0090-3493/87/1505-0459$02.00/0
CRITICAL CARE MEDICINE
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Vol. 15, No. 5
Printed in U.S.A.

editorial

Airway pressure release ventilation: A new concept in ventilatory support

Patients with severe acute lung injury (ALI) often have complicated clinical courses with the majority of patients suffering morbidity and mortality (1). It is agreed that mechanical ventilation often causes life-threatening complications that result from therapy, rather than being directly attributable to the disease process (2). Current mechanical ventilatory techniques originally were designed to support patients with neuromuscular inability or decreased drive to breathe adequately. Unlike patients with ALI, these patients had normal lungs with minimal gas exchange defects. Numerous modifications of traditional mechanical ventilators have been proposed to improve therapy and to decrease the complication rate, including assist mechanisms, intermittent mandatory ventilation (IMV), PEEP, reverse inspiration-expiration ratio, and high frequency, low-tidal volume capability. In spite of these attempts, the prognosis of patients with ALI has improved little since 1968 (3). Airway pressure release ventilation (APRV) is proposed as a possible improvement in the respiratory care of patients with ALI.

To provide APRV, continuous positive airway pressure (CPAP) is maintained so that the patient can breathe spontaneously without significant airway pressure (Paw) fluctuation. The appropriate level of CPAP may be determined by observing, measuring, and calculating a variety of physiologic responses to varying levels of CPAP. Changes in respiratory effort, respiratory rate, depth of respiration, Pa_{O_2}, calculated right-to-left intrapulmonary shunting of blood, and lung-thorax compliance help the clinician to determine an appropriate Paw.

Once a satisfactory level of CPAP is selected, if mechanically assisted ventilation is required, APRV may be initiated by cyclically releasing Paw to a lower level. This decreased Paw will allow gas to passively leave the lungs, thus eliminating CO_2. When the brief release period ends, Paw rapidly returns to the original CPAP level, thus increasing lung volume (Fig. 1). The degree of ventilatory assistance provided by APRV will be determined by the frequency of pressure release, the duration of pressure release, the CPAP level, the pressure release level, the patient's lung-thorax compliance, and flow resistance in the patient's airways and in the pressure release valve.

Pressure release and CPAP may be achieved in many ways, using a variety of valve configurations (Fig. 1). A continuous or intermittent flow of pressurized gas and a variety of threshold resistor valves may independently, or in combination, be used to provide CPAP and to allow pressure release. Gas flow must at least equal the patient's peak inspiratory flow. Flow resistance of the airway pressure release valve must be minimal to allow lung volume to rapidly decrease during pressure release. The CPAP valve must be a threshold resistor (4). Humidification of inspired gas, control of inspired oxygen concentration, alarm mechanisms, and monitoring functions must be addressed before routine clinical application of this technique. However, such devices should not increase flow resistance in the circuit.

Patients with ALI have reduced lung volume with mismatching of ventilation and perfusion leading to arterial hypoxemia. Decreased lung volume also is associated with reduced lung compliance, suprasternal and intercostal retractions, tachypnea, and increased work of breathing. This clinical presentation frequently leads to the impression that these patients require ventilatory assistance, which is usually achieved with positive-pressure mechanical ventilation (5). Yet, these

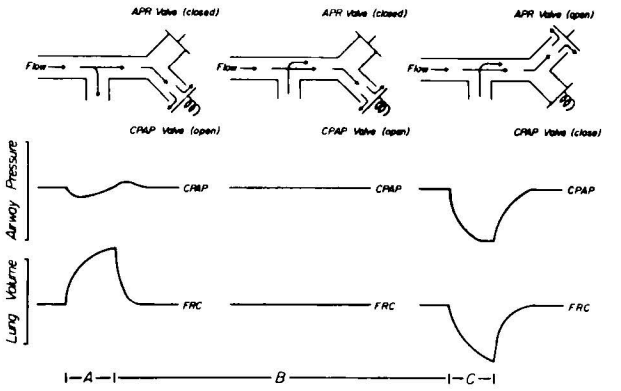

FIG. 1. A high gas flow is provided to the breathing circuit to maintain a nearly constant level of CPAP during spontaneous inspiration (*A*) and during exhalation (*B*). CPAP maintains increased lung volume compared to that which would occur during breathing of gas at atmospheric pressure. The increase in FRC is responsible for the reported benefits of CPAP. To assist breathing, CPAP is interrupted briefly to allow a transient decrease in FRC and elimination of CO_2 from the lungs (*C*). This period of release is usually much shorter than the expiratory time achieved with conventional ventilatory techniques. After closure of the pressure release valve, FRC is re-established.

patients rarely have impaired respiratory muscle strength or inadequate respiratory drive. Therefore, maneuvers designed to decrease work of breathing by increasing lung volume and lung compliance are physiologically more sound (6). Application of CPAP will accomplish these goals (7) and may decrease morbidity and mortality associated with the use of traditional ventilatory techniques for patients with ALI (8).

Many patients with ALI do not need ventilatory assistance when an appropriate CPAP level is applied (9). Occasionally, ventilatory failure occurs and results in elevation of $PaCO_2$, acidemia, and excessive work of breathing, even with CPAP. APRV is proposed as a unique way to augment alveolar ventilation without intermittently increasing Paw above the CPAP level when delivering a mechanical breath. APRV allows alveolar gas to be expelled passively from the lungs because of their natural recoil. Since ventilation occurs without increasing Paw above the CPAP level, barotrauma and adverse circulatory effects should be less frequent than during any conventional form of mechanical ventilation.

Current modes of positive-pressure ventilation usually are applied by transiently increasing Paw, causing fresh gas to enter the lungs. The duration of application of positive Paw can be limited by pressure (pressure-limited or pressure-cycled ventilation), volume (volume-limited or volume-cycled), time (time-cycled or controlled ventilation), or flow (flow-limited, pressure-assisted ventilation). The interval between positive-pressure breaths, expiratory time, determines ventilator frequency. It can be determined by time or pressure (assisted mechanical ventilation). Paw can be augmented with PEEP or CPAP during the ventilator's expiratory phase, prohibiting full exhalation of gas from the patient's lungs. Some ventilators will allow patients to breathe spontaneously between mechanical positive-pressure breaths (IMV) with, or without, CPAP. Although there are some similarities, APRV is unique when compared to previously described ventilatory techniques.

Although reinstitution of CPAP after pressure release may appear similar to conventional mechanical inspiration, significant differences distinguish these two therapies. These are illustrated by analysis of simultaneously generated Paw and lung volume tracings (Figs. 1 and 2). During APRV, the baseline lung volume, functional residual capacity (FRC), is determined by the CPAP level. With Paw release, lung volume decreases and, after reapplication of CPAP, increases back to FRC. With all other forms of mechanical ventilation and spontaneous breathing, lung volume is increased above FRC during inspiration and decreases to FRC with exhalation. APRV is the only form of mechanical ventilation that augments alveolar ventilation and causes elimination of CO_2 by decreasing lung volume below FRC. Thus, APRV is physiologically and philosophically different than conventional mechanical ventilatory techniques.

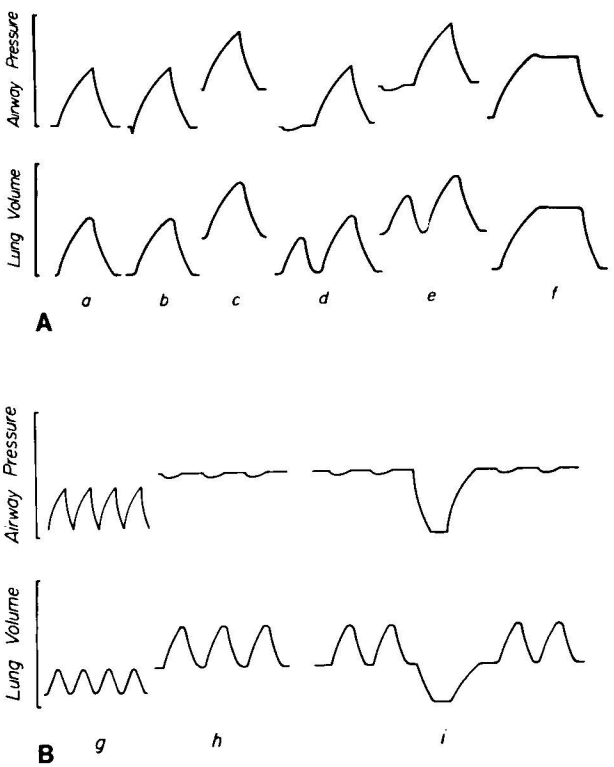

FIG. 2. Simultaneous changes in airway pressure and lung volume illustrate the differences between commonly applied ventilatory patterns and APRV. The following patterns are listed: *a*) controlled ventilation; *b*) assisted ventilation; *c*) continuous positive-pressure ventilation; *d*) IMV; *e*) IMV with CPAP; *f*) reverse inspiration: expiration ratio ventilation; *g*) high-frequency ventilation; *h*) CPAP; *i*) APRV

In the past, PEEP has been considered to be a therapy supplemental to mechanical ventilation. Successful use of CPAP in spontaneously breathing patients with reduced lung compliance demonstrated that the benefits of positive Paw usually are independent of the cyclic increase in Paw associated with traditional mechanical ventilation (9). This idea led to the unique notion that APRV might augment alveolar ventilation during CPAP therapy in contradistinction to the traditional concept of PEEP as an adjunct to positive-pressure ventilation.

Currently, we have documented the capability of APRV to provide CPAP and to augment alveolar ventilation in animals with normal and injured lungs (10). In an ongoing investigation, human subjects with mild ALI are receiving ventilatory support with APRV after a brief application of IMV or assist-control ventilation. If this comparison is favorable, patients with significant

ALI will receive CPAP, and APRV will be instituted, if alveolar ventilation requires augmentation. Such prospective evaluations will determine the efficacy of APRV as an alternative ventilatory technique.

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