Assisted ventilation · 6

Non-invasive and domiciliary ventilation: positive pressure techniques

M A Branthwaite

Intermittent positive pressure ventilation through an endotracheal or tracheostomy tube has been the mainstay of respiratory assistance for several decades. Some patients have been discharged home with a positive pressure device and tracheostomy but the number treated by these means in Britain has always been small.[1] Securing adequate gas exchange is usually easy and differs very little from that provided by the methods used in hospital (see article 2 in this series—November 1990;45: 885–90) but problems of organisation, finance, and training mean that this work has been concentrated in a few specialised centres where the necessary supervision and expertise were available.[2] These limitations have receded, however, with the advent of non-invasive methods of applying positive pressure to the airway, usually through a nasal mask but occasionally with a mouthpiece.[3] Other developments favouring the growth of domiciliary ventilation have been the recognition of nocturnal hypoventilation as a cause of respiratory and ultimately cardiorespiratory failure, the therapeutic success of mechanical ventilation used only during sleep, and a clearer understanding of the role of respiratory muscle weakness or fatigue. Assisted ventilation using negative pressure techniques is discussed in article 5 (February 1990;46: 131–5); this article deals solely with non-invasive positive pressure methods.

Terminology and techniques

A fundamental distinction must be made at the outset between continuous positive airway pressure and intermittent positive pressure ventilation. The former refers to a spontaneously breathing patient in whom airway pressure is held positive in relation to atmospheric pressure throughout the respiratory cycle (fig 1). Intermittent positive pressure ventilation differs in that gas flow in and out of the lungs is controlled primarily by the ventilator, and the airway pressure changes phasically throughout the cycle. Confusion has arisen because a single design of mask can be used with both techniques. Some details of suitable positive pressure ventilators are provided in the table.

Nasal continuous positive airways pressure was introduced as a means of splinting the upper airway open during sleep in patients with obstructive sleep apnoea.[4] Pressures of 5–10 cm are used most often and values above 15 cm are rarely either needed or tolerated. The presence of a positive pressure in the airway tends to reduce the work of breathing and to increase functional residual capacity. Thus it can provide modest benefit to patients who do not suffer from obstructive sleep apnoea—for example, those with weak inspiratory muscles, who have a tendency to develop atelectasis. Some patients notice difficulty in expiration, however, particularly if there is a loss of lung or chest wall elasticity, so that active contraction of the expiratory muscles is necessary.

Intermittent positive pressure ventilation is intended to deliver the entire tidal volume if necessary and then allow passive exhalation, either to atmospheric pressure or to a pre-

Some ventilators suitable for nasal intermittent positive pressure ventilation that can be used in the home*

|	Source	UK agent or manufacturer†	Comments
VOLUME PRESET VENTILATORS			
Bromptonpac/Airpac	UK	Pneupac Ltd, Luton	Independent compressor and ventilator
Lifecare PLV 100	USA	Medicaid Ltd, Bognor Regis	Integral battery
Monnal-D	France	Deva Medical Ltd, Runcorn	Maximum minute ventilation 20 litres on current model
Puritan-Bennett	USA	Puritan-Bennett UK, Hounslow	Several models with different capabilities
PRESSURE PRESET VENTILATORS			
Bantam	USA	Medicaid Ltd, Bognor Regis	Inexpensive, inflexible, no trigger
Respironics Bipap	USA	Medicaid Ltd, Bognor Regis	Light weight; adjustable expiratory pressure; maximum positive pressure 28 cm; no disconnect alarm
Ventimate	UK	Thomas Respiratory Systems, London	Inexpensive; maximum pressure 50 cm

Respironics nasal masks are available from Medicaid Ltd and Sefam masks from Thomas Respiratory Systems.
*All are available in the UK; 1990 costs range from about £2500 to £7000. †See appendix for addresses.

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Figure 1 Diagrammatic representation of airway pressure profiles during spontaneous ventilation and continuous positive airway pressure (CPAP).

cm H_2O

10

0

Spontaneous Ventilation

cm H_2O

10

0

CPAP
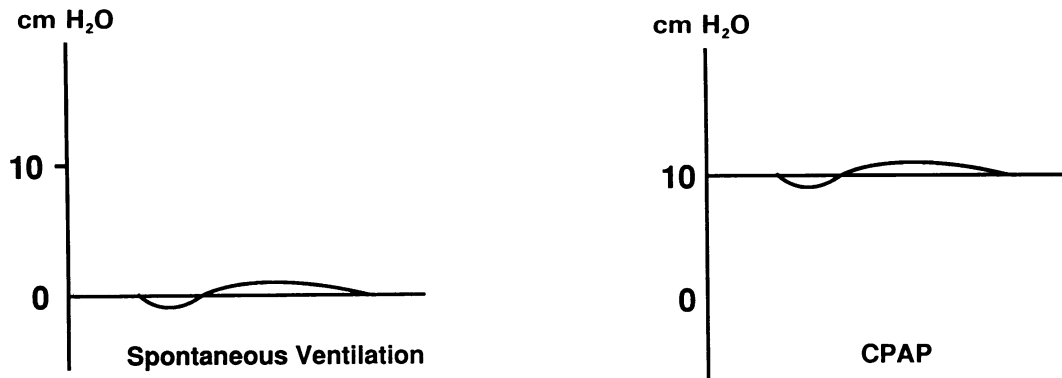
determined positive airway pressure. A difference in airway pressure of 15–20 cm H_2O or more between inspiration and expiration is likely, whatever end expiratory pressure is selected. The technique can be used to control ventilation entirely or to augment spontaneous respiratory efforts. Augmenting gas exchange can be achieved comfortably for conscious subjects only if the ventilator cycles into inspiration in response to the initiation of a spontaneous breath by the patient, a process described as "triggering" (fig 2). If there are no spontaneous inspiratory efforts or they are too feeble to trigger the ventilator, an automatic cycle must be imposed to ensure that gas exchange continues. The patient is then "controlled" by the ventilator. The so called assist/control mode can be used to ensure that breaths are triggered or imposed according to the magnitude of the spontaneous effort. It is important to recognise that when patients trigger the ventilator to deliver the next tidal volume they probably do not merely initiate the next breath. More often they continue to breathe throughout the delivery (fig 3) and this effort facilitates gas flow into the lungs and may enhance the total volume received. If on the other hand the start of the next breath is not followed immediately by gas flow from the ventilator there is a reflex increase in inspiratory effort, which is likely to make respiratory work greater than when they are breathing spontaneously. This means that the threshold of the ventilator trigger must be

low and the response time short if the system is to be comfortable, easy to use, and capable of reducing respiratory work.

Triggering the ventilator occurs only if the spontaneous inspiratory effort is sufficient to reach a predetermined mechanical threshold, usually a reduction in airway pressure below atmospheric. Airflow limitation causing premature airway closure results in air trapping and hence a sustained positive pressure within the lungs at the end of expiration—known as endogenous or auto PEEP (positive end expiratory pressure).[5] This means that a considerable inspiratory effort is needed to lower the intrathoracic pressure to below atmospheric pressure so that a negative pressure sufficient to reach the trigger threshold is generated at the nose. This physiological constraint on the ease with which the ventilator can be triggered also exists if change in flow rather than pressure is the variable sensed at the nose. Spontaneous respiratory efforts conflict with the ventilator cycle if they fail to reach this threshold, though the resulting asynchrony is rarely perceived as discomfort.

A more subtle difficulty exists if a premature inspiratory effort reaches the trigger threshold too early in expiration, particularly if this occurs because the patient is breathing with the ventilator and continues to inspire after gas flow from the device has ceased. Successive breaths will "stack" and so cause hyperinflation because the machine is triggered into the next inspiratory phase before expiration has occurred to any appreciable extent. This can be prevented if there is a "closed window" in the respiratory cycle, during which the trigger function is refractory. These requirements are needed particularly for patients who are conscious and unsedated or drifting off to sleep—when spontaneous breathing is often irregular in both depth and frequency. The alternative is to impose fully controlled ventilation, which some patients accept quite easily. They do so most readily if triggering the ventilator is difficult or uncomfortable, if their ventilatory requirements are easy to satisfy, and if they do not suffer from disorders that provoke dyspnoea independent of blood gas changes (for instance asthma, pulmonary oedema, and pulmonary fibrosis).

cm H_2O

25

0

Controlled Ventilation

cm H_2O
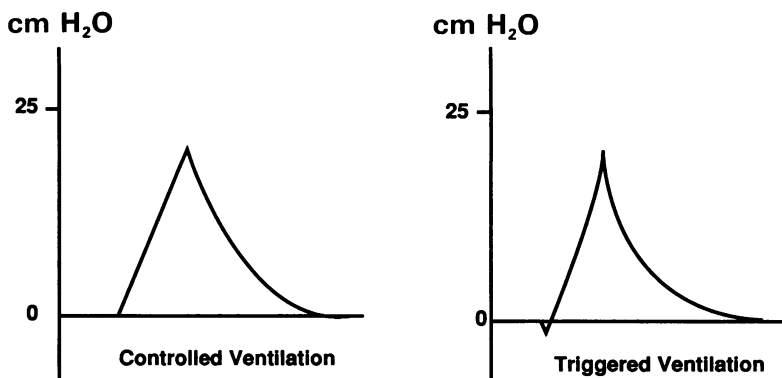
25

0

Triggered Ventilation

Figure 2 Diagrammatic representation of airway pressure profiles during controlled mechanical ventilation and triggered ventilation. Note the small negative pressure transient at the start of the triggered breath, which represents the patient's inspiratory effort.

SELECTION OF PATIENTS[6]

Patients needing mechanical assistance to breathe for 16 hours or more each day are

Figure 3 Diagrammatic representation of airway pressure profiles: (A) during spontaneous ventilation; (B) during fully controlled ventilation; (C) the resultant of the patient's inspiratory effort summating with the positive pressure pulse from the ventilator.

cm H₂O
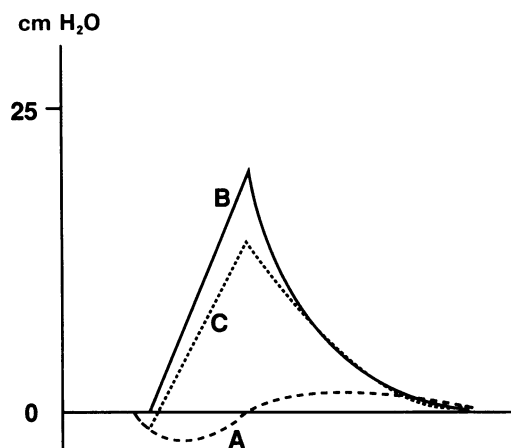
usually managed with a tracheostomy and positive pressure ventilator whether in hospital or at home. A chronic paralysing illness that does not interfere with mental function—for example, high transection of the spinal cord—is the usual kind of condition for which home care is considered. Phrenic pacing has a small role in these circumstances, usually as a means of enhancing daytime independence, but is feasible only if the nerve is capable of conduction and the diaphragm can contract effectively in response to the stimulus.

Non-invasive positive pressure ventilation is preferred for those who require ventilatory assistance only overnight. The hazards and discomforts of tracheostomy are avoided, external humidification is unnecessary, and daytime activities are totally unrestricted. Indications include central sleep apnoea, respiratory failure caused by thoracic deformity, static or only slowly progressive neuro-muscular disease affecting the respiratory muscles, and patients with healed pulmonary tuberculosis treated by ablative measures that have resulted in a combination of obstruction and restriction. It is a matter for debate whether similar methods should be considered for patients with rapidly progressive neuro-muscular disease affecting the respiratory muscles, even prophylactically, or for those with chronic obstructive pulmonary disease, in whom nocturnal exacerbation of hypoventilation is believed to contribute to daytime deterioration. Very few patients cannot be ventilated effectively with nasal intermittent pressure ventilation, but those unable to move their hands to their face will need to have the equipment fixed for them and may feel that it obtrudes on their limited ability to communicate. Negative pressure ventilation is sometimes preferred for these reasons.

TECHNIQUE OF NASAL POSITIVE PRESSURE VENTILATION[7]
Care is needed to ensure that the mask fits snugly and is comfortable. Several commercial models are available in multiple sizes, or individualised masks can be constructed to conform to facial contours. A poorly fitting mask is bound to leak. Efforts to secure it more firmly put pressure on the bridge of the nose, where the skin ulcerates very easily.

A tidal volume twice or one and a half times as great as that required during conventional intermittent positive posture ventilation is often needed. In part this reflects loss of gas through the open mouth or around the mask, but there is also more dead space because the entire upper respiratory tract is included in the ventilating volume.

The patient should be acclimatised to the system in hospital, where a period of intensive ventilatory assistance is often needed at the outset to restore normal daytime blood gas tensions and relieve heart failure. Intolerably breathless patients may have to be treated sitting upright but new users should preferably be trained while they are lying back on pillows or in an easy chair. This encourages them to relax and allows the operator to see whether accessory muscle activity has been abolished.

A few trial breaths should be offered first, asking the patient to hold the mask on his own nose, trying to prevent leaks around its edges and keeping the mouth closed firmly. Once confidence has been gained, the mask can be held in place for longer and longer periods while the operator adjusts the size and pattern of inspiration. It should be possible to abolish activity in the accessory muscles entirely, and tired or breathless patients often allow the ventilator to control them as soon as they feel they are receiving a sufficient volume. The relief of dyspnoea sometimes induces sleep almost immediately. Patients who are less ill at the outset may take longer to settle and their views on what settings are comfortable should be respected so far as possible.

The next stage is to secure the mask to the head with Velcro or elastic straps. This is best done with the mask disconnected from the ventilator. It can be reconnected as soon as the mask is in place and comfortable, but ventilation cannot be interrupted quite so quickly as when the mask is held by hand. It is worth starting with only two or three breaths before disconnecting the ventilator once more to check comfort and confidence.

Patients who are very breathless, severely hypoxaemic, or showing signs of circulatory distress should be given oxygen from the outset. Some ventilators provide for oxygen entrainment. Alternatively, a flow of 1 litre a minute, rarely more, added to a port on the front of the nasal mask usually suffices to achieve adequate arterial oxygenation and is unlikely to make an appreciable difference to either the settings on the ventilator or the resulting inflation pressure. Hypercapnia is less easily controlled if spontaneous respiratory efforts are abolished by relieving hypoxaemia but a rise in carbon dioxide tension is rare, even in patients who cannot tolerate any added oxygen while breathing spontaneously.[8]

Pulse oximetry provides a rough guide to safety initially but arterial blood gas measurements should be made half to one hour after the patient has been receiving nasal intermittent positive pressure ventilation, when the carbon dioxide tension will have reached a plateau. Many patients, however, continue to contribute some spontaneous

respiratory effort for several hours at least and so hypercapnia may return later unless the volume delivered from the machine is increased as they acclimatise to more fully controlled ventilation.

Patients should be encouraged to sleep as soon as possible while using the ventilator. There is no need to set the low pressure alarm (which detects leaks) with particular stringency at this stage, except for individuals particularly vulnerable to even a minor reduction in minute ventilation. Once the patient has acclimatised to sleeping for several hours or a whole night while using the machine, the alarm should be adjusted to ensure that appreciable leaks will be detected. Unfortunately not all patients are roused even by quite loud auditory signals. A pressure generating ventilator system, which provides some compensation for leaks, may be preferable in these circumstances.

The usual source of inadvertent volume loss is through the mouth in those who sleep with their mouths open. An elasticated chin strap secured to the bands holding the mask to the head is often sufficient to control the leak but is rarely successful in the edentulous patient. The position is improved if dentures are retained during sleep, but this can cause soreness of the gums or jaws where the denture is pressed inwards and upwards by the mask and chin-strap.

Soreness on the bridge of the nose usually resolves if a soft wedge is used to lift the apex of the mask away from the face and the skin is protected with a light dressing. Occasional patients complain of either rhinorrhoea or excessive nasal dryness, sometimes accompanied by small epistaxes. Fortunately these symptoms are usually self limiting. Gaseous distension of the abdomen may be troublesome when the impedance to inflation of the chest is high or where controlled breaths are imposed, rather than delivered in response to the initiation of inspiration by the patient, when gas flow into the lungs is facilitated. Sometimes the delivered volume must be reduced to alleviate gastric distension, even though a lower inflation pressure and less effective gas exchange will result.

Few patients need to use the ventilator at home except overnight, and only a small minority with intrinsic lung disease or severe pulmonary hypertension require domiciliary oxygen as well. Special provision for emergency power supplies is not usually needed, and most patients can tolerate a night or two without support in the event of a mechanical failure.

The adequacy of overnight ventilation should be confirmed before the final arrangements for discharge home are made. Arterial blood gas tensions during mechanical ventilation by day are often misleading because the mouth is usually closed more firmly than during sleep and at least some spontaneous respiratory effort is likely to persist and augment gas exchange. Quite substantial reductions in ventilation may pass unnoticed if only oxygen saturation is recorded, and transcutaneous or end tidal carbon dioxide values should prefer-ably be recorded as well.

Follow up

Outpatient follow up may be arranged as soon as good overnight control has been confirmed and the patient and family are familiar with the management and maintenance of the equipment. Regular measurement of arterial blood gas tensions is an essential component of follow up visits. Normal daytime values for arterial blood gas tensions are often restored and maintained when successful nocturnal ventilation is established for patients with respiratory failure caused by pure extrapulmonary restriction. More often the figures are not entirely normal, but an oxygen tension maintained above 8·0 kPa and a carbon dioxide tension below 7·0 kPa should be possible unless there is coincident lung disease. An exception is seen in patients with severe respiratory muscle weakness. No matter how good the overnight control, respiratory failure recurs by day because the spontaneously breathing patient cannot match ventilation achieved mechanically. This anomaly causes symptoms in a few cases, manifested as early morning dyspnoea when efforts to breathe spontaneously fail to match the preceding period of mechanical assistance.

The frequency of follow up should be determined by the nature of the disease, and factors such as the patient's motivation, compliance, and intelligence. An interval of three to six months is sufficient as soon as a satisfactory and stable condition has been achieved, and some patients need be seen no more than once a year. Reliable arrangements are necessary to ensure that contact can be re-established quickly if symptoms recur, usually as a result of respiratory tract infection. The same is true if any unrelated medical intervention is necessary, because the severity of the underlying respiratory disorder is often quite inapparent to others and undesirable risks may be incurred as a result. Regular maintenance of the equipment and provision of a prompt repair service are needed too; this should preferably be co-ordinated on a national basis in the interest of efficiency and economy.

Outcome

Domiciliary mechanical ventilation provides an impressive improvement in longevity and quality of life in appropriate circumstances.[9 10] Patients and their families prefer treatment at home whenever possible, and this is not only desirable but also economically advantageous. Several countries have established a national system to provide comprehensive respiratory care for patients at home,[11 12] including the supervision of mechanical ventilation. It seems likely that similar developments will follow eventually in the United Kingdom.

Appendix: Addresses of manufacturers or UK agents mentioned in the table

Bromptonpac/Airpac:
Pneupac Ltd, Crescent Road, Luton LU2 0AH

Respironics Bipap, Lifecare PLV 100, Bantam:
Medicaid Ltd, Hook Lane, Rose Green, Pagham,
Bognor Regis PO21 3PP
(Respironics nasal masks also available from Medicaid)

Monnal D:
Deva Medical Electronics Ltd, 8 Jensen Court,
Astmoor Industrial Estate, Runcorn WA7 1PF

Puritan-Bennett:
Puritan-Bennett (UK) Ltd, Heathrow Causeway,
152–176 Great West Road, Hounslow TW4 6JS

Ventimate:
Thomas Respiratory Systems, 33 Half Moon Lane,
London SE24 9JX.
(Sefam nasal masks are also available from Thomas
Respiratory Systems)

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