Airway pressure release ventilation, biphasic positive airway pressure

Alveolar ventilation is achieved by the time-cycled switching between two levels of CPAP. Inspiratory and expiratory pressure levels and times are set independently and unhindered spontaneous breathing is possible in any phase of the mechanical ventilatory cycle. APRV as originally described employs very high I:E ratios with a short expiratory time. With BiPAP the I:E ratio and flow rates can be varied over a wide range. BiPAP can also be patient-triggered. Changes in ventilatory demand do not result in alterations in the level of mechanical support. Peak airway pressures are minimized and theoretically the risk of barotrauma is reduced. BiPAP is now widely used, especially during NIV (see below).

Continuous positive airway pressure

CARDIORESPIRATORY EFFECTS OF CPAP

CPAP achieves for the spontaneously breathing patient what PEEP does for the ventilated patient. Not only can it improve oxygenation by the same mechanism, but lung mechanics improve, breathing becomes easier, respiratory rate falls, $V_T$ increases and both VC and inspiratory force have been shown to improve (Feeley et al., 1975; Katz and Marks, 1985; Venus et al., 1979).

The cause of the increased compliance can be appreciated by referring to Figure 3.23 (Chapter 3), which shows the compliance curve for the lung and chest wall combined. Normally, tidal exchange takes place from the resting expiratory position at which the propensity for the lungs to collapse is exactly counterbalanced by the tendency of the chest wall to expand. It can be seen that this is also the steepest point on the curve, where relatively small changes in pressure produce a large change in volume (i.e. compliance is greatest and the work of breathing least). As lung volume falls, however, the curve becomes flatter (i.e. the lungs become stiffer and the work of breathing increases). The application of positive airway pressure re-expands the lungs and compliance increases. If the lungs are overexpanded, however, compliance will again fall.

Because mean intrathoracic pressure is lower with CPAP than with IPPV plus PEEP, cardiovascular depression is minimized (Simonneau et al., 1982; Venus et al., 1979), renal perfusion is maintained and the incidence of barotrauma may be reduced. Furthermore, heavy sedation is unnecessary. A circuit suitable for applying CPAP is shown in Figure 7.11a.

CLINICAL USE OF CPAP

CPAP can be used as the primary treatment in patients with acute hypoxaemic respiratory failure who are not exhausted and in whom alveolar ventilation is adequate (Venus et al., 1979). The use of a tight-fitting facemask (Fig 7.11b) allows the application of CPAP without the need for tracheal intubation or tracheostomy (Greenbaum et al., 1976). This technique has been used extensively in the belief that clinical deterioration might be prevented, tracheal intubation could be avoided and outcome might be improved. This approach is supported by a study in which mask CPAP was shown to produce early physiological improvement as well as to reduce the need for intubation and mechanical ventilation in patients with severe hypercapnic cardiogenic pulmonary oedema (Bersten et al., 1991). CPAP is particularly useful in the management of postoperative respiratory failure associated with basal lung collapse/consolidation (see Chapter 8) and is indicated in the management of selected patients with chest trauma who remain hypoxic despite adequate analgesia and high-flow oxygen. In a randomized, controlled trial, however, application of CPAP by full facemask failed to reduce the need for tracheal intubation or improve outcome in patients with acute hypoxaemic, nonhypercapnic respiratory insufficiency due to acute lung injury (Delclaux et al., 2000). Worryingly, in this study there were four cardiac arrests in the CPAP group, compared to none in the standard therapy group: three occurred at the time of intubation and one when the mask was removed, precipitating extreme hypoxia. It may be that mask CPAP is most useful when the underlying cause of the respiratory failure is readily reversible, as is the case in cardiogenic pulmonary oedema or collapsed basal lung segments, but is less likely to be beneficial when the lung pathology is progressive and/or slow to resolve. Although there is some evidence that CPAP may benefit patients with acute exacerbations of COPD, NIV is now the treatment of choice in such patients (see below and Chapter 8).

CPAP masks are uncomfortable to wear for prolonged periods and the technique is only suitable for those who are alert, able to clear secretions and protect their airway. Gastric distension, vomiting and aspiration are a potential risk and a nasogastric tube should be inserted in most patients receiving mask CPAP.

Nasal masks may be better tolerated and safer, but mouth breathing renders them less effective. They are most useful when applied at night in patients with obstructive sleep apnoea and nocturnal hypoventilation (Jenkinson et al., 1999). Recently helmets that surround the patient’s head and neck have been introduced; these may be better tolerated than masks.

CPAP is also useful for weaning patients from mechanical ventilation since it prevents the alveolar collapse and hypoxia that may otherwise occur (Feeley et al., 1975). In general, therefore, patients who have required CPAP should not be allowed to breathe spontaneously through an endotracheal tube with ZEEP, but rather should be extubated directly from 5 cm H$_2$O PEEP. Once extubated, patients provide their own ‘physiological PEEP’.

Non-invasive ventilation

NIV involves the provision of mechanical respiratory support without invading the patient’s upper airway and can be delivered using either a nasal or full facial mask. Although nasal masks are generally better tolerated they require a cooperative
Fig. 7.11 (a) Circuit suitable for applying continuous positive airway pressure (CPAP) using a flow generator in a patient with an endotracheal tube in place. (b) CPAP can be applied using a tight-fitting facemask.

patient who is able to maintain mouth closure to be effective. In general alveolar ventilation, and consequently the reduction in $P_aCO_2$, is greater with full facemasks which are therefore the most appropriate choice for patients with acute respiratory failure. Nasal plugs or ‘pillows’ can also be effective but are often poorly tolerated. The application of non-invasive positive-pressure ventilation via a ‘helmet’ is also feasible but is not as effective in terms of carbon dioxide elimination (Antonelli et al., 2004). Most modern ventilators can provide NIV, but they are often unnecessarily complicated.
and portable non-invasive devices are now widely used, both on intensive care/high-dependency units and on respiratory wards. The most popular ventilators for this purpose are those providing BiPAP, which are simple to use, cheap and flexible. Alternatively ACV, volume control or PSV, with or without PEEP, can be delivered using a conventional mechanical ventilator.

Successful application of NIV requires considerable attention to detail, particularly in the first few hours, in order to ensure that the mask is comfortable, with minimal leaks, and that the ventilatory pattern is optimal (Brochard, 2000). Achieving a good mask fit is crucial both for patient comfort and to ensure effective ventilatory support; simply overtightening the headgear in an attempt to eliminate leaks is uncomfortable for the patient and increases the risk of skin damage. A better fit is obtained if dentures are left in place.

The patient’s response to NIV should be assessed by clinical evaluation, including patient comfort, conscious level, chest wall motion, accessory muscle use, coordination of respiratory effort with the ventilator, respiratory rate and heart rate and by continuous pulse oximetry supplemented by repeated blood gas analysis. The patient should be reviewed regularly to optimize ventilator settings.

Institution of NIV can rest the respiratory muscles, reduce respiratory acidosis and restlessness, improve clearance of secretions and re-expand collapsed lung segments. NIV may be undertaken as a therapeutic trial, recognizing that in the event of failure tracheal intubation will be required, or as the ceiling of treatment in patients who are not candidates for invasive respiratory support or admission to intensive care.

Advantages of NIV include:

- avoidance of tracheal intubation and associated complications, especially VAP;
- improved patient comfort and avoidance of sedation;
- preservation of airway defence mechanisms;
- spontaneous coughing and expectoration are not hampered;
- ventilatory assistance can be provided intermittently, allowing normal eating, drinking and communication (periods of NIV as short as 6–8 hours a day can be effective), as well as facilitating gradual weaning;
- ventilation can be interrupted to allow administration of nebulized medications, physiotherapy, coughing and expectoration;
- early mobilization is facilitated;
- patient morale is maintained;
- ventilatory support can be initiated at an earlier stage and in some cases admission to intensive care can be avoided.

Disadvantages include the absence of a route for endotracheal suction and the lack of airway protection. Complications include nasal bridge and facial ulceration, nasal congestion and eye irritation. Air swallowing is common and most patients receiving NIV should have a nasogastric tube in place. More serious complications, such as aspiration of gastric contents, cardiovascular instability and pneumothorax, are fortunately rare.

Contraindications to NIV include:

- recent facial or upper-airway surgery, burns or trauma;
- fixed obstruction of the upper airway;
- vomiting;
- recent upper gastrointestinal surgery or bowel obstruction;
- uncooperative patient, coma, confusion or agitation;
- inability to protect the airway or to cough and expectorate effectively;
- copious respiratory secretions;
- focal consolidation on chest X-ray;
- life-threatening hypoxaemia;
- haemodynamic instability;
- severe comorbidity.

NIV is most clearly indicated in the management of selected patients with an acute exacerbation of COPD who are not severely hypoxaemic and in whom a respiratory acidosis persists despite maximum medical treatment and controlled oxygen therapy. In this situation NIV has been used successfully both in intensive care/high-dependency units (Brochard et al., 1990, 1995, Girou et al., 2000; Martin et al., 2000; Meduri et al., 1991) and on general respiratory wards (Bott et al., 1993; Plant et al., 2000, 2001, 2003). Taken together these studies have demonstrated that in such patients appropriately applied NIV can reduce the need for tracheal intubation, the length of hospital stay, costs and the in-hospital mortality rate, a conclusion supported by a meta-analysis (Peter et al., 2002). The improved outcome with NIV seems to be at least partly explained by a reduction in the incidence of complications, especially VAP and other nosocomial infections (Brochard et al., 1995; Girou et al., 2000). Long-term survival is sufficiently good to lend further support to the use of NIV in this category of patient (Plant et al., 2001).

The role of NIV in the management of acute respiratory failure unrelated to COPD is less clear, however (Peter et al., 2002). In one study of patients with unresponsive acute respiratory failure and severe hypoxaemia non-invasive positive-pressure ventilation reduced the rate of serious complications and, in survivors, the length of ICU stay (Antonelli et al., 1998), whilst in another study the rate of tracheal intubation was reduced (Martin et al., 2000), although improved survival was only seen in those with COPD. Similarly, Confalonieri et al. (1999) found that in selected patients with acute respiratory failure caused by community-acquired pneumonia NIV was associated with a significant reduction in the rate of tracheal intubation and duration of ICU stay. Again 2-month survival was only improved in those with COPD. In a more recent study, the use of NIV prevented intubation, reduced the incidence of septic shock and improved survival in patients with severe hypoxaemic respiratory failure, except in those with ARDS (Ferrer et al., 2003b).
Non-invasive PSV has also been shown to lead to more rapid improvement in oxygenation and reduction in respiratory rate when compared to conventional oxygen therapy in acute cardiogenic pulmonary oedema (Masip et al., 2000; Nava et al., 2003; Park et al., 2004), although in some studies outcome was not improved (Masip et al., 2000; Nava et al., 2003) and it is unclear whether NIV/BiPAP is more efficacious than CPAP in this condition (Park et al., 2004). Indeed, a recent meta-analysis indicated that, compared with standard therapy, CPAP reduces mortality in acute cardiogenic pulmonary oedema but there was only a suggestion of a trend towards a reduction in mortality with bilevel NIPPV (Peter et al., 2006). There is even some suggestion that CPAP or NIV may reduce the need for tracheal intubation in selected patients with severe asthma (Fernández et al., 2001), although currently this approach cannot be recommended. Finally NIV may be particularly indicated in the management of immunocompromised patients with acute respiratory failure, in whom the rates of tracheal intubation and serious complications may be reduced and survival improved (Hilbert et al., 2001).

In conclusion, current evidence supports the use of NIV in acute hypercapnic respiratory failure associated with COPD, provided that the patient is not profoundly hypoxaemic, and suggests that the technique may also be useful in selected patients with acute hypoxaemic respiratory failure of various aetiologies. NIV may also be useful as an aid to early extubation of patients who cannot sustain unsupported spontaneous ventilation (Girault et al., 1999), although the influence of this approach on length of stay and survival is unclear (Girault et al., 1999; Nava et al., 1998). NIV is also the treatment of choice in decompensated ventilatory failure due to chest wall deformity or neuromuscular disease and has been used successfully in decompensated sleep apnoea (see Chapter 8).

**Extracorporeal gas exchange**

**EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO)**

The technique of ECMO using venoarterial bypass was introduced in an attempt to save the lives of some patients who would otherwise inevitably have died from severe progressive acute respiratory failure. It was based on the premise that the lungs of such patients would eventually recover provided death from hypoxia could be avoided. This proved not to be the case since in the majority of cases the lung lesion continued to progress, culminating in irreversible pulmonary fibrosis. When a prospective randomized study demonstrated that the mortality of patients with severe ARF was similar whether or not ECMO was used (Zapol et al., 1979), its use in adults was largely abandoned.

**LOW-FREQUENCY POSITIVE-PRESSURE VENTILATION WITH EXTRACORPOREAL CARBON DIOXIDE REMOVAL (Gattinoni et al., 1980, 1986)**

This technique uses a venovenous bypass, with low flows of only 20–30% of the cardiac output, to remove carbon dioxide. The lungs are ventilated at a very low frequency and oxygenation is maintained by applying a positive pressure to the airways and adjusting the $F_{O_2}$. Although alveolar oxygen concentrations may be high, the combination of normal pulmonary perfusion and minimum ventilation may avoid ventilator-associated lung injury, rest the lungs and provide optimal conditions for lung healing.

The major complication of this technique is bleeding, which is potentially fatal. The incidence of bleeding can be reduced by using surface heparinized extracorporeal circuits or by the simultaneous administration of aprotinin with heparin. In general, however, extracorporeal techniques are contraindicated in patients at risk of haemorrhage. In contrast to the use of ECMO, thromboembolic complications have not been reported and the technique is simplified by the use of percutaneous venous cannulation.

A later randomized controlled trial indicated that this technique may not improve outcome, especially when compared to protocol-driven ventilatory strategies designed to minimize levels of PEEP and $F_{O_2}$ (Morris et al., 1994).

Nevertheless, some authorities remain convinced that, when used by experienced teams in specialist centres, extracorporeal gas exchange can significantly reduce the mortality associated with severe ARDS, and that further technical improvements will facilitate the more widespread application of this technique.

**DISCONTINUING AND WEANING VENTILATORY SUPPORT**

*(MacIntyre et al., 2001)*

In view of the numerous complications associated with invasive respiratory support it is important to discontinue mechanical ventilation, and, if possible, to extubate the patient as soon as possible. On the other hand, premature attempts at weaning may be deleterious and can adversely affect the morale of conscious patients; during weaning a fine balance must be drawn between proceeding too quickly and unnecessarily prolonging the process.

Following a prolonged period of mechanical respiratory support ventilatory function may be compromised by:

- decreased central drive;
- weakness and wasting of skeletal muscle and the diaphragm;
- critical-illness polynuromyopathy (see Chapter 15);
- pathological changes in muscle, including corticosteroid-induced myopathy (Douglass et al., 1992);
- chest wall instability;
- operative or traumatic damage to the phrenic nerves;
- abdominal distension with upward displacement of the diaphragm.

The role of respiratory muscle fatigue is poorly understood but there is usually some persisting abnormality of gas exchange and lung mechanics, including, for example, dynamic hyperinflation. In patients who have been ventilated for any length of time, therefore, spontaneous respiration normally has to be resumed gradually.
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