

Laurent Brochard

Intrinsic (or auto-) PEEP during controlled mechanical ventilation

Published online: 17 August 2002
© Springer-Verlag 2002

L. Brochard (✉)
Medical Intensive Care Unit, Hôpital Henri Mondor,
Université Paris 12, INSERM U492, 94010 Créteil, France
e-mail: laurent.brochard@hmn.ap-hop-paris.fr

Introduction

Extrinsic positive end-expiratory pressure (PEEP) applied to the patient at the airway opening is used artificially to increase end-expiratory lung volume. Extrinsic PEEP is increased or decreased in small increments in ventilator-dependent patients because of its marked effects on cardiorespiratory status. Unintentional or unmeasured end-expiratory hyperinflation, called intrinsic or auto-PEEP, can also occur and have similarly marked profound cardiorespiratory effects in ventilator-dependent patients during controlled mechanical ventilation. Ventilatory settings can interact with the passive process of expiration and generate intrinsic or auto-PEEP [1, 2].

What is intrinsic (or auto-) PEEP?

During passive expiration of the lungs the elastic forces of the respiratory system are the driving forces and can be described by the relationship between lung volume and the elastic recoil pressure of the respiratory system. The lower the elastic forces, or the higher the resistive forces, the longer will be the time needed to fully expire the inspired tidal volume. In a single-compartment model of the lung in which the lung behaves as if it has a single resistance and compliance, the volume at any given time during expiration (V) is described by the monoexponential equation, $V = V_o - Ve^{-kt}$, where k is the time constant of the equation and is the product of resis-

tance times compliance (the reverse of elastance), and V_o is the end-inspiratory volume. In practical terms a time constant is the time required for the lungs to expire 63% of their initial volume. Thus the time needed passively to expire the inspired tidal volume is determined by the two main characteristics of the respiratory system: elastance and resistance. If expiration is interrupted before its natural end, i.e., by occurrence of the next inspiration, end-expiratory lung volume is higher than the so-called relaxation volume of the respiratory system, usually referred to as functional residual capacity. As a result the alveolar pressure at the end of expiration is higher than zero (zero being the atmospheric pressure), as predicted by the relationship between lung volume and the elastic recoil pressure of the respiratory system. This process is called dynamic hyperinflation, and the positive end-expiratory alveolar pressure associated with a higher than resting lung volume, is called intrinsic or auto-PEEP. Importantly for the clinician, this pressure is not directly measured at the airway opening and is thus not shown on the pressure dial of the ventilator. What the ventilator measures is the pressure in the ventilator circuit. Because the direction of the flow is still expiratory, the pressure measured by the ventilator at the end of expiration reflects only the relationship between flow and the resistance of the expiratory line, above the set PEEP. It does not give the clinician any information about the real alveolar pressure.

How one can suspect the presence of intrinsic (or auto-) PEEP

The presence of a positive alveolar pressure higher than the atmospheric pressure or higher than the external PEEP set on the ventilator (which is a new “reference pressure” for the lungs) can be identified by inspection of the expiratory flow-time curve. When the expiratory time is sufficient for lung emptying, expiratory flow de-

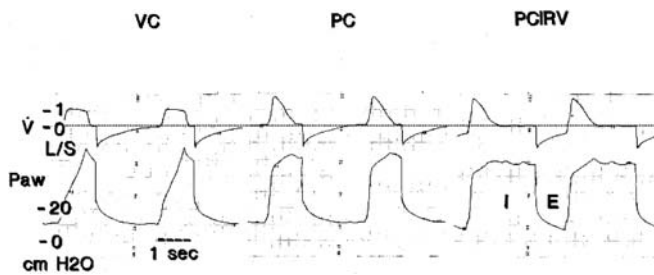


Fig. 1 Tracings of flow (\dot{V}) and airway pressure (P_{aw}) at the airway opening during volume controlled (VC), pressure-controlled (PC), and pressure-controlled inverse ratio ventilation (PCIRV). In the first two situations the expiratory flow declines gradually to zero; in the third case inspiration is lengthened by the inverse ratio setting and expiration shortened; the expiratory flow is abruptly interrupted, indicating the presence of dynamic hyperinflation and intrinsic or auto-PEEP. (From Lessard et al. [3])

clines from a maximum to zero or to the set PEEP. An interruption in this process results in an abrupt change in the slope of this curve, immediately continued by the next inspiratory flow. In other words, the next “inspiration” starts during “expiration.” Since the ventilator, which cannot generate flow into the patient’s lungs until the pressure at the airway opening exceeds the end-expiratory alveolar pressure, one way in which to measure intrinsic or auto-PEEP is to determine the airway pressure at the exact time of inspiratory flow. One can measure the intrinsic PEEP level by simultaneously recording airway pressure and flow data using a high-speed tracing. Figure 1 illustrates how shortening the expiratory phase generates such dynamic hyperinflation [3].

Is the level of intrinsic (or auto-) PEEP predictable?

If one assumes the respiratory system to be homogeneous and behave as a single compartment, a monoexponential equation can be used. By simple mathematics it takes three time constants (one being the product of resistance and compliance) to expire 96% of the inspired tidal volume. Therefore any longer expiratory time minimizes or fully avoids incomplete emptying. For instance, a resistance of $10 \text{ cmH}_2\text{O}\cdot\text{l}^{-1}\cdot\text{s}^{-1}$ and a compliance of $100 \text{ ml}\cdot\text{cmH}_2\text{O}^{-1}$ ($0.1 \text{ l}\cdot\text{cm H}_2\text{O}^{-1}$) results in a time constant of 1 s. Thus 3 s represents the minimal expiratory time needed to avoid intrinsic or auto-PEEP. Unfortunately, the diseased lungs are not only frequently inhomogeneous, making this calculation overly simplistic, but the presence of small airway collapse during expiration, also referred to as expiratory flow limitation, makes this even more complicated. Because of an abnormal structure of the small airways, when the pressure surrounding these conducts becomes higher than the pressure inside the airway, these small conducts collapse. The relationship between the “driving pressure” (pres-

sure in the alveoli minus pressure at the airway opening) on which is based the equation, disappears. In the setting of expiratory flow-limitation, the expiratory time required to minimize intrinsic PEEP is much longer than predicted by the time constant alone. By minimizing inspired minute ventilation the clinician can minimize intrinsic (auto-) PEEP.

Can intrinsic (or auto-) PEEP be reliably measured?

Since the reason for the presence of intrinsic PEEP is flow-dependent pressure gradients from the alveolus to the airway opening, occluding of the expiratory port of the ventilator at the exact end of expiration causes airway pressure to equilibrate rapidly with alveolar pressure and reliably measure the end-expiratory alveolar pressure. This occlusion takes place at the exact time where the next inspiration should start and is now available on most modern ventilators (“expiratory hold or pause”). If the patient is fully relaxed, this pressure measurement reflects the mean alveolar pressure at the end of expiration. Most of the time a plateau is reached after less than 1 s, but in the case of inhomogeneous lungs this pressure may require a few seconds to also reflect some very slow compartments. This airway occlusion pressure may not be homogeneously present in the whole lung but represents an average pressure of all regional levels of end-expiration alveolar pressure. Usually the difference between the expiratory pause airway pressure and the set external PEEP is called intrinsic or auto-PEEP, while the measured pressure is referred to as total PEEP.

Can the set external PEEP influence the total PEEP in the case of dynamic hyperinflation?

A frequent confusion is the belief that external PEEP could be useful in reducing the level of dynamic hyperinflation because it helps to reduce the value of auto- or intrinsic PEEP. Obviously this is not the case. The effect of external PEEP is to minimize the difference between the alveolar and the ventilator proximal airway pressure. This difference being called intrinsic or auto-PEEP, external PEEP application results in a decreased intrinsic or auto-PEEP. The level of dynamic hyperinflation, however, depends on the level of total PEEP and is either not influenced by external PEEP when external PEEP is less than intrinsic PEEP or is even worsened if external PEEP is set higher than the minimal level of regional intrinsic PEEP.

References

1. Pepe PE, Marini JJ (1982) Occult positive end-expiratory pressure in mechanically ventilated patients with airflow obstruction: the auto-PEEP effect. *Am Rev Respir Dis* 216:166–169
2. Rossi A, Polese G, Brandi G, Conti G (1995) Intrinsic positive end-expiratory pressure (PEEPi). *Intensive Care Med* 21:522–536
3. Lessard M, Guérot E, Lorino H, Lemaire F, Brochard L (1994) Effects of pressure-controlled with different I:E ratios versus volume-controlled ventilation on respiratory mechanics, gas exchange, and hemodynamics in patients with adult respiratory distress syndrome. *Anesthesiology* 80:983–991