Automatic Lung Ventilators

Duncan A. Holaday, M.D., and Christen C. Rattenborg, M.D.

When applying an automatic lung ventilator to a patient in respiratory failure, one must find satisfactory answers to the following questions. What kind of respirator will perform most reliably on this patient? How shall it be attached to the patient's airway? How does one adjust its controls to satisfy the patient's needs? How can one make certain that it will provide continuously satisfactory ventilation for as long as it is needed? What signs can be used to determine when it fails to ventilate the patient satisfactorily? The answers to these questions lie in knowledge of the principles of operation which determine the functions of lung ventilators, an understanding of the mechanical properties of the pulmonary systems of patients suffering from respiratory failure, and an appreciation of the interactions between them.

Characteristics of Lung Ventilators

Lung ventilators augment or replace the patient's own respiratory effort when attached to his upper airway. The mode of attachment may be by mask, mouth piece, or by tracheal tube. A tracheal tube may be inserted through the nose, mouth or a tracheostomy. The mode of attachment appropriate in a given case will be dictated by the functional characteristics of the ventilator, how long artificial respiration is required, and the condition of the patient. In our opinion, failure to maintain a satisfactory attachment to the upper airway and failure to adequately humidify inspiratory gases are more frequent causes of failure of sustained artificial respiration than inappropriate selection of a lung ventilator.

Assistors and Controllers

The functional characteristics of a lung ventilator depend in the first instance on whether it is an assistor or controller, or can operate as either. An assistor is a device which will inflate in response to an inspiratory effort initiated by the patient. Usually a sudden reduction of airway pressure is the signal to which the assistor responds, although respirators have been designed which will trigger in response to the electromyogram of respiratory muscles. A controller will cycle automatically on the totally apneic patient; a timing mechanism regulates its operation during all phases of the respiratory cycle. Lung ventilators which operate as obligatory controllers are relatively unaffected by and tend to override patient-initiated respiratory efforts. Those which can operate as both assistor and controller cycle automatically by the predetermined duration of the expiratory phase or both the expiratory and inspiratory phases. An assistor-controller can be triggered into the next phase at an earlier time, however, by patient generated signals.

Control of Tidal Volumes

The method by which tidal volume is regulated is of considerable importance in determining long term reliability and constancy of ventilation. Two principles of operation have been used. According to the first, the lung ventilator develops a certain airway pressure. The maximum airway pressure is adjusted by the operator to provide a suitable tidal volume. It seems appropriate to call such devices controlled pressure respirators since it is the maximum inspiratory pressure which is under the control of the operator. According to the second principle, the ventilator discharges a predetermined volume of gas during each inspiratory phase. These can be called controlled volume ventilators. A number of lung ventilators have been designed to share certain characteristics of each principle in order to incorporate the advantages of both.

The controlled pressure and controlled volume respirators will deliver a constant tidal volume so long as there are no changes in the
patient's resistances to inflation and there is no leakage from the airway. The force generated by a respirator during the inspiratory phase is expended against the resistance within the respirator to air flow, against the resistance of the patient's respiratory tract to air flow, and against the viscous and elastic resistances of the lung and chest wall to inflation. If airway resistance increases or if the compliance of the patient decreases, then more force will be required to produce the same tidal volume. A controlled pressure respirator will respond to changing resistances by reciprocally changing the amount of gas it forces into the patient. A controlled volume respirator, with adequate reserve power to discharge its predetermined volume, will overcome increases of resistance to inflation and deliver the tidal volume to the patient at a higher pressure, but very little modified from its original performance. Any leakage from the airway, however, will result in a direct subtraction from the tidal volume delivered by a controlled volume device, and increases of the patient's resistances to inflation will result in greater leakage and further decrease of ventilation.

**CONTROL OF FLOW**

The pressure in the airway reflects the speed and degree of inflation of the patient's lungs. The effect of leakage on the performance of a controlled pressure device will depend on the flow characteristics of the ventilator and on its method of control of cycling. Some controlled pressure ventilators will deliver high flow rates when the airway pressure is low, and will progressively slow as their maximum inspiratory pressure is approached. Such respirators can compensate for significant leaks in the airway. Others, while providing more positive control over flow rate, will be more restricted in the amount of air they can contribute to a leak. The latter will be more sensitive to leaks and may fail to achieve the airway pressure for which they have been set.

**CONTROL OF CYCLING**

The mechanism of cycling of all commercially available controlled pressure assistors and most controlled pressure assistor-controllers depends upon the tripping of a pressure sensitive toggle valve which is thrown into the inspiratory position by the inspiratory triggering pressure, and into the expiratory position when the maximum inspiratory pressure is achieved. It is, in fact, the adjustment of the sensitivity of this valve which determines the maximum inspiratory pressure setting. If, because of leakage and restriction of flow from the valve, the maximum inspiratory pressure can not be developed, a pressure cycled ventilator will stall in the inspiratory position and ventilation will not occur. Those assistor-controllers which regulate the maximum duration of the inspiratory phase by means of a timing mechanism will cycle whether the maximum inspiratory pressure is achieved or not, and will provide some degree of ventilation. These are timer-cycled ventilators.

**PRESSURE PATTERN**

Some lung ventilators are active only during the inspiratory phase, and hence produce only intermittent positive pressure patterns (IPPB). These possessing a relatively high resistance to exhalation will generate high mean mask pressures. It has been known for some time that elevated airway pressures will tend to impede venous return to the right heart and, in patients with diminished circulatory reserve, may seriously depress cardiac output. On the other hand, it is becoming clear that unimpeded expiratory flows may permit reversal of the transmural pressure gradient in the smaller bronchi and lead to air trapping and poor gas exchange. It seems appropriate, therefore, that lung ventilators be constructed with an adjustable resistance in the exhalation port.

There are lung ventilators which can produce a negative pressure during the exhalation phase. Commonly employed mechanisms for developing suction include a venturi-type aspirator, and a weighted bellows. Because of the interference with distribution of air flow within the lungs mentioned above (air trapping), the negative phase should be optional. Its use probably should be restricted to patients suffering from circulatory collapse or impending circulatory failure.

**AIR MIXING DEVICES**

Many lung ventilators are most conveniently operated by oxygen delivered from a wall line.
or compressed gas cylinder. Pure oxygen is poorly tolerated for periods of time longer than 12 hours. Oxygen toxicity may occur and result in hypersecretion and a hemorrhagic pneumonitis (see chapter on oxygen toxicity in this symposium). Atelectasis develops easily from rapid absorption of oxygen from poorly ventilated areas of the lungs. A number of lung ventilators are now equipped with air injectors, similar in principle to the venturi aspirators. These can deliver mixtures of air and oxygen containing as little as 40 per cent oxygen. In practice these instruments should be set to deliver the lowest concentrations of oxygen except when they are being used for resuscitation. The concentration of oxygen delivered by an injector depends on the efficiency of the venturi and the back pressure in the airway. The injector will modify the flow control characteristics of the ventilator since it constitutes a leak, or point of slippage, when high airway pressures are required.

**Humidification**

Humidification is now recognized as an essential component of all inhalational therapy, particularly that involving the use of dry medical gases. Recently, humidifiers of various types have been added to automatic lung ventilators, however, without discrimination as to whether the humidification is adequate or what effect the humidification apparatus has on other functions of the ventilator. Small aerosol generators, or nebulizers, without provision for continuous automatic filling, become dry in 10 or 15 minutes. An alert nursing staff is required to maintain their function satisfactorily. Large reservoir nebulizers, such as the Mistogen, are capable of day-long humidification if the capillary feed tube and air jet are kept clean. These devices may interfere with the cycling of a pressure-cycled ventilator because they contribute a continuous stream of gas to the inspiratory line regardless of the phasing of the respirator. This criticism applies to all aerosol humidifiers in which the nebulizing air stream operates continuously. Certain humidifiers consist of water reservoir having a large surface over which the inspiratory gas is lead or through which the gas is bubbled. These can be termed blow-over and blow-through humidifiers, respectively. The amount of humidification obtained from such devices is inadequate unless provision is made to heat the water. (See chapter on humidity in inhalational therapy, this symposium.)

**Information Feed-Back**

A certain amount of information concerning the effectiveness of operation of a lung ventilator can be obtained simply by observing it. A pressure-cycled ventilator will increase its frequency as the patient’s resistances to inflation increase, and will chatter in the face of complete obstruction. A timer cycled ventilator, whether of the controlled volume or controlled pressure type, will give no such indication. Changes of tidal volume resulting from alterations in resistance or leak may escape notice unless provision is made to measure the tidal volume directly. The most practical way appears to be measurement of the exhaled air by coupling a spirometer to the exhalation port. The Bennett Ventilation Meter, the Dräger “Volumeter” and Wright Ventilation Meter answer this purpose conveniently, but are, unfortunately, fragile and expensive. A British product, the Parkinson and Gowen Dry Gas Meter is more cumbersome, but is said to offer less impedance than domestic dry gas meters and to be more resistant to damage from moisture-laden air. A number of American lung ventilators have expiratory ports to which it is impossible to attach a spirometer. When measurement of expired air is not possible, periodic measurements of arterial saturation and end-expiration $P_{CO_2}$ or arterial blood $P_{CO_2}$ should be made, and the character of chest expansion and of the breath sounds should be noted at frequent intervals to insure adequate ventilation.

Airway pressures should be monitored when a controlled volume ventilator is being used. Changes of airway pressure in the presence of an air tight attachment reflect changes of airway resistance or compliance when the tidal volume is constant, just as the volume of exhaled air will change when the peak inflating pressure is held constant. This information is of great value in determining when secretions have accumulated and when aspiration from the trachea is in order.
If an adequate fit can not be quickly obtained with a mask, an endotracheal or tracheostomy tube should be inserted. In any event, a mask should never be securely strapped to a patient who may vomit or regurgitate gastric contents. Regurgitation may occur, be undetected, and cause a potentially fatal chemical pneumonitis.

Nasotracheal tubes are tolerated by conscious patients more readily and for longer periods of time than orotracheal tubes. It is generally recommended that they not be used longer than 48 hours. Fusion of the anterior laryngeal commissure may follow prolonged use. Theuffed endotracheal tube offers reliable leakfree fit to the airway and greatest protection against aspiration. The pressure in the cuff should be carefully adjusted to that pressure which just prevents leak at peak inspiratory pressures. This can be accomplished by listening at the mouth through several eycles and adding air to the balloon until reflux of air into the mouth does not occur. Endotracheal tubes should be replaced with fresh, sterile tubes of the smallest useful diameter at 24-hour intervals.

**Tracheostomy**

Tracheostomy is almost always required for artificial respiration of the patient suffering from prolonged coma, or inability to manage respiratory tract secretions. The Mörch swivel tracheostomy tube (modified Jackson tube, fig. 1) is tolerated well and affords convenient attachment of a lung ventilator and convenient access for suctioning. Although there may be justification for performance of tracheotomy solely to provide attachment of a lung ventilator, it must be recognized that this procedure entails significant transgression of protective mechanisms which guard proper function of the respiratory tract. The air warming and humidifying capacities of the upper respiratory tract, particularly of the nasal passages, are bypassed; the entire load of saturating the inspired air is placed on the restricted capacities of the tracheal and bronchial mucosa. Cough is impaired by loss of glottic closure, and secretions must be removed by suctioning. The lower respiratory tract, freshly exposed by tracheotomy, behaves like a fresh surgical wound and is prone to infection. Suctioning
AUTOMATIC LUNG VENTILATORS

The technique must be meticulously aseptic to avoid development of a tracheobronchitis which will convert a normal lower respiratory tract to a troublesome wet one.

Respiratory Tract Impedances

The resistances to inflation presented by the patient determine in large measure the airway pressure pattern and the ventilatory efficiency of a lung ventilator. These include upper airway obstruction, airway resistance, and lung and chest wall compliance.

Obstruction may occur at any point in the upper airway, although it is most commonly encountered at the lips, the soft palate and at the root of the tongue. When a mask is applied, the patient will always breathe exclusively through his nose, unless an oral airway is inserted. The relaxed soft palate can not interfere with inflation, but can act as a passive check valve and obstruct exhalation through the nose. A nasopharyngeal or oropharyngeal airway prevents this. Obstruction due to relaxation of the base of the tongue against the posterior pharyngeal wall can not always be prevented by an oropharyngeal or nasopharyngeal airway; it is most easily managed by hyperextension of the head or by endotracheal intubation.

Secretions may participate in decreasing compliance by reducing the amount of lung participating in effective gas exchange. Thus the patient with a wet lung will receive progressively smaller tidal volumes from a controlled pressure ventilator as secretions accumulate. The peak inspiratory pressures generated by a controlled volume ventilator will rise gradually with time and, if monitored, will reveal the need for removal of accumulated secretions.

Since chest-wall muscle tone is an important component of compliance, the ability of a patient to cooperate with the lung ventilator will determine the efficiency of ventilation. A dyspneic patient exhibiting tachypnea can cause an assistant to cycle so rapidly that it has no opportunity to discharge adequate tidal volumes. More effective gas exchange may be realized in this situation by imposing a fixed cycle with a controller. Because of the rapid fluctuations of the patient's resistances, a controlled volume ventilator may provide the best ventilation. Once adequate gas exchange has been established and the patient's dyspnea has been relieved, it matters little to the conscious patient whether he is ventilated with an assistant or a controller. In the absence of tachypnea the rhythm of the respiratory center seems to accommodate readily to imposed respiratory patterns.

Representative Lung Ventilators

The functional characteristics of representative lung ventilators in common use today are described below. No attempt has been made to present an exhaustive survey of commercially available instruments, and no bias is intended by the selection. Because there is need for methods of augmenting or replacing spontaneous respiratory effort without attachment to the upper airway, a body respirator and a rocking bed will also be described.

The reader is referred to the excellent monograph of Mushin, Rendell-Baker and Thompson 13 for further details of the mechanics and functional characteristics of most lung ventilators, commercial and experimental, in use today. Included in the appendix are a classification of automatic ventilators, a table of factors pertaining to functional analysis, a glossary and a list of manufacturers. The italicized parts of the classification presented herein do not correspond to that of Mushin, Rendell-Baker and Thompson. It represents a further effort to avoid ambiguous terminology in the description of the principle functional characteristics of automatic lung ventilators.

The Bennett Model PR-1A

Respiration Unit

The Bennett Model PR-1A (fig. 2) is a controlled pressure, assistant-controller designed for operation on an oxygen line. It features little regulation of flow rate. Tidal volume at a given setting will vary inversely with changes of patient impedances. As an assistant it is pressure cycled. Inspiration is triggered by a negative pressure signal, adjustable on recent equipment, from approximately ambient pressure to -2 cm. of water. Expiration is triggered at or near the maximum inspiratory pressure when the inspiratory flow rate has fallen to 2-4 liters per minute. The maximum
inspiratory pressure is determined by the main control knob which also regulates the maximum inspiratory flow rate to a small degree. Because unimpeded inspiratory flow rates are relatively high, it tolerates leaks in the airway fairly well. Optional cycling by pneumatic timers provide the controller function. Both the duration of the inspiratory and expiratory phases are determined by the controller knob. In this mode, the ratio of inspiratory time to total cycle time is approximately 0.4, independent of cycling frequency. Patient initiated pressure signals can override the timed cycle mechanism. A manual override control is available, operation of which will override both automatic cycling mechanisms. The functions of the PR-1A are restricted to generating intermittent positive pressures; a new model, PR-1N, also generates negative expiratory pressures. The PR-1A has a fixed, low resistance to exhalation flows. It contains an injector which will vary output oxygen concentrations between approximately 40 per cent and 100 per cent. Aerosols can be delivered into the inspiratory line from a 60 ml. capacity nebulizer which is powered by an adjustable, continuous flow of oxygen. The Puritan “All-Purpose” nebulizer is readily substituted and can serve as an efficient large reservoir, flow-through humidifier. A venturi suction device for tracheal aspiration is attached to the unit. An aneroid manometer indicates the operating pressure upstream to the automatic pressure-sensitive valve, and a second manometer indicates the downstream, or “airway” pressure. The exhalation port is not designed to permit attachment of a spirometer, and no other provision has been made.
for estimating tidal volume. The Bennett Model PR-1A Respiration Unit is useful in all situations where a controlled pressure assistor or controller is required. It will tolerate moderate leaks in the airway, and can be made to cycle in the presence of leaks so large as to prevent attainment of the maximum inspiratory pressure. Because it is not possible to monitor tidal volume or minute volume, adequacy of ventilation must be determined by clinical signs, or by blood gas or expired air analysis.

The Bennett Pressure Breathing Therapy Unit, Model TV-2P or PV-3P, possesses performance characteristics similar to the PR-1A, except that it lacks the timer cycling mechanisms, and operates as an assistor only.

**THE BIRD MARK VII RESPIRATOR**

The Bird Mark VII Respirometer (fig. 3) is a controlled pressure assistor-controller, with independent regulation of inspiratory triggering pressure, maximum inspiratory pressure and flow rate. The inspiratory triggering pressure control permits continuous adjustment of the inspiratory triggering pressure from approximately -5 cm. of water to a positive value. The maximum inspiratory pressure can be

**FIG. 3. The Bird Mark VII Respirometer.**
regulated over a range from near the ambient to 60 cm. of water positive pressure. An adjustable pneumatic timer can be used to limit the duration of the exhalation phase. An override provides for manual operation. The inspiratory flow rate is little affected by back pressures from the airway, but, allegedly, can be regulated continuously from 0 to 300 liters per minute. The wide range of flow rates permits compensation for sizable leaks. However, because of the constancy of flow at a given setting, relatively small increases in leak may prevent the maximum inspiratory pressure from being reached, and the respirator will stall in the inspiratory phase. Similarly, a decreased leak will result in too rapid approach to the maximum inspiratory pressure, and tripping into the exhalation phase may occur before an adequate tidal volume has been discharged into the patient. Since accommodation for leaks requires repeated adjustment of flow rate, this respirator performs most reliably when attachment is by a cuffed endotracheal or tracheostomy tube. An air
injector is provided by which inspiratory oxygen concentration can be set for either 40 per cent or 100 per cent. The air injector is efficient in the sense that, at the minimum oxygen concentration setting, it will deliver an oxygen concentration of 36 per cent into a back pressure of 2 cm. of water, and at a back pressure of 20 cm. of water the oxygen concentration rises only to 42 per cent. Thus, even with the air injector providing maximum dilution, flow rate is relatively unaffected by back pressure. The Mark VII will generate intermittent positive pressures only; the Mark VIII is equipped with a venturi which can generate adjustable negative expiratory pressures as well. The exhalation port is fitted with a perforated cap which can be used to impede exhalation to varying degrees. All controls are provided with scale markings. The markings are in arbitrary units because there is a certain amount of interaction between the controls. A manometer indicates the alvi-way pressure near the valve. The exhalation port is designed to accommodate the Wright respirometer or other ventilation meter when the expiratory impedance is removed. Considerable insight into its functional characteristics is necessary for successful operation of the Bird respirator. However, the many individual adjustments make it possible to develop a wide variety of pressure patterns, with which to satisfy the ventilation requirements of patients suffering from various combinations of respiratory and circulatory dysfunction.

The Möhr Piston Respirator

The Möhr Piston Respirator (fig. 4) is a motor driven, timer cycled controller which exhibits some of the characteristics of both a controlled pressure and controlled volume ventilator, and utilizes certain of the advantages of each. Its construction is simple (fig. 5) and it is simple to operate. An electric motor drives a large bore piston. The frequency is regulated by a variable speed gear; the stroke of the piston is determined by a variable crank. Air is drawn through a filter into the cylinder with provision for enrichment with oxygen. Air is expelled into the patient from the cylinder through an unwarmed, blow-over humidifier and an automatic, non-rebreathing valve. This ventilator

![Diagram of the Möhr Piston Respirator.](image-url)
was designed for attachment to a loose-fitting metal tracheostomy tube (fig. 1). In use, the stroke of the piston is adjusted to provide adequate expansion of the lungs and to accommodate the deliberate leak which serves to sweep secretions accumulating around the tube upward through the larynx. Variation in the resistance of the leak alters airway pressure, reciprocally, so that an increase of the leak will result in a lower airway pressure, and relatively less of the tidal volume will be lost through the leak than if the ventilator operated as a controlled volume device. Conversely, a reduction in the size of the leak causes an increase in airway pressure which increases the flow rate through the leak and protects the patient from over expansion. Assuming a constant leak, a decrease in lung compliance causes a rise in airway pressure which tends to compensate for the greater respiratory tract impedance. Thus, although tidal volume will vary with changing leak and changing patient resistances, the variation will be less than that resulting from a leak when a controlled volume ventilator is used, and less than that resulting from a decrease of compliance when a controlled pressure ventilator is used. No pressure-relief valve is included in the circuit, and very great pressures may be developed if flow from the airway is impeded. An auxiliary bellows is provided for manual operation in the event of electrical power failure.

The Engström Respirator
The Engström Respirator (fig. 6) is a controlled volume, timer cycled controller which features many devices for compensation of altered pulmonary mechanics and for information feedback. An electric motor driven piston in a double-ended cylinder drives air into a rigid plastic dome during the inspiratory
phase. A sliding valve mechanism in the cylinder releases the pressure generated by the piston before the stroke is completed so that the ratio of the inspiratory phase to total cycle duration is 0.33. A bag enclosed in the plastic dome is compressed and a predetermined volume of air is forced into the patient through a warmed, blow-over humidifier. During the exhalation phase the dome is evacuated by the piston and cylinder, and a measured amount of air, which can be enriched with oxygen, is drawn into the bag through an adjustable vent. The airway pressure in the inspiratory line is indicated by both an aneroid manometer and by a water manometer, which also acts as an adjustable pressure relief valve. Exhalation is into the room through a high impedance, pneumatically powered nonrebreathing valve. The expiratory port can be vented through a respirometer which measures the volume of the exhaled air, or it can be opened to a venturi which is powered by the opposite side of the cylinder and which can produce negative airway pressures to promote circulation or compensate for narrow lumened endotracheal tubes. A water manometer in the expiratory line indicates the airway pressure during exhalation when the negative pressure attachment is in use. The compliance afforded by the relatively large volume of the cylinder and the plastic dome permits flow into the patient to be retarded when his resistances increase. This presumably favors more even distribution of air in the lungs, and permits the same volume to be insufflated with a comparatively smaller pressure increase. Changes of airway resistance are easily detected on the water manometer by a rise in the inspiratory phase airway pressure; increased peak inspiratory pressures signal the need for tracheal aspiration. A decrease in the exhaled tidal volume displayed by the spirometer warns of a leak in the airway. The most satisfactory function is obtained when the respirator is attached to the airway by a cuffed, air-tight tracheostomy tube. The other half of the cylinder can be used to power a pneumatic belt or a cuirass respirator as a means of augmenting artificial respiration. The Engström Respirator is com-

![Image](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931641/)

**FIG. 7.** The plastic garment and shell of the Emerson Chest Respirator.
paratively bulky and expensive, and is based on the more unwieldy controlled volume principle. By virtue of its built-in monitoring devices and automatic compensators, however, it is probably more nearly capable of even, physiological ventilation than other commercial lung ventilators.

**THE EMERSON CHEST RESPIRATOR**

The Emerson Chest Respirator (fig. 7) is a controlled pressure body respirator which can be operated as a timer cycled controller or, alternately by means of the Emerson "Ucyclit" control unit (fig. 8) as an assistant-controller. The Chest Respirator consists of a loose-fitting plastic garment, or sleeve, which encloses the patient's neck, arms and trunk, and an expanded metal shell which holds the garment away from the patient's chest and abdomen. The model CRV electric powered vacuum blower lowers the pressure within the garment; this causes the garment to seal against the body, and expands the chest. A large knob on the control unit regulates tidal volume by adjusting the maximum inspiratory pressure. Intermittent negative pressure applied to the surface of the chest wall has essentially the same effect of inflating the lungs as does intermittent positive pressure applied to the airway. Inspiratory and expiratory times are independently adjustable. The "Ucyclit" control unit alters pressure within the shell in a similar manner to the model CRV pump. It can be controlled, however, by patient initiated inspiratory efforts. These are detected as a negative pressure signal at the nostril by a sensitive pressure switch. A timing mechanism can provide obligatory controller function, or act in a stand-by capacity in the event of apnea. The "Ucyclit" unit also features gradual release of the negative pressure, which can serve as an adjustable impedance to expiratory flow and so minimize air trapping. The Emerson Chest

![Image of Emerson Chest Respirator](image-url)
Respirator interferes less with nursing functions than do tank-type, total body enclosure respirators. It is considerably more effective than cuirass body respirators since the negative pressure is effectively applied to the entire surface of the chest wall and not simply to the anterior surface of the trunk. It has found effective use during bronchoscopy under general anesthesia, since it safely permits complete curarization of the patient.

**The Emerson Rocking Bed**

The Emerson Rocking Bed (fig. 9) augments respiration by the principle of the Eve tilt method of resuscitation. The weight of the viscera in the semi-erect position aids descent of the diaphragm, which is removed upon return to the recumbent position. The Emerson rocking bed cycles from 15 to 26 times per minute, and can be flexed at the pelvis and knees for more comfortable posture. The rocking bed is a useful aid to spontaneous respiration for the patient who is recovering from respiratory paralysis. It is not sufficient support for the apneic patient, but serves to wean the convalescent from dependency on a lung ventilator.

**Summary**

The principles of operation of automatic lung ventilators have been outlined, and their merits and disadvantages enumerated. The functional characteristics of several representative lung ventilators have been presented. An appreciation of the interactions between the various types of ventilators and the lungs of patients suffering from the various respiratory and circulatory dysfunctions is necessary for the successful management of prolonged respiratory failure.
References

HYPOVENTILATION Hypoventilation with accompanying hypercapnia has been observed in dogs with artificially increased respiratory dead space when they are allowed to breathe 50 per cent oxygen. Decreased ventilation during oxygen breathing does not depend solely on a state of hypoxia or of hypercapnia prior to the period of oxygen breathing. The circumstances under which hypoventilation occurs with oxygen breathing was not associated with a decreased ventilatory response to carbon dioxide attributable to acclimatization. The only change in response to carbon dioxide is that associated with an increase in the work required to ventilate the alveoli. It is unlikely that any single factor will be found to account for all instances of oxygen-induced hypoventilation in view of the complex relationships involved in the regulation of respiration. However, these data indicate that the increased work of breathing is one of the important factors in the development of this phenomenon. (Barnett, T. B., and Peters, R. M.: Studies on Mechanism of Oxygen-Induced Hypoventilation, J. Clin. Invest. 41: 335 (Feb. 1962.)

LUNG GAS DISTRIBUTION Functional residual capacity and distribution of pulmonary gas were measured in normal humans subjected to tilting on a table. Functional residual capacity was large in the head-up position and decreased as subjects were tilted head down. The relationship between functional residual capacity and angle of tilt was linear. Distribution of pulmonary gas was less uniform in the head-down position. This was probably related to mechanical factors, such as surface tension, which are manifestations of the smaller lung volumes occurring in this position. Bronchomotor tone has no appreciable influence on these postural changes in normal individuals. (Bouhuys, A., and Van Lenner, H. J.: Effect of Body Posture on Gas Distribution in the Lungs, J. Appl. Physiol. 17: 38 (Jan.) 1962.)