with a speciality interest and a respiratory team will not be on call each night. A simple protocol is therefore required to guide the on call staff as to when NIV should be instituted (see box 5). A number of studies have used similar guidelines.^{21 22 29} Regular educational sessions will be needed to ensure that medical staff are familiar with NIV and with these protocols. All patients started on NIV should be transferred to the care of a respiratory physician as soon as possible.

- *There should be a clear protocol for the on-call medical staff as to the indications for NIV, how to initiate treatment, and who has continuing responsibility for supervision of the patient. [D]*

Who should set up and maintain NIV?

ICU staff, doctors, physiotherapists, lung function technicians, clinical scientists and nurses have all been reported to set up and maintain NIV successfully. In the 1997 UK survey setting up was reported to be by nurses in 15%, physiotherapists in 9%, doctors in 33%, and a combination in 41%.⁹⁴ In the largest multicentre study trained nurses set up NIV in almost all hospitals. There have been no studies comparing the success of any of these groups in setting up. Some studies have only used NIV during the day, but if it is to be used outside normal working hours, nurses or physiotherapists will probably need to be involved. Outside the ICU or HDU the on-call medical staff will probably not have the time to set up NIV. A sample protocol for setting up NIV is given in box 6 and typical initial ventilator settings for bi-level pressure support in a patient with acute hypercapnic respiratory failure due to COPD are shown in table 2.

Box 5 When to use non-invasive ventilation**Patients**

- COPD
- Chest wall deformity, neuromuscular disorder, decompensated OSA
- Cardiogenic pulmonary oedema, unresponsive to CPAP

Blood gases

- Respiratory acidosis ($P_{aCO_2} > 6.0$ kPa, pH < 7.35 or $H^+ > 45$ nmol/l) which persists despite maximal medical treatment and appropriate controlled oxygen therapy (patients with pH < 7.25 or $H^+ > 56$ nmol/l respond less well and should be managed in an HDU/ICU).
- Low A-a oxygen gradient (patients with severe life threatening hypoxaemia are more appropriately managed by tracheal intubation).

Clinical state

- Sick but not moribund
- Able to protect airway
- Conscious and cooperative
- Haemodynamically stable
- No excessive respiratory secretions
- Few co-morbidities

Contraindications excluded

- Facial burns/trauma/recent facial or upper airway surgery
- Vomiting
- Fixed upper airway obstruction
- Undrained pneumothorax

Premorbid state

- Potential for recovery to quality of life acceptable to the patient
- Patient's wishes considered

Early work suggested that NIV required extra nursing time.⁹⁴ Extra time is required to set up NIV when compared with routine care, but maintenance of the patient on NIV does not require a large amount of extra nursing or physiotherapy time.^{25 28 95 96} However, nursing numbers, especially at night, should reflect the number of patients on ventilators.

- *Trained ICU staff, doctors, physiotherapists, lung function technicians, and nurses can successfully set up and maintain NIV. When setting up an acute NIV service, it is recommended that NIV to be initiated and run by nursing staff.* [C]

SETTING UP AND RUNNING AN NIV SERVICE

In setting up a NIV service the involvement of senior staff in the initial stages is crucial to success. There should be at least one member of staff who has spent time in a centre which already has an established service. Matters to be considered are the purchase of ventilators and disposables, identification of which staff will initiate and maintain NIV, training (see below), and drawing up agreed protocols for initiation and

Table 2 Typical initial ventilator settings for bi-level pressure support in a patient with acute hypercapnic respiratory failure due to COPD

Mode	Spontaneous/timed
EPAP	4–5 cm H ₂ O
IPAP	12–15 cm H ₂ O (to be increased as tolerated to 20 cm H ₂ O)
Triggers	Maximum sensitivity
Back up rate	15 breaths/min
Back up I:E ratio	1:3

Box 6 How to set up non-invasive ventilation

- (1) Decide about management plan if trial of NIV fails, after discussion with senior medical staff, and document in the notes.
- (2) Decide where trial of NIV should take place (ICU, HDU, or respiratory ward).
- (3) Consider informing ICU.
- (4) Explain NIV to the patient.
- (5) Select a mask to fit the patient and hold it in place to familiarise the patient.
- (6) Set up the ventilator (see table 2).
- (7) Attach pulse oximeter to patient.
- (8) Commence NIV, holding the mask in place for the first few minutes.
- (9) Secure the mask in place with straps/headgear.
- (10) Reassess after a few minutes.
- (11) Adjust settings if necessary (see box 3).
- (12) Add oxygen if $SpO_2 < 85\%$.
- (13) Instruct the patient how to remove the mask and how to summon help.
- (14) Clinical assessment and check arterial blood gases at 1–2 hours.
- (15) Adjust settings/oxygen if necessary.
- (16) Institute alternative management plan if P_{aCO_2} and pH have deteriorated after 1–2 hours of NIV on optimal settings. If no improvement, consider continuing with NIV and reassess with repeat arterial blood gas analysis after 4–6 hours. If no improvement in P_{aCO_2} and pH by 4–6 hours, institute alternative management plan.

monitoring of NIV. In deciding on the location of the NIV service, it may be advisable to start NIV in one area such as an ICU or HDU and subsequently roll it out to other wards.

Training

In 1997 NIV was available in 48% of hospitals surveyed in the UK.⁹⁴ Lack of training and finance were the major reasons why a service had not been set up. At present there are no recognised guidelines for the training of staff undertaking NIV techniques. This has the potential of leading to widespread variations in clinical practices across the UK. One of the difficulties in the development of guidelines is that NIV services may be provided by a wide range of disciplines within the multiprofessional care team. Each discipline has a different baseline knowledge so the start point of training packages will vary. If training standards are to be developed to fulfil both local and national requirements, then the range of entry levels to these programmes will need to be considered.

A training programme for the provision of an NIV service should provide a combination of knowledge based learning supported by clinical experience in the workplace. This should include:

- Understanding of normal respiratory anatomy and physiology
- Understanding of the pathophysiology of respiratory failure
- Understanding of treatment options available to the relevant patient population
- Awareness of signs demonstrating worsening respiratory failure
- Understanding of the operation, maintenance, and troubleshooting of NIV equipment
- Knowledge of patient interfaces used in NIV
- Knowledge of selection criteria for NIV
- Ability to interpret all relevant data (saturation monitor, blood gas analysis, etc)
- Ability to assess the response to NIV and act accordingly in treatment failure

- Knowledge of existing literature on NIV
- Practical experience in a centre offering an NIV service
- An assessment of competency

The BTS website contains up to date details of courses on NIV and centres which are able to offer placements for practical experience.

- *All staff involved in an acute NIV service should receive training appropriate to their baseline knowledge and role in providing the service. Training in NIV should be available for consultants in respiratory medicine and should be included in all specialist registrar training programmes. [C]*
- *A training programme for the provision of an NIV service should provide a combination of knowledge based learning supported by clinical experience in the workplace. [C]*

Audit

The use of NIV in acute respiratory failure should be the subject of regular audit. This may be performed alongside other related audit activity such as the care of acute COPD admissions or augmented care period audit of HDU activity. The most important issues, particularly in the early stages of setting up an acute NIV service, include the following:

- Is an acute NIV service available?
- Is NIV being used appropriately?
 - Are all patients in whom NIV is indicated being treated?
 - Are patients receiving NIV when they would be better managed by intubation?
- Is NIV being used safely?
 - Is the monitoring of patients satisfactory?
 - Are plans for escalating treatment in the event of failure being made?
- Is NIV being used effectively?
 - Is the proportion of patients who succeed with NIV similar to other hospitals?
- Are patients being referred appropriately for long term NIV?

In order to answer these questions, the organisation of the NIV service and the progress of patients receiving NIV must be audited. In addition, data must be collected on all patients with acute hypercapnic respiratory failure, with more detail on those receiving NIV. The organisational audit might form part of a wider audit of respiratory services—for example, the BTS peer review scheme. Since a large proportion of patients treated will have COPD, background information on all admissions with acute hypercapnic respiratory failure might be obtained with the BTS COPD audit tool.

The following points could be used to provide a framework for audit:

(A) Organisational

- (1) Is NIV available 24 hours per day for patients with acute respiratory failure?
- (2) How is it initiated, by whom, and in which clinical areas?
- (3) Who is responsible for the service?
- (4) Are there agreed guidelines for initiating NIV? What are these? How are they disseminated?

(B) Process and outcome of patients with acute hypercapnic respiratory failure secondary to COPD

- (5) Performance status
- (6) Arterial blood gas analysis on admission (or at time after admission when respiratory failure developed). Repeat arterial blood gas analysis within 12 hours of initial pH <7.35 (H^+ >45 nmol/l)

- (7) Presence of peripheral oedema
- (8) Chest radiographic appearance at this time
- (9) Prescription of oxygen
- (10) Use of ventilatory support
- (11) Use of corticosteroids
- (12) FEV₁
- (13) Screening for LTOT
- (14) Smoking cessation advice
- (15) Discharge letter to GP

(C) For patients who received NIV

- (16) Previous ventilatory support: invasive/non-invasive
- (17) Arterial blood gas analysis 1 hour after starting NIV: whether done, actual values
- (18) Arterial blood gas analysis 4–6 hours after starting NIV: whether done, actual values
- (19) Hours of NIV in first 24 hours
- (20) Recorded decision on action to be taken if NIV fails?
- (21) Outcome of NIV: subdivide as successful/improved and failure/no benefit. If failure/no benefit, did the patient receive tracheal IPPV? Reason(s) for failure: (a) intolerance of mask, (b) secretions, (c) nasal bridge erosions, (d) other (specify)
- (22) Outcome of admission
- (23) Length of stay

An example of an audit form, which has been piloted in several centres with an established NIV service, is given in appendix 2.

- *The use of NIV in acute respiratory failure should be the subject of regular audit. In addition to collection of data on patients receiving NIV, details of the number of patients admitted with acute hypercapnic respiratory failure will be required, together with the use of invasive ventilation in these patients. [D]*

Infection control and equipment safety

There is no published evidence which addresses infection control issues specifically in relation to NIV. To date there have been no case reports of nosocomial pneumonia associated with this treatment modality. Nonetheless, equipment used in delivering NIV may be exposed to potentially infectious material during routine use through contact with the patient's skin, mucous membranes, respiratory secretions, and blood. Hospital policies to reduce the likelihood of cross infection should be developed in conjunction with local infection control teams.

While some NIV providers may opt to use single use/disposable products to reduce risk of cross-contamination, the costs involved—for example, trying several masks on each patient—are likely to be prohibitive for those intent on providing a high level of service. However, items stamped for single use should not be recycled between patients.

Masks and exhalation valves licensed by the manufacturer as reusable require high level disinfection between patients. They should be disassembled into their component parts before undergoing an automated process employing a combined washer/disinfector/drier using heat at a moderate but effective temperature—for example, the Health Technical memorandum HTM2030 cycle which peaks at 87°C for 1 minute. Items which are heat sensitive at this temperature may be reprocessed using a cycle which reaches 71°C for 3 minutes. Reusable tubing is very difficult to decontaminate effectively using this method (because of the length and diameter of the lumen) but can be autoclaved at 134°C for 3.5 minutes. Headgear and chinstraps should be reprocessed in a washing machine with a cycle which reaches either 65°C for 10 minutes or 71°C for 3 minutes. All reprocessed equipment should be inspected for integrity prior to reuse and manufacturers' guidelines should be followed regarding the maximum

recommended number of cleaning/disinfection cycles for a given item.

In most ventilators used for NIV there is no airflow from the patient back into the ventilator. Provided a bacterial filter is used, the risk of contamination of the ventilator is extremely low and superficial cleaning of the ventilator between patients is satisfactory. Maintenance of ventilators should follow the manufacturers' recommendations. Planned preventative maintenance should be undertaken at regular intervals. Electrical safety checks should be undertaken at least annually.⁹⁷

- *Reusable masks and exhalation valves should be reprocessed in an automated washer/disinfector/drier machine after disassembly into their component parts.* [C]
- *A bacterial filter should be attached to the ventilator outlet during NIV and the external surface of the ventilator cleaned between patients.* [C]
- *Maintenance and electrical safety checks on ventilators should be undertaken according to the manufacturers' recommendations, and at least annually.* [D]

AREAS OF FURTHER RESEARCH

Many of the recommendations in this document have been given evidence grades below [A], indicating the need for much research in this field. For some of the recommendations the studies needed to improve the evidence base would be extremely difficult or impossible to carry out. Some areas where research is likely to be productive in this field are listed below.

Modes of ventilation

Bi-level pressure support is becoming established as the main mode used for acute NIV, but the optimal settings remain to be determined. There is still a need for studies which compare this mode directly with pressure and volume controlled ventilators. The role of PAV in acute hypercapnic respiratory failure needs to be investigated. Comparisons of NIV with CPAP have only been done in heart failure. Different interfaces have not been compared in randomised controlled trials.

Indications

It is clear that NIV is beneficial when used at an early stage in COPD, but the exact indications need refinement. NIV needs to be compared with tracheal intubation in more severely acidotic patients. Randomised controlled trials are required in conditions other than COPD and cardiogenic pulmonary oedema.

Monitoring

The duration of NIV, target Sp_{O_2} , adjustment of ventilator settings, and weaning from ventilatory support all require further investigation.

Long term NIV

The place of longer term domiciliary nocturnal NIV in COPD needs to be clarified.

ACKNOWLEDGEMENTS

The following reviewed these guidelines at various stages of their preparation: R Angus, Liverpool; S Bourke, Newcastle; C Bucknall, Glasgow; A Cohen, Intensive Care Society; J Gibson, Newcastle; E Glucksman, London; M Greenstone, Hull; D McAuley, Belfast; J Moxham, London; M Polkey, Royal College of Physicians, London; J Shneerson, Cambridge; A Simmonds, London; J Stradling, Oxford; J Wedzicha, London; A Woodcock, Manchester.

Funding: Meeting rooms and travel expenses were provided by the British Thoracic Society. No other funding was received for this project

Conflicts of interest: Craig Davidson has received an educational grant from Breas Medical. No other conflicts of interest were declared.

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APPENDIX 1: SIGN grading

Levels of evidence

- 1++ High quality meta analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias
- 1+ Well conducted meta analyses, systematic reviews, or RCTs with a low risk of bias
- 1– Meta analyses, systematic reviews, or RCTs with a high risk of bias
- 2++ High quality systematic reviews of case-control or cohort studies
High quality case-control or cohort studies with a very low risk of confounding or bias and a high probability that the relationship is causal
- 2+ Well conducted case-control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal
- 2– Case-control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not causal
- 3 Non-analytical studies, eg case reports, case series
- 4 Expert opinion

Grades of recommendation

- A** At least one meta analysis, systematic review, or RCT rated as 1++, and directly applicable to the target population, or
A body of evidence consisting principally of studies rated as 1+, directly applicable to the target population, and demonstrating overall consistency of results
- B** A body of evidence including studies rated as 2++, directly applicable to the target population, and demonstrating overall consistency of results, or
Extrapolated evidence from studies rated 1++ or 1+
- C** A body of evidence including studies rated as 2+, directly applicable to the target population, and demonstrating overall consistency of results, or
Extrapolated evidence from studies rated 2++
- D** Evidence rated 3 or 4, or
Extrapolated evidence from studies rated 2+

APPENDIX 2: Audit record

AUDIT RECORD																
Patient's name: _____	Hospital number: _____ Date of admission: _____															
Q1 Sex: <input type="checkbox"/> Male <input type="checkbox"/> Female	Q2 Date of Birth: ____/____/____															
Q3 Diagnosis:	<input type="checkbox"/> COPD <input type="checkbox"/> Chest wall/neuromuscular <input type="checkbox"/> Obesity/hypoventilation <input type="checkbox"/> Other: <input type="checkbox"/> Cardiogenic pulmonary oedema															
Respiratory failure:	<input type="checkbox"/> Type 1 (hypoxaemic) <input type="checkbox"/> Type 2 (hypercapnic)															
Q4 Performance status:	<input type="checkbox"/> Normal activity without restriction <input type="checkbox"/> Strenuous activity limited, can do light work <input type="checkbox"/> Limited activity but capable of self care <input type="checkbox"/> Limited activity, limited self care <input type="checkbox"/> Confined to bed/chair, no self care <input type="checkbox"/> No record															
Q5 Focal consolidation on CXR:	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> No record															
Q6 Arterial/capillary blood gases:	<table border="0" style="width: 100%;"> <tr> <td></td> <td style="text-align: center;">FiO₂</td> <td style="text-align: center;">PaO₂</td> <td style="text-align: center;">PaCO₂</td> <td style="text-align: center;">pH (or H⁺)</td> </tr> <tr> <td></td> <td style="text-align: center;">(% or</td> <td style="text-align: center;">(kPa or</td> <td style="text-align: center;">(kPa or</td> <td style="text-align: center;">(units or</td> </tr> <tr> <td></td> <td style="text-align: center;">l/min)</td> <td style="text-align: center;">mmHg)</td> <td style="text-align: center;">mmHg)</td> <td style="text-align: center;">nmol/l)</td> </tr> </table>		FiO ₂	PaO ₂	PaCO ₂	pH (or H ⁺)		(% or	(kPa or	(kPa or	(units or		l/min)	mmHg)	mmHg)	nmol/l)
	FiO ₂	PaO ₂	PaCO ₂	pH (or H ⁺)												
	(% or	(kPa or	(kPa or	(units or												
	l/min)	mmHg)	mmHg)	nmol/l)												
(i) On admission/onset of respiratory failure	<input type="checkbox"/> No record _____															
(ii) After 1-2 hours of NIV	<input type="checkbox"/> No record _____															
(iii) After 4-6 hours of NIV	<input type="checkbox"/> No record _____															
(iv) Pre-discharge	<input type="checkbox"/> No record _____															
Q7 Recorded decision on action to be taken if NIV fails:	<input type="checkbox"/> Yes <input type="checkbox"/> No															
Q8 Place where NIV initiated:	<input type="checkbox"/> A&E <input type="checkbox"/> Medical admissions unit <input type="checkbox"/> HDU <input type="checkbox"/> ICU <input type="checkbox"/> Respiratory ward <input type="checkbox"/> General medical ward <input type="checkbox"/> Other:															
Q9 Outcome of NIV:	<input type="checkbox"/> Success/improved <input type="checkbox"/> Failure/no benefit Tracheal intubation <input type="checkbox"/> Yes <input type="checkbox"/> No Reasons for failure: <input type="checkbox"/> Intolerance of mask <input type="checkbox"/> Excessive secretions <input type="checkbox"/> Nasal bridge erosions <input type="checkbox"/> Other:															
Q10 Complications of NIV:																
Q11 FEV₁:	<input type="checkbox"/> Not done _____ . _____ litres _____ % predicted															
Q12 Outcome of admissions:	<input type="checkbox"/> Discharged from hospital without NIV <input type="checkbox"/> Discharged from hospital with home NIV <input type="checkbox"/> Died – likely cause of death respiratory <input type="checkbox"/> Died – likely cause of death non-respiratory <input type="checkbox"/> Other:															
Q15 Length of stay: _____ days	Q16 Respiratory OPA arranged: <input type="checkbox"/> Yes <input type="checkbox"/> No															