Proper Use of Mechanical Ventilators*

JAMES P. BAKER, M.D.

Associate Professor of Medicine,
Director, Respiratory Intensive Care Unit,
Medical College of Virginia, Richmond, Virginia

The widespread use of mechanical ventilators over the past ten to fifteen years has greatly complicated respiratory care. As ventilators become more sophisticated, the requirement for physician knowledge becomes greater, since most of this equipment can cause major harm as well as provide adequate ventilation.

There are two basic types of mechanical ventilators: the pressure cycled and the volume cycled. Each has inherent assets and problems. The pressure cycled ventilator is generally operated from a compressed gas source and delivers to the patient varying mixtures of oxygen, depending upon the source gas and the pressure-flow relations of the machine and the patient's airways. This is a major problem with most pressure cycled ventilators. The concentrations of oxygen are unknown unless they are carefully measured and controlled. In addition, the pressure cycled ventilator cycles off when it arrives at a pressure set by the operator, thus tidal volumes can be greatly varied as lung compliance changes. Therefore, one must measure the oxygen delivery and tidal volume generated by such ventilators to provide adequate oxygenation and ventilation. The major assets of pressure cycled ventilators are that they are relatively inexpensive, small in size, and very versatile.

The volume ventilators, by contrast, deliver to the patient a controlled tidal volume, independent of the pressure required to generate such a volume. With constant volume delivery, minor variations in lung compliance and airways resistance are less likely to result in major ventilatory changes. Most volume ventilators have a device which directly controls oxygen delivery to the patient, or a system with a nomogram which allows one to arrive at the inspired oxygen percentage. However, there are some which require that oxygen percentage also be measured as in the pressure cycled ventilators.

It can be recognized that the primary factor in the proper use of mechanical ventilators is physician and/or inhalation therapist knowledge of a particular machine, and their ability to relate the patient to such a machine. In considering what a mechanical ventilator should do, the following equation demonstrates that to increase a patient's alveolar oxygen percentage, one can either increase the inspired oxygen percentage, decrease oxygen consumption, or increase alveolar ventilation.

$$F_{A_{O_2}} = F_{I_{O_2}} - \dot{V}_{O_2}/\dot{V}_A.$$

$F_{A_{O_2}}$ = % alveolar O_2.
$F_{I_{O_2}}$ = % inspired O_2.
$\dot{V}_{O_2}$ = O_2 consumption.
$\dot{V}_A$ = effective alveolar ventilation.

Mechanical ventilators function in several ways to provide these changes. The inspired oxygen concentration can be controlled at any level necessary for a given patient. By assuming part of the work of breathing, mechanical ventilators will decrease oxygen consumption, particularly in those patients who have a remarkable increase in the work of breathing. Additionally, alveolar ventilation can be increased or decreased with a mechanical ventilator by adjusting the patient's tidal volume and/or respiratory rate. Since all of these factors are of direct importance in oxygenation, it is valuable to remember this equation. Also important to keep in mind is that the level of carbon dioxide tension is controlled by the level of alveolar ventilation. As alveolar ventilation is increased, carbon dioxide tension will be decreased and vice versa. (Since we are discussing the proper use of mechanical ventilators, I have chosen to disregard the use of ventilators for intermittent positive pressure breathing therapy.)

---

* Presented at the 25th Annual Stoneburner Lecture Series, February 26, 1972, at the Medical College of Virginia, Richmond.

In considering the mechanical ventilators, one must think of the indication for their use:

1. To substitute for the normal work of breathing.
2. To assume an increased work of breathing with increased airway or tissue resistance or increased dead space ventilation.
3. To change to a more effective pattern of ventilation.
4. To stabilize the chest wall after chest trauma.
5. To manage pulmonary congestion or edema.
6. To improve oxygenation when severe hypoxemia cannot be corrected by other means.

Although some of these indications might be better satisfied with a particular type of respirator, with proper knowledge and experience a pressure or volume cycled ventilator might reasonably well provide for any of these indications. This is a very important consideration as people become more and more dependent upon the more expensive volume cycled ventilators. It may be easier to manage a patient with multiple complications with these types of ventilators, however, it is in many circumstances unnecessary. Therefore, it is appropriate to contrast the complications which occur with these two types of ventilators.

Complications of Mechanical Ventilation

1. Problems of tubes or tracheostomies
2. Reduction of venous return
3. Atelectasis
4. Oxygen toxicity
5. Infection
6. Acid-base abnormalities
7. Gastrointestinal complications
8. Technical and mechanical complications
9. Emotional problems
10. Miscellaneous

Intubation of a major bronchus leading to atelectasis of the other lung, tube dislodgment, laryngeal damage or edema, or post-extubation laryngeal problems are well known to anesthesiologists. The tracheostomy avoids these problems which occur above the tracheostomy site; however, it contributes the additional problems of an open wound and a rigid tube through the neck, which might lead to bleeding, tracheostomy-site infection, or necrosis with erosion of vessels. Tracheal stenosis may follow either tracheostomy or indotracheal tube intubation. There is little difference in the frequency of these complications with a pressure or volume cycled ventilator.

Reduction in venous return resulting in decreased cardiac output, in our experience, has been much more commonly a problem in patients who are hypovolemic. Autonomic dysfunction and prolonged hypoxemia also are factors with this complication. To avoid this, one must monitor the blood pressure and urine output, and reduce mean inspiratory pressure, in addition to providing adequate fluid volume. This is probably the major indication for the use of a volume ventilator to deliver the tidal volume rapidly, particularly in patients with high compliance losses or high airway resistance. In these instances, a pressure cycled ventilator may require too long a time to provide an adequate inspiration maintaining a positive intrathoracic pressure for excessive periods. Most ventilators are fitted with a negative pressure device which operates during the end of exhalation to enhance venous return. This in our hands has been of little or no value and, at least in patients with chronic obstructive pulmonary disease, is relatively contraindicated since it produces closure of the poorly supported airways, leading to miliary atelectasis.

Atelectasis occurs in patients on prolonged mechanical ventilation, particularly in those with a high-inspired oxygen percentage. It may be manifested in numerous ways; however, typically it is indicated by an increase in oxygen requirement and decreasing compliance. Compliance loss is indicated by increasing inspiratory pressures to provide the same tidal volume or a decrease in tidal volume with a fixed inspiratory pressure. To avoid this problem, a proper respiratory pattern which provides for overall ventilation of the lungs must be established. Continuous positive pressure ventilation, inflation hold, and intermittent sighing are all approaches to this problem. Most volume ventilators have the ability to perform one or more of these functions. However, they can also be readily handled with a pressure cycled ventilator with proper inhalation therapy or nursing care to provide for intermittent deep breathing of patients and adequate airway toilet. A very important factor in prevention of atelectasis is adequate humidification of inspired gases. Chest physiotherapy, suction, and bronchoscopy are also helpful in the avoidance and treatment of this problem.

I would like to mention that oxygen toxicity usually occurs only with high-inspired oxygen percentages and it is greatly enhanced by prolonged exposure. There are obviously multiple factors involved. It is of interest in our experience that if it does occur, it appears largely reversible if the patient survives. Particularly important to mention is that most all pressure cycled ventilators deliver higher oxygen concentrations than one would suspect. A common misconception is that on the air dilute setting these ventilators deliver 40% oxygen. Therefore, one must set up this type of respirator by measuring oxygen delivery to avoid oxygen toxicity. This is done either by operating the pressure cycled ventilator with compressed air and adding oxygen, or by adding compressed air to an oxygen-driven machine while monitoring inspired oxygen percentage. One must be aware that as the pattern of the patient's breathing changes, there will be varying percentages of oxygen delivered by these types of ventilators.

Infection is a major problem with mechanical ventilators since the warm, humid inspired gases, tubing, nebulizers, and humidifiers provide good culture media for many gram negative organisms. Mechanical ventilators have been found to be a source of gram negative infection in many hospitals. In our experience in culturing respirators, we have found that no respirator had organisms cultured from it prior to the organism being grown from the patient's sputum. Thus if respirator tubing is changed at least daily and sterilized properly prior to each use, the probability that these machines will result in spread of infection decreases. The practice of using a machine on more than one patient must be condemned unless everything from the respirator head out to the patient is changed between patients. Infection is managed with proper identification of the organism and specific therapy.

Inadequate humidification of inspired gases is one of the major problems in the use of mechanical ventilators. At room temperature (70°F), a gas saturated with water vapor contains approximately 20 mg of water per liter of gas. At body temperature, 44 mg of water are required to saturate a liter of gas. Since normal tracheal air is 100% humidified at body temperature, it is practically impossible to provide adequate quantities of water to equal the normal condition without passing the inspired gas mixture through a heated humidifier or nebulizer. This fact makes the use of heated humidifiers or nebulizers absolutely necessary with ventilators to avoid drying and damaging airway mucosa and obstruction of airways with inspissated secretions.

Most patients who have chronic respiratory failure will have a compensated respiratory acidosis. As carbon dioxide is removed with an efficient mechanical ventilator, severe post-hypercapneic metabolic alkalosis may be produced. The ability of dissolved carbon dioxide to traverse the blood brain barrier with great ease and the resistance of bicarbonate to cross the same barrier may result in central nervous system alkalosis if $PaCO_2$ is too rapidly reduced. This can lead to convulsions, coma, and death, and must be considered in all patients who are being placed on mechanical ventilators. For this reason, the arterial pH rather than the $PaCO_2$ should be the controlled variable. There is evidence to indicate that patients on mechanical ventilators will retain fluid, therefore, patients must be weighed daily and electrolytes must be measured frequently.

A significant number of gastrointestinal complications are seen in patients severely ill with respiratory failure. The most life threatening is gastrointestinal bleeding. This, while a significant problem, has not been too common in our experience. A more common problem is gastric distension or paralytic ileus in patients with severe lung disease. This may result in limitation of movement of the diaphram and a decrease in ventilation as well as basilar lung atelectasis.

Technical and mechanical problems must always be considered. The ventilator which becomes disconnected from a patient or malfunctions is of no value to the patient. Thus there must be a positive connection between the patient and the respirator for the machine to function properly. We have adopted the use of the Mörch tracheostomy tube and have had little difficulty with disconnection following this change. Since such problems may be life threatening and each type of respirator has a particular set of associated problems, the therapist or physician must be familiar with the problems which are possible with a particular type of ventilator. Changes in ventilatory or oxygen requirements must always be considered in managing patients on ventilators. Therefore one must measure these modalities frequently. Obviously, there are human errors in management and the scope of these is beyond this discussion.

The miscellaneous complications which occur are multiple. Major cardiovascular problems, such as arrhythmias, digitalis toxicity, and pulmonary emboli are not necessarily related to ventilators; however, they must be recognized in patients on ventilators. Pneumothorax and mediastinal emphysema must be anticipated, since they may cause marked difficulty and frequently occur in ventilator patients.

The other major problem is weaning a patient from a ventilator. There are several factors to utilize in deciding when to begin weaning a patient:

1. Oxygen requirement: alveolar-arterial oxygen gradient should be less than 300 mm Hg breathing 100% O_2
2. Tidal volume: greater than 10 cc per kg body weight off respirator
3. Vital capacity: greater than twice the tidal volume
4. Ratio dead space to tidal volume (Vd per Vt): less than 0.5
5. Inspiratory negative pressure: more than 20 cm H_2O negative pressure

These are obviously not the only factors in weaning. The clinical judgment of the nurses and inhalation therapists is of major importance and is relied on heavily in our respiratory care unit. There are several problems which we routinely see in patients who are difficult to wean from respirators. The patient must be ready emotionally as well as physiologically to be removed from the respirator. He should have arterial blood gas values controlled near to those that he can support on his own without assisted ventilation. The patient should be cycling the ventilator himself; although this is unnecessary, it is helpful. Adequate humidification must be provided at all times when he is off the ventilator or he will have further problems with secretions and airway obstruction. His secretions should be under optimal control. One should begin with brief periods off the ventilator, that is, five to ten minutes per hour. Time off the ventilator is prolonged as the patient's tolerance increases. Even while the patient is off the ventilator, his lungs should be hyperexpanded frequently. Arterial blood gases, vital signs, and patient condition must be observed repeatedly during this period. We have always allowed the patient initially to sleep on the ventilator and be weaned only during the daytime; then he finally is allowed to sleep without ventilatory assistance. Another very important aspect of weaning the patient is emotional support. A patient who can communicate vocally has a much better opportunity for a reasonable emotional state. Our policy is to put in a lightweight plastic tracheostomy tube which can be plugged to allow the patient to talk while he is being weaned. This procedure in many circumstances has been of great value.

The proper use of mechanical ventilators is related to many problems; however, the primary one is the knowledge of the physician, nurse, inhalation therapist, and other paramedical personnel with a given ventilator. It is important to remember that there are certain inherent problems with all ventilators. These problems must be carefully searched for and avoided.

REFERENCES

BENDIXEN, H. H., *et al. Respiratory Care.* Saint Louis: The C. V. Mosby Company, 1965.

COMROE, J. H., FORSTER, R. E., DUBOIS, A. B., BRISCOE, W. A., AND CARLSEN, E., JR. *The Lung.* Chicago: Yearbook Medical Publications, 1962.

KILBURN, K. H. Shock, seizures, and coma with alkalosis during mechanical ventilation. *Ann. Int. Med.* 65:977–984, 1966.

REINANZ, J. A., *et al.* The potential role of inhalation therapy equipment in nosocomial pulmonary infection. *J. Clin. Invest.* 44:831–839, 1965.

SLADEN, A., *et al.* Pulmonary complications and water retention in prolonged mechanical ventilation. *New Eng. J. Med.* 279:448–453, 1968.