Using non-invasive ventilation in acute wards: part 1

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Summary

Non-invasive ventilation (NIV) is increasingly being used in domestic and acute health settings. Part one of this article identifies the benefits of NIV and describes the use of continuous positive airway pressure (CPAP). Part two, published in next week's *Nursing Standard*, discusses bilevel NIV, which has fewer complications and so is largely replacing CPAP. Part two also examines how to monitor and assess patients receiving NIV.

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Key words

- Non-invasive ventilation
- Respiratory failure
- Respiratory system and disorders

These key words are based on subject headings from the British Nursing Index. This article has been subject to double-blind review.

NON-INVASIVE ventilation (NIV) is being used increasingly in acute wards to provide support during acute exacerbations of chronic respiratory failure. Other short-term uses of NIV include pre-surgical optimisation (Wilson *et al* 1999), post-operative respiratory failure, pulmonary oedema and intermittent physiotherapy (Reynoldson *et al* 2001). Ward nurses therefore need the knowledge and skills to care safely for patients receiving NIV. NIV is also used in the community setting to support people with chronic orthopnoea, for example, people with sleep apnoea.

This two-part article discusses the two main types of NIV used to provide ventilatory support:

- Continuous positive airway pressure (CPAP).
- Bilevel non-invasive ventilation (bilevel NIV).

In part one of this article, the benefits and potential complications of NIV are identified and CPAP is described. CPAP has been available for many years, although until recently it was mainly used in critical care areas. Part two examines bilevel NIV, and the clinical observations for all patients receiving NIV, including those on CPAP. Many of the benefits and problems of CPAP identified in the first part also apply to bilevel NIV, therefore, the second part of this article focuses on the differences between these two methods of ventilation.

Historically, artificial ventilators, popularly called life-support machines, have been highly invasive, necessitating endotracheal intubation and sedation. These ventilators create so many actual and potential problems that their use is confined to specialist areas such as intensive care units (ICUs). Admission to ICU may be detrimental to the patient's wellbeing and is often not available. Intubation significantly increases the risk of pneumonia (Girou *et al* 2000, Matthews and Matthews 2000, Young and Ridley 1999), and often necessitates sedation. As well as creating psychological complications, sedation can cause hypotension and other physiological problems. Invasive and non-invasive ventilation have similar short-term mortality, but NIV results in fewer readmissions and less need for long-term oxygen therapy (Conti *et al* 2002). Some patients, in particular critically ill patients, need the additional support of invasive ventilation, but NIV is appropriate as it avoids many complications (Bach *et al* 2001, Meduri *et al* 1996), and may support patients for whom invasive ventilation is not appropriate. If invasive ventilation can be avoided, it is usually in patients' best interests. NIV should be available in all acute hospitals that admit patients with acute respiratory illness (BTS 2002, Elliott 2002).

Much of the literature on NIV is from a medical rather than a nursing perspective, and is drawn especially from:

- Domiciliary ventilation (mainly sleep apnoea).
- Intensive care (especially weaning).

CPAP has traditionally been considered the best treatment for sleep apnoea (Douglas 1998, Douglas and Engleman 1999), significantly reducing road traffic accidents (George 2001) and improving quality of life for patients and carers (Smith *et al* 1998). Less has been written about use of NIV in acute wards. Many studies almost inevitably have small sample sizes, and evidence from sleep apnoea studies may not always be generalisable to patients with acute respiratory failure. Evidence-based practice therefore needs to evaluate the quality and applicability, as well as the quantity, of available evidence.

Although NIV is a medical treatment, nurses often monitor its effectiveness as well as caring for the patient. This article synthesises current evidence and knowledge for nursing practice. NIV can create many complications for patients. Nurses should be aware of these problems both through theoretical knowledge and also by trying out whatever equipment they use, so they can resolve or minimise as many problems as possible. Nurses should be actively involved in the purchase of equipment, assessing it for comfort and other problems, such as noise.

Physiology

Respiratory failure can be classified into two groups: type 1 and type 2. Type 1 (oxygenation failure) is hypoxia

Box 1. Contraindications to non-invasive ventilation

- Raised intracranial pressure, as raised intrathoracic pressure impedes venous return, increasing intracranial hypertension
- Impaired consciousness
- Inability to protect the airway
- Pneumothorax, until a chest drain is inserted
- Severe hypoxaemia
- Patients with copious respiratory secretions
- Routine use in acute asthma
- Recent facial or upper airway surgery
- Facial abnormalities such as burns or trauma
- Fixed obstruction to the upper airway
- Vomiting
- Recent upper gastrointestinal surgery

(BTS 2002)

(PaO_2 <8kPa) with normocapnia ($PaCO_2$ <6kPa) (BTS 2002). The main treatment for type 1 respiratory failure is supplementary oxygen. Type 2 respiratory failure (ventilatory failure) is hypoxia (PaO_2 <8kPa) combined with hypercapnia ($PaCO_2$ >6kPa), and may require additional ventilatory support (BTS 2002).

Ventilation is the process by which gases move in and out of the lungs (Anderson *et al* 2002), and affects carbon dioxide removal from the body and oxygenation. Carbon dioxide, being highly soluble, diffuses more easily than oxygen. Diseases that increase the barrier between alveolar gas and pulmonary blood, such as chest infection or pulmonary oedema, may cause hypoxia, but are less likely to affect carbon dioxide removal. There is virtually no carbon dioxide (0.04 per cent) in environmental air, so carbon dioxide removal relies on the size and frequency of breaths. Hypoventilation (low respiratory rates or depth, or both) causes insufficient carbon dioxide clearance from alveoli, resulting in decreased diffusion from pulmonary blood and therefore hypercapnia, in addition to hypoxia.

Carbon dioxide in blood forms carbonic acid, so high carbon dioxide levels cause respiratory acidosis, an almost inevitable consequence of type 2 respiratory failure. Removing more carbon dioxide therefore reverses respiratory acidosis. Hypoventilation may require ventilatory support to improve oxygenation and remove carbon dioxide.

Breathing involves muscular work, and muscular work consumes oxygen. This is termed the 'work of breathing'. If more oxygen is used by the respiratory muscles, less remains for the rest of the body, including the heart and brain. At rest, respiratory muscles use 1-3 per cent of the total amount of oxygen consumed by the body, but with respiratory failure this may rise to 25-30 per cent (Hinds and Watson 1996), aggravating tissue hypoxia. One of the main goals of managing respiratory failure is to reduce the work of breathing and thereby improve tissue oxygen supply.

Non-invasive ventilation

NIV is simpler and safer than invasive ventilation. It also allows patients to continue many activities of living, such as talking, eating and drinking and mobilising. For a few patients, NIV will not provide adequate support, but it is difficult to predict which patients will need invasive ventilation (Poponcik *et al* 1999). The decision to attempt NIV should, therefore, include preparations for early intubation or withdrawal should this form of ventilatory support fail (BTS 2002). The British Thoracic Society (2002) lists a number of contraindications to NIV (Box 1). In addition to these medical contraindications, refusal by the patient should also preclude the use of NIV.

Benefits Maintaining positive pressure and thus the volume of air in the lungs between breaths can:

- Reverse atelectasis/recruit alveoli.
- Improve oxygenation and reduce work of breathing.
- Reduce (cardiogenic) pulmonary oedema.
- Improve cardiac function (in some patients).

Reverses atelectasis/recruits alveoli – When two moist surfaces such as the alveolar walls join together, they become difficult to separate, an effect that can be mimicked by placing a drop of water between two laboratory microscope slides. Alveoli are inherently unstable and prone to collapse (atelectasis). Once collapsed, alveoli are difficult to reinflate. To reduce this surface tension, the alveoli produce a chemical called surfactant, which helps the alveoli to re-inflate. However, surfactant production is often poor or abnormal in respiratory disease, so patients with severe respiratory failure often develop widespread atelectasis.

Maintaining continuous positive pressure in the airways keeps the alveoli partly inflated, preventing atelectasis. Positive pressure outside collapsed alveoli helps to re-inflate the alveoli (also termed recruitment). Short periods of CPAP can significantly reduce arterial carbon dioxide, and as carbon dioxide clearance relies on the amount of alveolar ventilation, this suggests that significant alveolar recruitment can occur in one hour (Delclaux *et al* 2000) or perhaps even as little as 15 minutes (Webber and Pryor 1998).

Improves oxygenation – Between breaths, air trapped in the alveoli continues to exchange gases. Although residual air remains relatively oxygen-poor, in patients with chronic obstructive pulmonary disease (COPD) NIV provides rapid, if transient, improvements in oxygenation and dyspnoea (Delclaux *et al* 2000). NIV should be used early before severe acidosis develops to treat acute exacerbations of COPD (Lightowler *et al* 2003).

Improved oxygenation reduces breathlessness, but some patients find CPAP so uncomfortable that their breathing may become more, rather than less, distressed. With higher levels of CPAP, difficulty in stretching already distended alveoli may increase the work of breathing (Isaacson *et al* 2000).

Reduces pulmonary oedema – In patients with heart failure, impaired return to the left side of the heart may cause relatively leaky pulmonary capillaries to become engorged, resulting in pulmonary oedema. Increased alveolar pressure reduces cardiogenic pulmonary oedema (BTS 2002, Masip *et al* 2000, Mehta *et al* 1997, Pang *et al* 1998) by forcing interstitial fluid back into the pulmonary circulation.

Improves cardiac function – People with sleep apnoea frequently have poor cardiac function. In these patients, up to 10 cmH_2O of CPAP can improve cardiac function (Nelson *et al* 2001), although some improvement is probably due to better myocardial oxygenation. Whether CPAP improves cardiac function in other patients is questionable (Sin *et al* 2000, Yin *et al* 2001). The current Canadian Positive Airway Pressure for Heart Failure trial may resolve this unanswered question.

Figure 1. Continuous positive airway pressure circuit

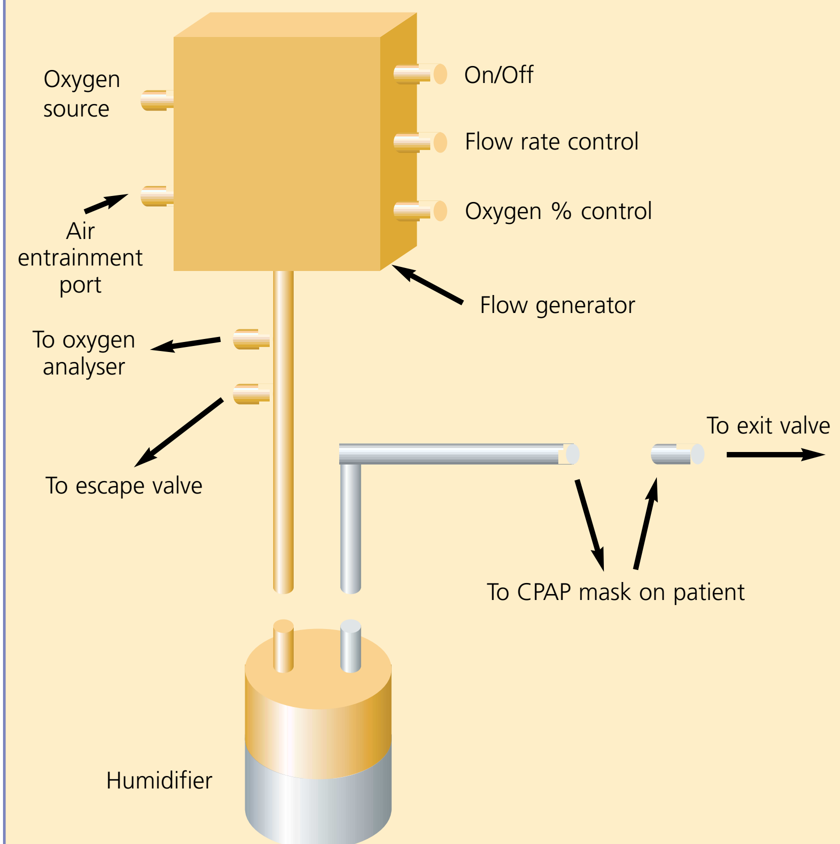
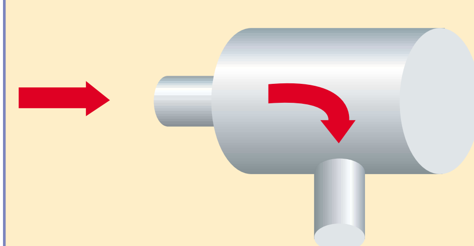


Figure 2. Continuous positive airway pressure valve



Box 2. The CPAP circuit

- Flow generator
- Oxygen analyser
- Pressure relief (escape) valve
- Humidification
- Face or nasal mask, usually requiring a near-complete seal
- CPAP valve

CPAP circuit

CPAP circuits may be either high-flow or low-flow systems. Low-flow systems use small volumes of air or oxygen to create sufficient pressure to provide low pressures of CPAP. In community and first-aid settings these low-flow systems can provide useful, simple and compact support. However, acute settings such as hospitals traditionally use high-flow circuits that can achieve higher and more effective pressures. High-flow systems are described below. Some low-flow systems have been marketed in acute settings, so readers could encounter systems that use significantly different principles and equipment to those described. Before investing in new systems, readers are recommended to evaluate evidence of their effectiveness carefully.

Some systems use self-contained circuits or equipment, while others use flow generators to which further items need to be added. This article describes flow generator circuits (Figure 1). Although different systems may look dissimilar, the principles of CPAP remain generic. CPAP circuits should include the items listed in Box 2. The CPAP valve is shown in Figure 2.

Flow generator Systems produced for domestic use only require low flow, which can be provided by air compressors. In acute care settings CPAP relies on high flow to maintain positive airway pressure. As supplementary oxygen is almost invariably needed, flow generators can be attached to oxygen supplies. Many systems indicate flow only by a triangle or ramp rather than precise volumes, but flows often need to exceed 75 litres per minute, five times the maximum volume from standard oxygen flow meters. Such high flows can quickly drain oxygen cylinders, so whenever possible CPAP should be connected to piped oxygen.

Flow may be generated by bellows or a Venturi system. The Venturi system relies on rapid oxygen flow past a valve to create a vacuum, which entrains atmospheric air. The percentage of oxygen delivered depends on how much air is entrained by the Venturi system. Theoretically, oxygen percentages could range from 21-100 per cent, but many systems can only deliver around 30-95 per cent.

Atmospheric air contains bacteria, and hospital air contains disproportionately large numbers of potentially pathogenic organisms (Humphreys 2001). Air should therefore be filtered by adding a bacterial filter, such as a heat moisture exchanger (HME) or a bacteriostatic filter to the air entrainment port.

Oxygen analyser The oxygen dials on flow generators seldom indicate the percentage of oxygen delivered, so an oxygen analyser is added to the circuit (via a T-piece). The analyser should be calibrated before setting up the circuit and at least once every shift. If analysers become moist they are more liable to malfunction, so water humidifiers should always be placed after the analyser.

Pressure relief valve To maintain positive airway pressure, most circuits are closed except for the exit valve. Any obstruction before the exit valve, such as tubing being trapped in bed mechanisms, would rapidly result in dangerously large volumes of gas entering the patient's lungs, probably causing a pneumothorax. An escape valve is, therefore, attached near the start of the circuit via a T-piece. Because this valve should not normally open and some pressure is lost as gas flows through semi-pliant circuit

Box 3. The main problems caused by CPAP

- Discomfort
- Pressure ulcers
- Hypercapnia
- Reduced lung compliance
- Humidification
- Cardiovascular instability
- Gastric/gut distension
- Noise
- Non-compliance with therapy

tubing, valve pressure should be 10cmH_2O above the exit valve (if possible). In the author's experience, some units use 20cmH_2O pressure relief valves routinely.

Humidifier The upper airway warms and moistens air, so alveolar air is 100 per cent saturated and warmed to body temperature. Warm air can carry more water vapour than cold air (Brown 2000), so air fully saturated air at 20°C absorbs airway moisture. Room air in the UK is about 50 per cent saturated at 20˚C (Ballard *et al* 1992), and can absorb as much air again as it already contains. As air is warmed to body temperature, even more moisture is absorbed, and oxygen, being a dry gas, will further exacerbate drying of the airways. In health, moisture absorption from the airways should not cause problems, but respiratory failure often makes people too breathless to drink much. Airway dehydration makes mucus secretions sticky (tenacious) and may damage airway epithelium and cilia (ACCP 1993). People with sleep apnoea who use CPAP often experience oral and nasal dryness (Brown 2000); airway drying and damage from high-flow CPAP may increase the work of breathing (Lellouche *et al* 2002), cause sputum retention, obstruct the airways and, if severe, result in respiratory arrest. High-flow unhumidified CPAP dries the oral mucosa, so patients frequently want additional drinks or mouthcare. The frequency of mouthcare should depend on individual assessment, but may be needed every two to four hours.

Heated humidification can prevent drying of the airway (de Araújo *et al* 2000), thereby improving compliance with treatment (Massie *et al* 1999), but some high-flow circuits cannot support humidifiers. Where humidifiers can be added, high-flow rates may cause rapid emptying of the fluid chamber, so staff should check water levels frequently (initially every hour).

Air above 37°C may cause airway burns. Heated humidification should be regulated by a thermostat with alarms and nurses should check humidifier temperatures every hour. Heated water also provides a medium for bacterial growth and may also burn people. For these reasons, heated humidifiers should only be used if the benefits outweigh the risks. To prevent infection in already immunocompromised patients, sterile water should be used, if possible through a closed circuit.

Mask Domestic users may have nasal masks; Aly (2001) describes the use of nasal prongs for neonates. In acute hospitals, however, full-face masks with a seal similar to resuscitation masks are usually used. When fitting these masks, nurses should ensure the seal around the face is sufficient to achieve continuous positive pressure. Leaks are especially likely to occur around the nasal bridge. Some systems can create sufficiently large flows to compensate for leaks, but before investing in equipment, nurses should seek advice from hospital technicians about reliability, because some systems designed for short-term emergency (for example, paramedic) use are not sufficiently reliable for longer-term use on acute wards.

Exit valve Most of each exhalation is forceful enough to create a higher pressure than the resistance from the exit valve. As the pressure falls towards the end of each breath, resistance from the valve exceeds airway pressure, causing it to close and trap the last part of each breath in the airways. CPAP valves are produced in increments of 2.5cmH_2O between 2.5-20 cmH_2O, although some machines can achieve higher pressures. CPAP is usually started at lower pressures (often 5cmH_2O), but optimum CPAP depends on balancing the benefits against the risks. Higher pressures generally create more complications, so increases are usually by increments of 2.5cmH_2O if indicated and tolerated.

Disadvantages of CPAP

Although CPAP can support patients with respiratory failure, it creates potential problems that may result in non-compliance with NIV. The main problems are listed in Box 3.

Nurses caring for patients receiving CPAP should actively plan individualised care to minimise the problems caused to patients, and explain the benefits of this form of NIV.

Discomfort While continuous positive pressure supports inspiration and increases breath size, expiration is resisted by the same level of positive pressure. This can make breathing out uncomfortable and even increase the work of breathing. For some patients, relief from dyspnoea and hypoxia makes CPAP a welcome support, but for others CPAP is too uncomfortable and claustrophobic to tolerate. Refusal may be overt, but in the author's experience it is more likely to be covert, such as attempting to remove the mask frequently. Nurses using CPAP are recommended to try it themselves so that they understand what patients are experiencing.

CPAP masks are larger than standard oxygen masks, and many systems rely on tight-fitting masks, using straps to hold the mask against the patient's face. Design and appearances of these straps vary, but their tightness can make them uncomfortable, while the resemblance of some to a horse's harness can be embarrassing and undignified. Using a high-flow rate may adequately compensate for leaks in some systems, although discomfort relieved by a looser mask may be offset by greater discomfort from higher flows.

Although NIV does help maintain many normal activities of living, it also limits the extent to which these can be practised. Eating, drinking, attending to mouthcare and talking necessitate removing face masks. High-flow CPAP is noisy, making it difficult to hear and to be heard, impairing communication and thus isolating patients. Difficulty in removing the mask combined with the length of tubing limits mobility. Patients often find these limitations frustrating, especially if the treatment confining them is also uncomfortable.

Pressure ulcers Pressure from tight-fitting masks may cause ulcers, especially at the nasal bridge. Every effort should be made to ensure the circuit chosen suits the patient's contours. A hydrocolloid dressing placed on the bridge of the nose prophylactically before commencing CPAP can help prevent ulcers developing (Callaghan and Trapp 1998). The skin of many patients with respiratory failure is either clammy or dry and flaky and because of this dressings may fall off, so the hydrocolloid from which the piece is cut should be retained for redressing the area. Individualised nursing assessment of patients' needs should include actively assessing risk and checking for pressure ulcers. Periodically removing the mask and washing the patient's face and mask may help delay or prevent skin damage.

Hypercapnia Improved alveolar function may increase carbon dioxide clearance from pulmonary blood, but continuous positive pressure also causes gas trapping in the alveoli. CPAP may therefore paradoxically result in raised blood carbon dioxide levels (hypercapnia). Blood gases should be measured one hour after commencing CPAP to assess these levels.

Reduced lung compliance Compliance describes the elasticity of lung (or other) tissue. Like balloons that remain continuously inflated, the stretch (tone) of alveolar walls can be reduced by prolonged CPAP, thus reducing compliance (Naik *et al* 1996). Reduced compliance impairs carbon dioxide removal during CPAP, and may reduce depth of breathing when CPAP is removed.

Cardiovascular instability With normal negative pressure breathing, negative intrathoracic pressure during inspiration increases venous return to the right atrium. Continuous positive pressure increases intrathoracic pressure, placing mechanical pressure on the heart, which impedes venous return. Reduced blood volume returning to the right atrium may cause hypotension. Kiely *et al* (1998) found that 10cmH_2O of CPAP caused significant hypotension in people who had atrial fibrillation. CPAP can also reduce cardiac sympathetic nervous activity (Kaye *et al* 2001), causing slower heart rates, which contribute further to hypotension.

While CPAP should improve oxygenation, hypotension reduces perfusion, so the benefits of increased oxygen saturations should be weighed against impaired perfusion. Initially, blood pressure should be measured regularly (every ten minutes for half an hour). Bowie *et al* (2001) found that CPAP of five and 10cmH_2O did not significantly affect cerebral blood flow in volunteers, although as measurements were taken after five minutes it is possible this allowed insufficient time for significant effects to become apparent. Critically ill patients are more likely to be susceptible to hypotension. For example, in a study by Delclaux *et al* (2000) four of the 18 patients receiving CPAP had cardiac arrests compared with none of the six patients in the control group. While other factors might contribute to myocardial infarction, hypotension is likely to be a significant factor.

Gastric/gut distension The oesophagus and trachea lead off the pharynx, so some air is inevitably swallowed. Positive pressure in the airways forces more air into the stomach (Preston 2001), while impeding oesophageal reflux. About half the patients receiving CPAP develop gastric distension (Parsons *et al* 2000), potentially splinting the diaphragm and thereby reducing lung expansion. Gastric distension may also make the patient feel nauseous. If air is not released, it may pass through the gut causing flatulence (Parsons *et al* 2000).

All patients receiving CPAP in acute settings should have a nasogastric tube inserted to prevent gastric distension. If left on free drainage, considerable volumes of air may pass into the collection bag. This should be observed frequently and the air released as necessary. Released air might be malodorous, so air fresheners should be readily available. All patients on whom NIV is used should be prescribed as-required antiemetics in case they develop nausea. Despite having a nasogastric tube, some patients still develop flatulence. Peppermint and warm water may help to relieve discomfort and embarrassment.

Noise CPAP devices are often noisy. Constant noise is irritating and impairs quality and quantity of sleep, which may delay recovery. Nurses should use whatever strategies can reasonably reduce noise. Increasing the length of expiratory tubing prevents air jetting onto the patient's skin and removes noise from air exiting the circuit further from the patient's ear.

Non-compliance with therapy Many patients find CPAP so uncomfortable and distressing that they either refuse it openly or covertly resist it by seeking excuses to remove it frequently. Douglas and Engleman's (1999) study of patients with sleep apnoea identified concerns with:

- Nasal snuffiness.
- Sensation of cold air.
- Noise.
- Mask pressure.

Patients who require long-term support have surprisingly high rates of non-compliance. For example, 13 out of 33 patients in Russo-Magno *et al*'s (2001) study were non-compliant with CPAP. Non-compliance rates may be even higher in acute care settings.

As with any other treatment, CPAP should only be used on patients following informed consent. Treatment given without informed consent can result in civil and/or criminal prosecution for assault and battery (Dimond 2002). However, obtaining informed consent from acutely hypoxic patients is problematic. Nurses should remain sensitive to the patient's wishes, observing verbal and non-verbal

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cues. Reversing life-threatening hypoxia is (usually) in patients' best interests, but staff instigating and managing CPAP should explain the benefits and gain informed consent as far as they reasonably can. Discussion of legal and ethical dilemmas is beyond the scope of this article, although the case of Re C (refusal of medical treatment) Family Division 1994 1 All ER 819 established the precedent that if patients are mentally competent they can refuse life-saving treatment (Dimond 2002).

Commencing hypoxic, breathless and anxious patients on NIV can be difficult. Staff need to be sensitive to patients' needs and anxieties, and gain their trust in them and the use of ventilation equipment. Seeing someone approach you with a mask, which is then strapped on to the face, can be frightening for any patient. Patients may gain confidence in the system if they are given the mask to hold, then place it on their own face, before it is strapped on. With particularly anxious patients, an inhaler-like mouthpiece may be useful in the initial stages of ventilatory support.

If the patient's refusal is covert rather than overt, resulting in the mask being removed frequently, CPAP will probably not improve oxygenation, because the benefits of CPAP take about 20 minutes to be effective, while the negative psychological and physiological effects of stress may be detrimental. Distress initiates release of catecholamines (adrenaline/epinephrine and noradrenaline/norepinephrine), which trigger 'fight or flight' responses, including:

- Tachycardia.
- Hypertension.
- Tachypnoea.
- Hyperglycaemia.

While the release of catecholamines is life-saving for healthy people needing to deal with an emergency situation, for critically ill patients with respiratory failure these responses may prove life-threatening. Non-compliance is likely to make the treatment ineffective, distress the patient and expose staff to risks of accusations of assault, therefore every effort should be made to obtain informed consent.

Conclusion

NIV techniques are being used increasingly in domestic and acute health settings. This article has identified the benefits of NIV and CPAP – the main type of NIV during the 1990s, which is still widely used – has been described. CPAP can, however, create problems for patients and nurses. Bilevel NIV, which is discussed in the second part of this article, creates fewer problems and is being used to replace CPAP. Part two of this article also examines ways of monitoring and assessing NIV. Whatever type of ventilatory support is provided, the patient's condition and the effectiveness or otherwise of treatment should be closely monitored

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