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# Equipment needs for noninvasive mechanical ventilation

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**ABSTRACT: Noninvasive mechanical ventilation (NIV) has a long tradition for the treatment of chronic respiratory failure and more recently has also been applied in acute respiratory failure. Based on this experience both critical care ventilators and portable ventilators are used to perform NIV. The individual choice of ventilator type should depend on the patient's condition and also on the expertise of attending staff, therapeutic requirements and the location of care.**

**The majority of studies have used pressure-targeted ventilation in the assist mode. Positive qualities of pressure support ventilation (PSV) are leak compensation, good patient/ventilator synchrony and the option of integrated positive end-expiratory pressure to counteract the effect of dynamic hyperinflation. In this article, some crucial issues concerning PSV (*i.e.* triggering into inspiration, pressurisation, cycling into expiration and carbon dioxide rebreathing) and some corrective measures are discussed.**

**The parameters which should be monitored during noninvasive ventilation are presented. The interface between patient and ventilator is a crucial issue of noninvasive ventilation. Advantages and disadvantages of face and nasal masks are discussed. Finally, causes and possible remedies of significant air leaks and some technical accessories for noninvasive ventilation are dealt with.**

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Successful assisted ventilation depends critically upon adapting mechanical ventilation to the patient's needs. This is particularly true when the noninvasive mode is used because the patient is conscious and if ventilation is ineffective or uncomfortable the patient may reject it. In patients with chronic respiratory failure (CRF), noninvasive ventilation (NIV) is performed during sleep and comfort is particularly important if sleep is not to be compromised and ventilation to be effective. An understanding of the technical equipment, in particular the modes of ventilation and the potential problems with each, is crucial, as is the selection of an appropriate interface [1]. This article deals with the equipment needs for NIV; in particular the major ventilator types and modes, monitoring, different interfaces and supplies.

## Different modes of ventilation

Ventilators can be categorised by the way that the ventilator is set to deliver gas flow and how it cycles between inspiration and expiration. Pressure-cycled machines deliver a predetermined pressure and the volume delivered will depend upon the impedance to inflation. If there is a leak in the circuit, flow will increase to compensate, but if there is airway obstruction, tidal volume will be reduced. Volume-cycled machines deliver a fixed tidal or minute volume and will generate a pressure sufficient to achieve this. If the impedance to inflation is high, pressure will be increased and the targeted tidal volume will be delivered. However, if there is a leak, there will be no increase in flow rate to compensate, a lower pressure will be generated, and the delivered tidal volume will fall. Triggering into inspiration and

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cycling into expiration can be timed by the machine or on the basis of detection of patient initiated changes in flow or pressure.

Mechanical ventilation can be "controlled" (*i.e.* the machine determines respiratory frequency), "assisted" (*i.e.* the machine augments the patient's spontaneous breaths), or a combination of the two, "assist/control" (A/C) mode, which is called "spontaneous-timed" (S/T) mode in pressure targeted ventilators. The backup rate is usually set at slightly below the spontaneous breathing rate. Pure control modes have rarely been applied in acute respiratory failure (ARF) but if they are used, the breathing frequency of the ventilator must be set higher than the patient's spontaneous breathing frequency to avoid patient respiratory efforts that are not supported by the ventilator. In CRF, timed modes alone may be used in patients with unreliable respiratory effort, unstable ventilatory drive or mechanics, apnoea or hypopneas, massively overloaded respiratory muscles or in patients where the assist mode fails to augment spontaneous breathing. In practice, however, the A/C or S/T combination has the advantages of the timed mode but allows augmentation of extra spontaneous efforts that may occur with irregular breathing patterns that may be seen at sleep onset or during rapid eye movement (REM) sleep. The proportion of breaths which are assisted and those which are controlled will depend upon the backup rate that is set.

Synchronised intermittent mandatory ventilation (SIMV) is still available in many portable volume-targeted ventilators. In SIMV, spontaneous breathing is possible beside mandatory ventilation. During spontaneous ventilation, neither demand nor continuous gas flow systems are available and the associated work of breathing is high [2]. For this reason SIMV should no longer be used as a mode for NIV.

### *Continuous positive airway pressure*

Continuous positive airway pressure (CPAP) may be administered using "demand", "flow-by" or "continuous flow" techniques. CPAP is delivered either by a flow generator with a high pressure gas source, or using a portable compressor. It requires a spontaneously breathing patient and is unable to support ventilation in the case of apnoea. By delivering a constant pressure during both inspiration and expiration, CPAP influences breathing mechanics (*e.g.* functional residual capacity), improves the shunt fraction and reduces inspiratory work of breathing in patients with left heart failure [3]. In patients with chronic obstructive pulmonary disease (COPD), CPAP reduces the work of breathing by counterbalancing the inspiratory threshold load when there is intrinsic positive end-expiratory pressure (PEEP) [4]. It has been used in ARF caused by a variety of aetiologies with variable success [5, 6].

### *Pressure-targeted ventilation*

Pressure support ventilation (PSV) allows the patient to control inspiratory and expiratory times while providing a set pressure; this in conjunction with patient effort and respiratory mechanics determines the inspiratory flow and tidal volume. With pressure-controlled ventilation the timing of inspiration is determined by the ventilator, as is cycling into expiration. Pressure-targeted ventilators have leak compensating abilities. However, using a test lung model it was found that leak compensating capabilities between six different pressure-targeted ventilators differed markedly [7]. The new generation of pressure-targeted ventilators include higher maximal inspiratory pressure (up to 40 $cmH_2O$), adjustable pressure rise time, adjustable minimum and maximum inspiratory times and sophisticated monitoring and alarm systems. Particularly in terms of efficacy and safety, this new generation of ventilators has overcome most concerns about the application of portable pressure ventilators as an intervention in ARF. Pressure-targeted ventilators have several advantages compared to volume-targeted ventilators and are the preferred NIV devices in the treatment of ARF. Accordingly, in the French epidemiological survey, ARF was treated with PSV with or without PEEP in 67% of patients, whereas assist-control volume-targeted ventilators were only used in 15% [8]. There are a number of potential problems with PSV, which are summarised in table 1 with suggested remedies.

*Triggering into inspiration.* Some ventilators have a fixed trigger, whereas in others the sensitivity can be varied. In the past, ventilators were usually pressure triggered, but it has been shown that flow-triggered devices are more sensitive than pressure-triggered devices [9–11]. The sensitivity of the inspiratory trigger needs to balance two extremes: 1) an insensitive trigger increases work of breathing; and 2) a trigger that is too sensitive leads to auto triggering. Auto triggering may also be caused by air leaks [12]. In a test lung model, designed to simulate an acute exacerbation of COPD, the triggering behaviour of 13 different ventilators was studied [13]. The authors found long triggering delay times, which appeared to be mainly due to the intrinsic properties of the devices. In a complex mathematical model investigating PSV, HOTCHKISS *et al.* [14] showed that unstable behaviour of the ventilator performance could impose breath-to-breath variability in the effort required for inspiratory triggering. A moving time window, analysing the variation in the slope of the pressure signal, enabling the trigger sensitivity to be adjusted and optimised, is a new development. A machine with an effective trigger is critical to the success of NIV, particularly in ARF.

*Pressurisation.* The ability of the ventilator to meet the patient's flow demand is another technical challenge. Flow demand mainly depends on the underlying pathophysiology (*e.g.* resistance and compliance). Both increasing the inspiratory pressure support and reducing the pressure rise time (the time to reach the preset inspiratory pressure) improves pressure delivery and lowers the work of breathing [15]. Depending on the type of ventilator, the pressure rise time can be individually adjusted or fixed. There is little data about

Table 1. – Troubleshooting of crucial issues of pressure support ventilation

| Problem | Potential cause | Corrective measure |
|---|---|---|
| Inspiratory trigger failure | Air leak | Adjust mask or change type |
| | Autocycling | Reduce trigger sensitivity |
| | Increased work of breathing | Adjust trigger sensitivity or change to a flow trigger if pressure trigger used |
| Inadequate pressurisation | Pressure rise time too long | Reduction of pressure rise time |
| | Pressure support too low | Increase inspiratory pressure |
| Failure to cycle into expiration | Air leak leading to "inspiratory hang up" | Adjust mask or consider switch from nasal to face mask |
| | High end-inspiratory flow | Increase end-inspiratory flow threshold and set time limit for inspiration |
| $CO_2$ rebreathing | Single circuit with no true exhalation valve | Use two lines and use nonrebreathe valve |
| | High respiratory rate | Lower respiratory rate |
| | No PEEP | Add PEEP to lavage mask |
| | Large mask dead space | Reduce dead space with padding |

$CO_2$: carbon dioxide; PEEP: positive end-expiratory pressure.

the effect of this on patient comfort or the work of breathing.

*Cycling into expiration.* The criteria used to end inspiration and cycle into expiration may have a clinically relevant impact on expiratory effort and can cause desynchronisation between patient and ventilator [16, 17]. The two extremes affecting the adjustment of cycling into expiration are: 1) premature termination of inspiration (*i.e.* cycling too sensitive); and 2) prolonged inspiration and increased work of expiratory muscles (*i.e.* cycling insensitive). The criteria used to cycle into exhalation are a decrease of inspiratory flow from a peak to a threshold value (*e.g.* 25% of peak flow) or to a fixed flow rate. Particularly in COPD patients, it is crucial to adjust the end inspiratory flow threshold to achieve good expiratory synchrony; due to a relatively high end-inspiratory flow a high flow threshold (25–40% of peak flow) should be chosen. Additionally, in some devices a time limit of inspiration (*e.g.* 0.1–3 s) is available, at which time the ventilator will cycle into expiration, regardless of the flow. Clearly, inspiratory times of 3-s duration are not appropriate, but this is a safety feature that will prevent severe inspiratory hang up (see Leak section).

*Carbon dioxide rebreathing.* Carbon dioxide ($CO_2$) rebreathing has been documented with some common home bilevel ventilators that have a single gas delivery circuit and do not contain a true exhalation valve [18, 19]. The risk of rebreathing is greater with high respiratory rates and low external PEEP because these are associated with shorter expiratory times and low $CO_2$ lavage from the circuit. To the best of the current authors' knowledge no studies have been performed testing more up-to-date systems using higher intentional leak rates. Systems that use true exhalation valves have shown significant variation in the resistance to exhalation through the valve. This increased resistance can increase the work of breathing associated with difficult exhalation [17]. However, the question of whether $CO_2$ rebreathing is a clinically important issue remains unresolved.

*Extrinsic positive airway pressure.* COPD is characterised by dynamic hyperinflation and intrinsic PEEP, which may cause patient/ventilator asynchrony [20, 21] and an increase in the work of breathing. External PEEP, which is an integral option in pressure-targeted ventilators, is set to counteract the effect of intrinsic PEEP on ventilator triggering and work of breathing [22]. PEEP may also stabilise the upper airway function during sleep, increase functional residual capacity or decrease micro- and macroatelectasis.

*Proportional assist ventilation.* Proportional assist ventilation (PAV) has recently been proposed as a mode of synchronised partial ventilatory support in which the ventilator pressure output is proportional to instantaneous patient effort [23]. From a pathophysiological point of view, the specific effect of PAV in patients with ARF due to COPD has been recently illustrated in a study by RANIERI *et al.* [24]. In this study, it was found that PAV unloads the resistive burden proportionally to inspiratory muscle effort. The efficacy of PSV and PAV, in terms of breathing frequency, dyspnoea scale, blood gases and intubation rate, was equal, although PAV may offer an advantage with respect to patient comfort and acceptance [25, 26]. In a physiological study, the effects of mask PAV in patients with COPD and ARF were evaluated [27]. PAV increased tidal volume and minute ventilation and improved blood gases. Currently, however, PAV remains an experimental ventilation mode and its clinical impact as a mode for NIV has not been established [28]. In particular, its use during sleep when patient effort may be reduced has not been studied.

### *Volume-targeted ventilation*

During volume-targeted ventilation the ventilator delivers a set tidal volume for each breath and inflation pressures may vary. Compared to PSV volume-targeted ventilators are rarely used in ARF and were only used exclusively in one study [29]. Volume-targeted modes cause more gastric distension

than pressure-targeted machines and variability of pressure; for instance if the patient swallows or coughs, may be uncomfortable for the patient. To minimise leaks due to high peak pressures the mask head straps may need to be tightened, resulting in pressure sores and skin necrosis. Volume-targeted support may be preferred in patients with a changing respiratory impedance, in order to ensure a given tidal volume, though higher pressures may simply increase leakage without a corresponding increase in tidal volume delivery to the patient. Volume ventilators generally have a more elaborate alarm system than pressure-targeted machines and are capable of generating high positive pressures. The volume provided by the ventilators should be constant, but LOFASO *et al.* [30] found that some volume-targeted home ventilators were inaccurate in delivering the preset tidal volume, especially when a high airway resistance was simulated. Volume-targeted ventilators have no integrated PEEP but interchangeable PEEP valves can be added to the exhalation port, however these may be heavy and drag at the mask. In addition, these devices are associated with potential shortcomings, such as inaccurate settings, dislocation and loud noise.

### *Ventilators with mixed volume and pressure-targeted modes*

In order to make the most of the advantages of pressure and volume ventilators, new machines which combine the two modes have recently been released [2]. These respirators are similar to critical care (CC) ventilators and may be useful for difficult-to-adapt patients and those with rapidly changing breathing patterns and mechanics. The clinical impact of these "dual ventilators" has not been well evaluated and therefore it is not known if they offer important advantages to other respirators in routine practice.

## Comparison of different noninvasive ventilation modes

A few studies have investigated the difference between PSV and A/C volume ventilation in ARF. In a prospective randomised study comparing both modes in hypercapnic respiratory failure no difference was shown in terms of patient tolerance and quality of ventilation [31]. VITACCA *et al.* [32] found no difference in clinical outcome and blood gas changes, even though a lesser incidence of side-effects was associated with PSV. In the study by MEECHAM JONES *et al.* [33], comparing PSV, PSV plus PEEP, CPAP and A/C mode, there was no significant difference in terms of improved oxygen pressure; the change in carbon dioxide was variable and PEEP caused no advantage in terms of blood gases. GIRAULT *et al.* [34] found similar improvements in breathing pattern and gas exchange. The A/C mode was associated with a lower respiratory workload, but with greater discomfort, more frequent loss of control of breathing and less mask leak compensation than PSV. However, comparing pressure support with assist control ventilation in terms of the effect on work of breathing, CINNELLA *et al.* [35] found that for high tidal volumes there was no difference; at moderate tidal volume and low flow rates, inspiratory assistance delivered at a constant pressure reduced the respiratory work rate more effectively than assist control ventilation.

There have been several studies in patients with CRF comparing different modes of ventilation. In a short-term study, RESTRICK *et al.* [36] found no difference in overnight oxygenation when patients with CRF used volume-targeted ventilation compared with pressure-targeted ventilation for one night each. SMITH and SHNEERSON [37] reported an improvement in diurnal blood gas tensions in patients who switched from volume-targeted ventilation to pressure-targeted ventilation. In a long-term case series study in 30 patients with CRF who started NIV, SCHONHOFER *et al.* [38] compared volume-targeted ventilation and pressure-targeted ventilation consecutively, both in the controlled mode over 4 weeks in a sequential manner. With volume ventilation, all but two patients improved blood gases during spontaneous breathing and symptoms. In the subsequent interval, 10 out of 28 patients significantly deteriorated with pressure ventilation but improved again after reintroduction of volume ventilation. The authors concluded that in a subpopulation with clinically stable CRF volume may be superior to pressure ventilation. However, at the end of the study the majority of patients with equal efficacy of both ventilation modes preferred pressure ventilation as the definitive mode for long-term mechanical ventilation for reasons of comfort (*e.g.* noise, weight and handling).

## Critical care *versus* portable ventilators

CC ventilators can be used for NIV. They are manufactured to a high technical specification and benefit from elaborate monitoring, but are expensive. The elaborate alarms may be counter-productive since they frequently indicate very minor air leaks that are common during NIV and not of clinical significance. Furthermore, the circuit of CC ventilators is often heavy, which may be a problem during NIV. The simpler, smaller and less expensive portable ventilators, which were initially designed to be used for home mechanical ventilation, can also be used in the hospital in ARF. Unsurprisingly, in a French epidemiological survey concerning the use of NIV in intensive care units, there was a predominance of CC ventilators used (76% compared with 24% portable ventilators) in the treatment of ARF [8]. The principal limitation to the use of home ventilators during ARF is the lack of direct "on line" monitoring of pressure, volume and flow provided by these devices. The evaluation of patient/ventilator asynchrony is more difficult without visualisation of flow and pressure waveforms [39]. These are important features, especially during the first period of ventilation when it is important to assess the patient/ventilator interaction, respiratory mechanics, and the expired tidal volume [40]. Nonetheless, there are many studies reporting effective NIV in ARF using portable ventilators.

Another difference between home and CC ventilators

is the use of single limb circuits in the portable devices, which may have an effect upon $CO_2$ elimination. The evaluation of one established CC ventilator and six portable home devices delivering pressure support showed differences in terms of occurrence of $CO_2$ rebreathing, speed of attainment of stable pressure support level and expiratory resistance [18]. These differences may be of clinical importance but a variety of bilevel devices have been used with benefit in clinical studies, suggesting that differences found during bench testing may not be so important in the clinical arena. Another study investigated the technical performance in a lung model with respect to seven variables of nine portable home pressure ventilators compared to a CC ventilator [41]. The authors found that most of the portable ventilators evaluated were able to respond to high ventilatory demands and even outperformed the CC device.

## Interfaces

Apart from the choice of ventilator type, mode and setting, another crucial issue when starting NIV is to find an optimal interface. However, despite a broad variety, until now only little attention has been focused on the choice of interface and no generally accepted consensus has been reached concerning the management of interfaces. In general, five different types of interface exist: full face masks, nasal masks, nasal pillows or plugs, mouthpieces and custom fabricated masks. The current authors performed a Medline search, with reference to NIV interfaces used for NIV, and found that in ARF facial masks predominated (~70%), followed by nasal masks (~25%) and nasal pillows (~5%). However, in patients with CRF, commercially available nasal masks are better tolerated than both facial masks and nasal pillows [31]. Advantages and disadvantages of both mask types are given in table 2.

Early studies dealing with NIV in ARF used nasal masks. The nasal mask adds less dead space, causes less claustrophobia and allows expectoration and oral intake. In order to reduce mouth leaks while wearing a nose mask a chin strap is sometimes required but is rarely effective. The improvement in arterial blood gas tensions appear to be slower in some studies using nasal masks compared to face masks [42]. The full face mask is often superior in patients with predominant mouth breathing, reducing oral air leakage. The face mask delivers higher ventilation pressures with less leakage, requires less patient cooperation, and permits mouth breathing. Compared to nasal masks, the more common application of full face masks in ARF is also a reflection of better quality of ventilation (at least during the initial phase of the intervention) in terms of minute ventilation and improved blood gases [31, 43]. Compared to nasal masks, face masks are generally more claustrophobic, impede communication, limit oral intake and increase the dead space [44] which may cause $CO_2$ rebreathing. The clinical impact of masked-associated dead space in continuous flow circuits, which utilise an intentional leak to eliminate $CO_2$, *versus* valved systems, where dead space may have a higher impact, has not been explored. However, based on practical experience, dead space does not seem to reduce the effectiveness of NIV in ARF. In addition, further types of full face masks both for open and closed circuits are available. Some of these masks have addressed the issue of dead space and have increased leak rates, which may improve the quality of NIV. If claustrophobia prevents the acceptance of a full face mask a nasal mask may be an acceptable alternative.

Table 2. – Advantages (+) and disadvantages (-) of face and nasal mask

| Clinical aspect | Face mask | Nasal mask |
|---|---|---|
| Mouth leak and mouth breathing | + | - |
| Influence of dental status | + | - |
| Airway pressure | + | - |
| Dead space | - | + |
| Communication | - | + |
| Eating, drinking | - | + |
| Expectoration | - | + |
| Risk of aspiration | - | + |
| Risk of aerophagia | - | + |
| Claustrophobia | - | + |
| Comfort | - | + |

Mask-induced pressure sores, usually caused by over tightening the straps, are an important disadvantage which may lead to a reduced tolerance. Different dressings have been evaluated to prevent nasal bridge abrasion, especially in ARF. The fit of the nasal mask can be improved by applying mask cushions and seal and support rings. Variations include the bubble type mask or gel masks. Semi-customised masks consist of a prefabricated frame in which a quick-drying filler is injected and afterwards moulded to the individual facial contours. Whether custom-fabricated nasal or facial masks, which are often used in CRF, may be an alternative option in ARF needs further investigation. Masks moulded directly on the face, using small nasal openings, may have increased resistance, which could impact on ventilating pressures and cause decreased ventilation.

## Leak

Leak can result from poor apposition of the mask to the skin or through the open mouth reducing alveolar ventilation and synchrony between the patient and the machine. In addition, the quality of sleep during NIV may be compromised. Therefore, the amount of leakage should be monitored and will influence the choice of mask type (see Interface section). In order to compensate for a significant leak a ventilator needs high flows. Pressure-targeted ventilators have leak compensating abilities with peak inspiratory flow rates of 120–180 $L \cdot min^{-1}$ (see Pressure-targeted ventilation section). Modern pressure ventilators can compensate for very large leaks, but if they are allowed, sleep quality may be sacrificed. Recently, respiratory system model studies have been published which investigated mask mechanics and

leak dynamics during simulated NIV [45]. Based on another test lung model it has been found that leak compensating capabilities between six different devices differed markedly [7]. Leak compensation is much more limited in volume-targeted ventilators; adding a leak to the circuit of these ventilators caused a fall in tidal volume of >50% [37]. However, moderate leaks can be compensated for by increasing the tidal volume. Another approach to mouth leaks is to tape the mouth shut and the effect of this on the quality of ventilation and sleep during NIV has been investigated in patients with CRF [46]. Taping the mouth was associated with a marked reduction of leak, improved ventilation (*i.e.* decrease of carbon dioxide pressure) and sleep quality (*i.e.* reduction of arousal index and increase of REM sleep). However, there have been no reports of mouth taping in patients with ARF and it is unlikely to be acceptable to the majority of patients.

## Accessories for noninvasive ventilation

### *Humidification*

Although no data dealing with humidification in NIV have been published to date, it seems reasonable to transfer the findings of studies dealing with humidification in CPAP as a treatment of sleep apnoea to NIV. Mouth leaks during NIV may be particularly important because they cause unidirectional inspiratory nasal airflow and progressive drying of the nasal mucosa [47]. This is also known to promote the release of inflammatory mediators and to increase nasal airway resistance [47, 48], which increases mouth breathing and further leakage. It has been shown that despite a severe mouth leak, heated humidification significantly increased relative humidity in the airways [49] and reduced nasal resistance [47]. An increased compliance rate (*i.e.* hours of usage) with CPAP was found in patients with heated humidification compared to unheated humidifiers and no humidification at all [50]. Different types of humidification include heated or unheated pass-over devices, pass through devices, and heat and moisture exchangers, however with pressure-targeted ventilators only pass-over humidifiers should be applied, since pass through devices, and heat and moisture exchangers may compromise pressure and flow delivery and triggering.

### *Oxygen supplementation*

None of the portable home mechanical ventilators are designed to deliver a precise inspired oxygen ($O_2$) concentration. However, $O_2$ can be added to the inspiratory circuit or the mask itself. In some volume-targeted ventilators an $O_2$ accumulator is attached to the entry port. The delivered $O_2$ concentration ($F_{i,O_2}$) is variable. There are formulas provided to calculate $F_{i,O_2}$, but they are only correct for the assumption of control mode without a relevant leak, which therefore does not apply during NIV. The delivery of a high $F_{i,O_2}$ may be impossible using a portable ventilator and therefore CC ventilators, or those with an integral blender, are preferred when oxygenation is severely compromised, for instance in patients with acute lung injury [8, 51, 52].

### *Drugs nebulisation*

In intubated COPD patients it has been shown that inhaled bronchodilators reduce the airway resistance and the intrinsic PEEP [53, 54]. The administration of aerosols *via* metered-dose inhalers during NIV, performed in different settings and conditions in stable patients with COPD, also leads to a significant bronchodilation without reduced quality of mechanical ventilation [55, 56]. Future studies are needed to investigate whether these findings also apply to patients with ARF. Nebulisation of drugs can be carried out using most bilevel devices with continuous flow circuits without changing the delivered pressures. Many of these devices have the capability of altering patient flow, based on added flow to the circuit preventing pressure fluctuation. This is not the case with modes using circuits with exhalation valves and caution should be exercised. Additional flow is usually limited to 15 $L \cdot min^{-1}$.

### *Power supply*

For patients with a high level of dependency upon the ventilator, a battery power source is mandatory in case of failure of the electricity supply, for movement outside the home or for transfers within the hospital. Many volume-targeted ventilators can be operated not only with household ac but also by external and internal dc. The built-in backup batteries power the ventilator for at least 20 min. KACMAREK and colleagues [2, 57] have published comprehensive overviews dealing with the technical profile of the currently available ventilators. Technical details (operation and charging times of the internal battery) of each ventilator are given. In contrast, many pressure-targeted ventilators only operate with standard ac current and have no internal battery. Some can be attached to an external battery [57] and the option of an integral battery is a feature of newer models. Newer devices on the market incorporate automatic switch over, making external battery use much easier, and motor technology has advanced tremendously such that newer bilevel devices have low-power usage, allowing a long duration of operation.

## Conclusion

The topic "Equipment for noninvasive ventilation", with respect to both CRF and ARF, is characterised by the discrepancy between increasing usage and a severe dearth of evidence that supports specific strategies. Given that NIV for CRF is usually administered during sleep, there is a paucity of evidence about the effects of different modes on gas exchange during sleep and sleep quality.

The individual ventilator mode, type of interface

and monitoring have to be selected whilst considering the experience of the clinical team, the location where noninvasive ventilation is delivered and the underlying pathophysiology. Continuous advances in the development of the equipment is needed to increase patient tolerance. Applying "intelligent" algorithms to future ventilators should combine optimal resting of the respiratory muscles, improved sleep, gas exchange and the capability of closely anticipating the patient's desired breathing pattern in addition to providing information allowing clinicians to evaluate these aspects. Allowing the patient to maintain control of the breathing pattern probably increases compliance in the acute and chronic application of noninvasive ventilation. Comprehensive educational programmes which deal with equipment for noninvasive ventilation must be available. Finally, research investigating technical equipment is needed to increase the evidence base for different strategies of providing ventilatory support noninvasively.

## References


1. International consensus conferences in intensive care medicine: noninvasive positive pressure ventilation in acute respiratory failure. *Am J Respir Crit Care Med* 2001; 163: 283–291.
2. Kacmarek RM, Hill NS. Ventilators for noninvasive positive pressure ventilation: technical aspects. *In*: Muir JF, Ambrosino N, Simon AK, eds. Noninvasive mechanical ventilation. Sheffield, European Respiratory Monograph, 2001; 6: pp. 76–105.
3. Lin M, Yang YF, Chiang HT, Chang MS, Chiang BN, Cheitlin MD. Reappraisal of continuous positive airway pressure therapy in acute cardiogenic pulmonary edema. Short-term results and long-term follow-up. *Chest* 1995; 107: 1379–1386.
4. Petrof BJ, Legare M, Goldberg P, Milic-Emili J, Gottfried SB. Continuous positive airway pressure reduces work of breathing and dyspnea during weaning from mechanical ventilation in severe chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1990; 141: 281–290.
5. Delclaux C, L'Her E, Alberti C, *et al.* Treatment of acute hypoxemic nonhypercapnic respiratory insufficiency with continuous positive airway pressure delivered by a face mask: A randomized controlled trial. *JAMA* 2000; 284: 2352–2360.
6. Pang D, Keenan SP, Cook DJ, Sibbald WJ. The effect of positive pressure airway support on mortality and the need for intubation in cardiogenic pulmonary edema: a systematic review. *Chest* 1998; 114: 1185–1192.
7. Mehta S, McCool FD, Hill NS. Leak compensation in positive pressure ventilators: a lung model study. *Eur Respir J* 2001; 17: 259–267.
8. Carlucci A, Richard JC, Wysocki M, Lepage E, Brochard L. Noninvasive *versus* conventional mechanical ventilation. An epidemiologic survey. *Am J Respir Crit Care Med* 2001; 163: 874–880.
9. Aslanian P, El Atrous S, Isabey D, *et al.* Effects of flow triggering on breathing effort during partial ventilatory support. *Am J Respir Crit Care Med* 1998; 157: 135–143.
10. Giuliani R, Mascia L, Recchia F, Caracciolo A, Fiore T, Ranieri VM. Patient-ventilator interaction during synchronized intermittent mandatory ventilation. Effects of flow triggering. *Am J Respir Crit Care Med* 1995; 151: 1–9.
11. Nava S, Ambrosino N, Bruschi C, Confalonieri M, Rampulla C. Physiological effects of flow and pressure triggering during non-invasive mechanical ventilation in patients with chronic obstructive pulmonary disease. *Thorax* 1997; 52: 249–254.
12. Bernstein G, Heldt GP, Mannino FL. Synchronous mechanical ventilation of neonates. *Crit Care Med* 1993; 21: 1984–1985.
13. Stell IM, Paul G, Lee KC, Ponte J, Moxham J. Noninvasive ventilator triggering in chronic obstructive pulmonary disease. A test lung comparison. *Am J Respir Crit Care Med* 2001; 164: 2092–2097.
14. Hotchkiss JR Jr, Adams AB, Stone MK, Dries DJ, Marini JJ, Crooke PS. Oscillations and noise: inherent instability of pressure support ventilation? *Am J Respir Crit Care Med* 2002; 165: 47–53.
15. Bonmarchand G, Chevron V, Chopin C, *et al.* Increased initial flow rate reduces inspiratory work of breathing during pressure support ventilation in patients with exacerbation of chronic obstructive pulmonary disease. *Intensive Care Med* 1996; 22: 1147–1154.
16. Fabry B, Guttmann J, Eberhard L, Bauer T, Haberthur C, Wolff G. An analysis of desynchronization between the spontaneously breathing patient and ventilator during inspiratory pressure support. *Chest* 1995; 107: 1387–1394.
17. Lofaso F, Aslanian P, Richard JC, *et al.* Expiratory valves used for home devices: experimental and clinical comparison. *Eur Respir J* 1998; 11: 1382–1388.
18. Lofaso F, Brochard L, Hang T, Lorino H, Harf A, Isabey D. Home *versus* intensive care pressure support devices. Experimental and clinical comparison. *Am J Respir Crit Care Med* 1996; 153: 1591–1599.
19. Ferguson GT, Gilmartin M. $CO_2$ rebreathing during BiPAP ventilatory assistance. *Am J Respir Crit Care Med* 1995; 151: 1126–1135.
20. Elliott MW, Mulvey DA, Moxham J, Green M, Branthwaite MA. Inspiratory muscle effort during nasal intermittent positive pressure ventilation in patients with chronic obstructive airways disease. *Anaesthesia* 1993; 48: 8–13.
21. Nava S, Bruschi C, Fracchia C, Braschi A, Rubini F. Patient-ventilator interaction and inspiratory effort during pressure support ventilation in patients with different pathologies. *Eur Respir J* 1997; 10: 177–183.
22. Appendini L, Patessio A, Zanaboni S, *et al.* Physiologic effects of positive end-expiratory pressure and mask pressure support during exacerbations of chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1994; 149: 1069–1076.
23. Younes M, Puddy A, Roberts D, *et al.* Proportional assist ventilation. Results of an initial clinical trial. *Am Rev Respir Dis* 1992; 145: 121–129.
24. Ranieri VM, Grasso S, Mascia L, *et al.* Effects of proportional assist ventilation on inspiratory muscle effort in patients with chronic obstructive pulmonary disease and acute respiratory failure. *Anesthesiology* 1997; 86: 79–91.
25. Gay PC, Hess DR, Hill NS. Noninvasive proportional assist ventilation for acute respiratory insufficiency: Comparison with pressure support ventilation. *Am J Respir Crit Care Med* 2001; 164: 1606–1611.
26. Wysocki M, Richard JC, Meshaka MD. Nonivasive

proportional assist ventilation compared with noninvasive pressure support ventilation in hypercapnic acute respiratory failure. *Crit Care Med* 2002; 30: 323–329
27. Vitacca M, Clini E, Pagani M, Bianchi L, Rossi A, Ambrosino N. Physiologic effects of early administered mask proportional assist ventilation in patients with chronic obstructive pulmonary disease and acute respiratory failure. *Crit Care Med* 2000; 28: 1791–1797.
28. Patrick W, Webster K, Ludwig L, Roberts D, Wiebe P, Younes M. Noninvasive positive-pressure ventilation in acute respiratory distress without prior chronic respiratory failure. *Am J Respir Crit Care Med* 1996; 153: 1005–1011.
29. Bott J, Carroll MP, Conway JH, *et al.* Randomised controlled trial of nasal ventilation in acute ventilatory failure due to chronic obstructive airways disease. *Lancet* 1993; 341: 1555–1557.
30. Lofaso F, Fodil R, Lorino H, *et al.* Inaccuracy of tidal volume delivered by home mechanical ventilators. *Eur Respir J* 2000; 15: 338–341.
31. Navalesi P, Fanfulla F, Firgerio P, Gregoretti C, Nava S. Physiologic evaluation of noninvasive mechanical ventilation delivered with three types of masks in patients with chronic hypercapnic respiratory failure. *Crit Care Med* 2000; 28: 1785–1790.
32. Vitacca M, Rubini F, Foglio K, Scalvini S, Nava S, Ambrosino N. Non-invasive modalities of positive pressure ventilation improves the outcome of acute exacerbations in COLD patients. *Intensive Care Med* 1993; 19: 450–455.
33. Meecham Jones DJ, Paul EA, Grahame-Clarke C, Wedzicha JA. Nasal ventilation in acute exacerbations or chronic obstructive pulmonary disease: effect of ventilator mode on arterial blood gas tensions. *Thorax* 1994; 49: 1222–1224.
34. Girault C, Richard JC, Chevron V, *et al.* Comparative physiologic effects of noninvasive assist-control and pressure support ventilation in acute hypercapnic respiratory failure. *Chest* 1997; 111: 1639–1648.
35. Cinnella G, Conti G, Lofaso F, *et al.* Effects of assisted ventilation on the work of breathing: volume-controlled *versus* pressure-controlled ventilation. *Am J Respir Crit Care Med* 1996; 153: 1025–1033.
36. Restrick LJ, Fox NC, Braid G, Ward EM, Paul EA, Wedjicha JA. Comparison of nasal pressure support ventilation with nasal intermittent positive pressure ventilation in patients with nocturnal hypovention. *Eur Respir J* 1993; 6: 364–370.
37. Smith IE, Shneerson J. Secondary failure of nasal intermittent positive pressure ventilation using the Monnal D: Effects of changing ventilator. *Thorax* 1997; 52: 89–91.
38. Schonhofer B, Sonneborn M, Haidl P, Bohrer H, Kohler D. Comparison of two different modes for noninvasive mechanical ventilation in chronic respiratory failure: volume *versus* pressure controlled device. *Eur Respir J* 1997; 10: 184–191.
39. Kacmarek RM. NIPPV: patient-ventilator synchrony, the difference between success and failure? *Intensive Care Med* 1999; 645–647.
40. Calderini E, Confalonieri M, Puccio PG, Francavilla N, Stella L, Gregoretti C. Patient-ventilator asynchrony during noninvasive ventilation: the role of expiratory trigger. *Intensive Care Med* 1999; 25: 662–667.
41. Bunburaphong T, Imanaka H, Nishimura M, Hess D, Kacmarek RM. Performance characteristics of bilevel pressure ventilators: a lung model study. *Chest* 1997; 111: 1050–1060.
42. Meduri GU, Turner RE, Abou-Shala N, Wunderink R, Tolley E. Noninvasive positive pressure ventilation *via* face mask. First-line intervention in patients with acute hypercapnic and hypoxemic respiratory failure. *Chest* 1996; 109: 179–193.
43. Brochard L. What is really important to make noninvasive ventilation work. *Crit Care Med* 2000; 28: 2139–2140.
44. Criner GJ, Travaline JM, Brennan KJ, Kreimer DT. Efficacy of a new full face mask for noninvasive positive pressure ventilation. *Chest* 1994; 106: 1109–1115.
45. Schettino P, Tucci R, Sousa R, Barbas V, Amato P, Carvalho R. Mask mechanics and leak dynamics during noninvasive pressure support ventilation: a bench study. *Intensive Care Med* 2001; 27: 1887–1891.
46. Teschler H, Stampa J, Ragette R, Konietzko N, Berthon-Jones M. Effect of mouth leak on effectiveness of nasal bilevel ventilatory assistance and sleep architecture. *Eur Respir J* 1999; 14: 1251–1257.
47. Richards GN, Cistulli PA, Ungar RG, Berthon-Jones M, Sullivan CE. Mouth leak with nasal continuous positive airway pressure increases nasal airway resistance. *Am J Respir Crit Care Med* 1996; 154: 182–186.
48. Togias AG, Naclerio RM, Proud D, *et al.* Nasal challenge with cold, dry air results in release of inflammatory mediators. Possible mast cell involvement. *J Clin Invest* 1985; 76: 1375–1381.
49. Martins De Araujo MT, Vieira SB, Vasquez EC, Fleury B. Heated humidification or face mask to prevent upper airway dryness during continuous positive airway pressure therapy. *Chest* 2000; 117: 142–147.
50. Massie CA, Hart RW, Peralez K, Richards GN. Effects of humidification on nasal symptoms and compliance in sleep apnea patients using continuous positive airway pressure. *Chest* 1999; 116: 403–408.
51. Antonelli M, Conti G, Rocco M, *et al.* A comparison of noninvasive positive-pressure ventilation and conventional mechanical ventilation in patients with acute respiratory failure. *N Engl J Med* 1998; 339: 429–435.
52. Hilbert G, Gruson D, Vargas F, *et al.* Noninvasive ventilation in immunosuppressed patients with pulmonary infiltrates, fever, and acute respiratory failure. *N Engl J Med* 2001; 344: 481–487.
53. Mancebo J, Amaro P, Lorino H, Lemaire F, Harf A, Brochard L. Effects of albuterol inhalation on the work of breathing during weaning from mechanical ventilation. *Am Rev Respir Dis* 1991; 144: 95–100.
54. Guerin C, Chevre A, Dessirier P, *et al.* Inhaled fenoterol-ipratropium bromide in mechanically ventilated patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1999; 159: 1036–1042.
55. Nava S, Karakurt S, Rampulla C, Braschi A, Fanfulla F. Salbutamol delivery during non-invasive mechanical ventilation in patients with chronic obstructive pulmonary disease: a randomized, controlled study. *Intensive Care Med* 2001; 27: 1627–1635.
56. Dhand R, Duarte AG, Jubran A, *et al.* Dose-response to bronchodilator delivered by metered-dose inhaler in ventilator-supported patients. *Am J Respir Crit Care Med* 1996; 154: 388–393.
57. Kacmarek RM, Hess D. Equipment required for home mechanical ventilation. *In*: Tobin MJ, ed. Principles and practice of mechanical ventilation. New York, McGraw-Hill, Inc., 1994; pp. 111–154.