

*Current Concepts***NONINVASIVE VENTILATION**

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WHEN ventilatory support is delivered without establishing an endotracheal airway, it is termed noninvasive ventilation. Traditionally, noninvasive ventilation has been given with the use of devices that apply intermittent negative extrathoracic pressure. The advent of positive-pressure ventilation that is delivered through a nasal or face mask has greatly expanded the use of noninvasive ventilation. Such ventilation has a role in the management of acute and chronic respiratory failure in many patients and may have a role for some patients with heart failure. Noninvasive approaches can preserve normal swallowing, feeding, and speech. Cough and physiologic air warming and humidification are also preserved. Noninvasive ventilation can often eliminate the need for intubation or tracheostomy, preventing such problems as injury to the vocal cords or trachea and lower respiratory tract infections. This review will briefly describe some techniques that use negative pressure and then concentrate on recent developments in positive-pressure noninvasive ventilation.

NEGATIVE-PRESSURE VENTILATION

Negative-pressure ventilators support ventilation by exposing the chest wall to subatmospheric pressure during inspiration, with expiration occurring as the pressure around the chest wall is allowed to return to atmospheric levels. Several devices are available that generate negative extrathoracic pressure and augment tidal volume, and their use has been reviewed elsewhere.¹⁻³

Body ventilators apply negative pressure to the entire body below the neck. The Emerson iron lung was widely used in the 1950s during the poliovirus epidemic. Fiberglass descendants of the iron lung weigh less than 45 kg (100 lb). Less bulky and more portable devices have been designed to apply nega-

tive pressure to the thorax and abdomen. These include rigid, inflexible cuirass devices and the poncho-wrap, which uses a plastic grid over the thorax that is covered with a windproof fabric sealed at the neck, waist, and arms.⁴

Several uncontrolled studies reported benefits of intermittent negative-pressure ventilation in patients with chronic respiratory failure due to chest-wall, neuromuscular, or central hypoventilation diseases.⁵⁻⁷ In patients with stable, severe chronic obstructive pulmonary disease (COPD), however, a large double-blind, prospective study found that 12 weeks of negative-pressure ventilation had no benefit.⁸

The role of negative-pressure ventilation in the management of acute respiratory failure is unclear. Studies of the use of the body ventilator or poncho-wrap for patients with COPD, neuromuscular disease, and chest-wall deformity with acute respiratory failure suggest some benefit from these devices, but the studies have not been prospective and controlled.³ Negative-pressure ventilation has not been widely used, because of poor acceptance by patients, inadequate effectiveness for many patients, the awkward size of the devices, and the development of upper-airway obstruction in some patients. However, patients with neuromuscular disease, chest-wall deformity, central hypoventilation, or diaphragm paralysis often do benefit from negative-pressure ventilation.

NONINVASIVE POSITIVE-PRESSURE VENTILATION

Over the past decade noninvasive positive-pressure ventilation delivered by a nasal or face mask has gained increasingly widespread acceptance for the support of both chronic and acute ventilatory failure. The development of improved masks and ventilator technology made this mode of ventilation acceptable. Fear that the delivered tidal volume or inspiratory pressure would escape through the mouth proved to be unfounded, since the soft palate flops against the tongue in nasal ventilation or closes the nasopharynx in oral ventilation, securing an acceptable air passage into the trachea. An occasional patient requires a chin strap to prevent air from leaking out of the mouth. Many types and sizes of masks are available,⁹ including face masks that cover the nose and mouth, nasal masks, "nasal pillows" that fit into the nostrils, and cushion devices that fit across the nostrils (Fig. 1).

Noninvasive positive-pressure ventilation can be given by a volume ventilator, a pressure-controlled ventilator, a bilevel positive-airway-pressure (bilevel PAP) ventilator, or a continuous-positive-airway-pressure (CPAP) device (Table 1). Small portable ventilators are available when nocturnal or intermittent home use is desired.⁹ Several manufacturers offer relatively inexpensive, simple-to-operate portable venti-

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Figure 1. Noninvasive Positive-Pressure Masks.

The nasal mask (left) covers the nose but not the mouth. The nasal pillows (center) insert into the nares and are held in place by a strap. The central tube that connects to the respirator is secured to a cap or by straps across the forehead. The face mask (right) covers both the nose and the mouth.

lators capable of producing different inspiratory and expiratory pressures (i.e., bilevel PAP). These machines can maintain pressure while providing adequate flow to meet a patient's needs.

Volume Ventilation

Volume-cycled noninvasive ventilation, in which the ventilator delivers a set volume for each breath, can improve outcomes in acute respiratory failure^{10,11} and has been used to manage chronic respiratory failure.¹²⁻¹⁴ However, patients' tolerance of this therapy is often poor,^{10,15} in part because the inspiratory pressure may be elevated, which can be uncomfortable and cause leaks.¹⁶

Pressure Ventilation

Positive-pressure noninvasive ventilation, in which the ventilator delivers a set pressure for each breath, is commonly given with bilevel PAP ventilators or with standard ventilators that use pressure support or pressure control. Administering ventilation noninvasively through a nasal or face mask and a standard ventilator allows the physician to set the inspired oxygen concentration, prevent the rebreathing of exhaled gas, and use the ventilator monitors and alarms. Standard ventilators using flow-by systems allow the patient to breathe without expending effort to open valves. The pressure-support mode increases the pressure when the ventilator senses a patient-initiated breath and terminates the higher pressure when it detects a fall in the flow rate below a threshold value or after a prolonged period (e.g., three seconds). Pressure support is usually well tol-

erated by patients. However, there can be problems terminating inspiratory flow if an air leak is present¹⁷ or if inspiratory flow is prolonged, as is often the case in patients with severe obstruction.¹⁸ This problem can be prevented by the use of the ventilator's pressure-control mode, which sets a fixed inspiratory time and also provides a backup rate. For patients with apnea, a ventilator mode that provides a backup pressure-cycled rate is essential.

Bilevel PAP ventilators provide continuous high-flow PAP that cycles between a high positive pressure and a lower positive pressure. In the spontaneous mode, bilevel PAP responds to the patient's own flow rates and cycles between higher pressure (inhalation) and lower pressure (exhalation). It reliably senses a patient's breathing efforts, even if there are air leaks in the patient's circuit. When inspiration is detected, the higher pressure is delivered for a fixed time or until the flow rate falls below a threshold level. The spontaneous mode of bilevel PAP is similar in concept to pressure-support ventilation. The terminology differs, however, in that the expiratory pressure with bilevel PAP is equivalent to the positive end-expiratory pressure (PEEP) and the inspiratory pressure is equivalent to the sum of PEEP and the pressure-support level. Thus, a bilevel PAP setting of 12 cm of water for inspiratory pressure and 5 cm of water for expiratory pressure is equivalent to a standard ventilator setting of 7 cm of water for pressure support and 5 cm of water for PEEP. Another mode of ventilation is worth mentioning because of its confusing terminology. Biphasic PAP ventilation alternates at fixed intervals between two

TABLE 1. MODES OF NONINVASIVE POSITIVE-PRESSURE VENTILATION.**Volume mechanical ventilation**

Usually breaths of 250–500 ml (4–8 ml/kg)
Pressures vary

Pressure mechanical ventilation

Usually pressure support or pressure control at 8–20 cm of water
End-expiratory pressure of 0–6 cm of water
Volumes vary

Bilevel positive airway pressure (bilevel PAP)

Usually inspiratory pressure of 6–14 cm of water and expiratory pressure of 3–5 cm of water
Volumes vary

Continuous positive airway pressure (CPAP)

Usually 5–12 cm of water
Constant pressure, volumes vary

TABLE 2. SELECTING PATIENTS FOR NONINVASIVE VENTILATION.**Inclusion criteria**

Acute or chronic respiratory failure
Acute pulmonary edema
Chronic congestive heart failure with sleep-related breathing disorder

Relative contraindications

Failure of prior attempts at noninvasive ventilation
Hemodynamic instability or life-threatening arrhythmias
High risk of aspiration
Impaired mental status
Inability to use nasal or face mask
Life-threatening refractory hypoxemia ($\text{PaO}_2 < 60$ mm Hg with 1.0 FIO_2)*

* PaO_2 denotes partial pressure of oxygen, and FIO_2 fraction of inspired oxygen.

pressures and allows unrestricted breathing at both pressures.¹⁹ This differs from the spontaneous mode of bilevel PAP, which cycles on the basis of the flow rates of the patient's own breathing.

With bilevel PAP, supplemental oxygen is diluted by a high flow of air through the system. Patients thus may require a higher flow of oxygen when they are receiving bilevel PAP than when they are using a nasal cannula. Devices that use a common inspiratory and expiratory line can cause rebreathing of exhaled gas and persistent hypercapnia.²⁰ Rebreathing has been shown to occur with low expiratory-pressure settings and the standard exhalation device during bilevel PAP.^{21,22} The use of an alternative exhalation device or expiratory pressures of at least 4 cm of water reduces rebreathing of carbon dioxide.

Noninvasive positive-pressure ventilation works best if the patient is relaxed and is less effective if the patient is anxious, uncooperative, or fighting the ventilator. Preparation of patients is critical. In non-

emergency situations, the first few sessions can be used simply to fit the mask and familiarize the patient with the apparatus. For pressure-cycled ventilation, it is best to start at low pressures and gradually increase the inspiratory pressure (usually to 8 to 14 cm of water) and the end-expiratory pressure (usually to 4 to 6 cm of water). Clinical effectiveness can be determined by palpating the sternocleidomastoid muscle to see whether its use has decreased, as well as by determining that lower thoracic expansion has increased and that blood gas values have improved.^{23,24}

Limitations of Noninvasive Positive-Pressure Ventilation

When noninvasive positive-pressure ventilation is applied, patients must be monitored and attention given to their comfort, level of dyspnea, respiratory rate, and oxyhemoglobin saturation. Patients must be watched for signs of ventilator-patient asynchrony, nasal-mask intolerance, serious air leaks, gastric distention, drying of the eyes, and facial-skin breakdown, especially at the bridge of the nose. Gastric distention is very unlikely with pressure-support levels lower than 25 cm of water.²⁵ Eye irritation or conjunctivitis has been reported in 16 percent of patients.¹⁵ Facial-skin necrosis has been reported in 2 percent²⁶ to 18 percent²⁷ of patients. Intrinsic PEEP is often present in patients with COPD and can require much respiratory effort to trigger the ventilator.²⁸ This can be alleviated by the addition of external PEEP.²⁹

When a leak-tolerant noninvasive positive-pressure ventilation system is used, it is not necessary to apply the interface so securely that it is airtight. The device can usually be loosened enough to be comfortable. Selecting masks that fit without excessive pressure on the skin, using nasal pillows, or alternating between different types of masks can reduce the breakdown of skin. For long-term use of these devices it is important to have a home care company that is reliable and knowledgeable and that can help the patient comply with prescribed treatment, help adjust the straps and masks, and monitor oxyhemoglobin saturation and vital signs.

The patients most likely to benefit from noninvasive ventilation are those with acute or chronic respiratory failure and few relative contraindications (Table 2). For a variety of reasons, noninvasive ventilation techniques are not always successful. Hemodynamic instability, deteriorating mental status, and increasing respiratory rate indicate failure. Increasing respiratory acidosis, the inability to maintain adequate oxyhemoglobin saturations, and problems with respiratory secretions can limit the success of these techniques. Some patients are unable to tolerate or refuse to use the selected device. In general, noninvasive ventilation should not be used in patients who are unable to cooperate or who have impaired con-

sciousness, problems with retained secretions, or hemodynamic instability.

Although a patient's difficulty with retained secretions is sometimes a reason to use intubation instead of noninvasive ventilation, the use of manually or mechanically assisted coughing techniques can often provide adequate clearance of secretions and allow the use of noninvasive ventilatory support.³⁰

APPLICATIONS OF NONINVASIVE POSITIVE-PRESSURE VENTILATION

Chronic Respiratory Failure

Noninvasive positive-pressure ventilation is commonly used at night for management of chronic respiratory failure.³¹ It has also proved useful in the long-term management of neuromuscular disease.³²⁻³⁵ Noninvasive positive-pressure ventilation during sleep significantly improves daytime arterial-blood gases, lung volumes, and respiratory-muscle strength³⁶ and reduces the number of hospitalizations³⁵ of patients with respiratory insufficiency due to severe kyphoscoliosis. Noninvasive positive-pressure ventilation improves nighttime oxygen desaturation and hypoventilation in patients with chest-wall diseases but without daytime respiratory failure.³⁷ The use of positive-pressure ventilation and other options for ventilatory support in neuromuscular diseases has been reviewed elsewhere.³⁸

Noninvasive ventilation can be used as maintenance therapy in patients with intrinsic lung disease and marked hypercapnia (e.g., partial pressure of carbon dioxide greater than 60 mm Hg).²¹ Short-term use of this therapy for a few hours per day improves the respiratory pattern and blood gases in patients with stable COPD who have chronic hypercapnia.³⁹ Longer-term use of nasal positive-pressure ventilation has been shown to be beneficial in some hypercapnic patients with COPD. A prospective, randomized study found improvements in quality-of-life measures, sleep, partial pressure of arterial oxygen, and partial pressure of arterial carbon dioxide after three months of positive-pressure ventilation.⁴⁰ However, many patients with severe chronic COPD do not tolerate long-term bilevel PAP.⁴¹ Noninvasive ventilation can be helpful in some patients with intractable dyspnea.²⁴ Lastly, noninvasive pressure-support ventilation can be introduced into the care of patients with known borderline compensation whose conditions are stable in order to acclimate them to the device, so that during a future emergency their readiness for noninvasive ventilatory support can obviate the need for endotracheal intubation.

Acute Respiratory Failure

Noninvasive positive-pressure ventilation is an effective means of treating patients with acute respiratory failure due to a variety of causes.^{9,42-44} Uncontrolled studies,⁴⁵⁻⁴⁸ those using historical controls,^{25,49,50} and

prospective, randomized studies^{26,27,51} have consistently had good results. Most used inspiratory pressures of 12 to 20 cm of water and expiratory pressures of 0 to 6 cm of water and excluded patients with hemodynamic instability, uncontrolled arrhythmias, gastrointestinal bleeding, or a high risk of aspiration.

Two recent prospective, randomized studies strongly support the use of noninvasive mechanical ventilation in patients with severe exacerbations of COPD. Kramer et al.²⁷ used bilevel PAP ventilation through a nasal mask, with an average inspiratory pressure of 11 cm of water and an expiratory pressure of 3 cm of water. Among patients with COPD, the need for intubation was reduced from 67 percent among control patients to 9 percent among those given bilevel PAP. Brochard et al.²⁶ found significant benefits of noninvasive pressure-support ventilation (inspiratory pressure of 20 cm of water and expiratory pressure of 0 cm of water) delivered by face mask as compared with standard treatment among 85 of 275 patients with COPD. The noninvasive-ventilation group had significantly lower rates of complications (16 percent vs. 48 percent), a reduced need for endotracheal intubation (26 percent vs. 74 percent), shorter hospital stays (23 days vs. 35 days), and lower mortality (9 percent vs. 29 percent) than those receiving standard treatment. It is important to note that 69 percent of the total group of patients with COPD who had acute or chronic respiratory failure were excluded from the study.

Some of the benefits of noninvasive ventilation in acute respiratory failure in COPD may be related to the application of positive expiratory pressure, which can improve exhalation in the presence of intrinsic PEEP. This idea is supported by the study by Goldberg et al.⁵² that found improvements in dyspnea, inspiratory effort, respiratory-muscle work, and arterial-blood gas values with the administration of CPAP to patients with COPD who had acute respiratory failure.

Noninvasive positive-pressure ventilation is a safe and effective means of ventilatory support for many patients with acute respiratory failure, is generally well tolerated, and reduces complications. It can be given effectively by nasal bilevel PAP or by face mask and mechanical ventilator. Noninvasive ventilation for acute respiratory failure appears to be effective in 50 to 80 percent of patients who meet the criteria for inclusion. Further studies are needed to define the optimal mode of ventilation and the specific patient populations who might benefit the most.

Congestive Heart Failure

Noninvasive CPAP has been shown in randomized, controlled trials to be an effective therapy for acute pulmonary edema, improving oxygenation and

hypercapnia, decreasing respiratory work, and reducing the rate of endotracheal intubation.^{53,54} A study of nasal bilevel PAP (initial inspiratory pressure of 5 to 8 cm of water, increased to a mean of 10.8 cm of water; initial expiratory pressure of 3 to 5 cm of water, increased to a mean of 5.8 cm of water) in patients with congestive heart failure and severe respiratory distress found the therapy effective with a low (9 percent) rate of intubation.⁵⁵ In a controlled study,⁵⁶ nasal bilevel PAP (inspiratory and expiratory pressures of 15 and 5 cm of water, respectively) improved the partial pressure of arterial carbon dioxide, pH, respiratory rate, and dyspnea more rapidly than nasal CPAP (10 cm of water) in patients with acute pulmonary edema. However, the bilevel-PAP group had a more rapid fall in blood pressure and a higher rate of myocardial infarction (71 percent vs. 31 percent), causing concern about the use of this therapy for acute pulmonary edema. Until further studies define the role of bilevel PAP, it is prudent when using it to treat acute pulmonary edema to begin with low pressures and titrate according to the patient's clinical response.

Nocturnal noninvasive CPAP therapy in patients with chronic congestive heart failure and sleep-related breathing disturbances reduces the frequency of apnea, improves nocturnal oxygenation, improves symptoms of heart failure, improves the left ventricular ejection fraction,^{23,57,58} and decreases sympathetic nervous activity.⁵⁹ Sleep disturbances are common in patients with congestive heart failure; nearly half of those with stable and optimally treated congestive heart failure have an apnea-hypopnea index of more than 26 episodes per hour.⁶⁰ Patients with congestive heart failure commonly have Cheyne-Stokes respiration,⁶¹ central apnea, or obstructive apnea during sleep associated with oxygen desaturation. Mortality is increased among patients with congestive heart failure who have Cheyne-Stokes respiration.⁶² CPAP appears to be a safe and effective adjunctive treatment for patients with congestive heart failure and sleep disturbances. The role of CPAP in the treatment of patients with chronic congestive heart failure who do not have significant sleep-related breathing disturbances has not yet been established.

In patients with congestive heart failure, CPAP may improve oxygenation by recruiting atelectatic alveoli, redistributing lung water, and improving ventilation-perfusion matching. It can improve left ventricular function and cardiac output by reducing preload and afterload.⁶³ It increases lung volumes and thus lung stores of oxygen and carbon dioxide, which helps stabilize blood gas values during periods of apnea or decreased ventilation. Apnea can lead to bursts of sympathetic nervous outflow,⁶⁴ which could be detrimental to cardiac function.⁶⁵ By reducing the frequency and severity of sleep-related

apnea, CPAP improves oxygenation and reduces sympathetic activity.⁵⁹

Mechanisms of Improvement with Intermittent Noninvasive Ventilation

As little as two hours per day of noninvasive ventilation can improve symptoms of dyspnea, and four to six hours of therapy per night usually improves daytime gas exchange and symptoms of dyspnea. Several theories have been proposed to explain why intermittent noninvasive ventilation is effective.^{31,66} One possible explanation is that intermittent rest of chronically fatigued muscles improves respiratory-muscle function. During noninvasive ventilation, diaphragmatic electromyographic activity and respiratory-muscle work are reduced.^{25,67} Another possible explanation is that intermittent noninvasive ventilation improves lung compliance in patients with neuromuscular or chest-wall disease,⁶⁸ possibly by reexpanding areas of microatelectasis. A third possible explanation is that by preventing nocturnal hypoventilation, nocturnal noninvasive ventilation prevents the blunting of the central ventilatory drive that occurs with hypercapnia.⁶⁹

CONCLUSIONS

Many patients can avert the trauma and hazards of intubation and mechanical ventilation by using noninvasive ventilation. Recent studies show that noninvasive positive-pressure ventilation is an effective treatment for selected patients with acute respiratory failure, with lower rates of endotracheal intubation, fewer complications, and improved survival. Noninvasive ventilation can improve dyspnea, sleep, partial pressure of arterial oxygen, partial pressure of arterial carbon dioxide, and the quality of life in selected patients with chronic respiratory conditions. Whereas CPAP therapy appears to benefit patients with acute cardiogenic pulmonary edema and those with congestive heart failure and sleep-related breathing disorders, its role in patients with congestive heart failure who do not have sleep-related breathing disorders has yet to be determined. An expanded awareness of noninvasive ventilation devices and techniques promises to increase the therapeutic options for patients with severe respiratory insufficiency.

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