The role of PEEP in patients with chronic obstructive pulmonary disease during assisted ventilation

A. Rossi, R. Brandolese, J. Milic-Emili, S.B. Gottfried

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Abstract: In patients with acute respiratory failure (ARF) due to acute exacerbation of chronic obstructive pulmonary disease (COPD), the intrinsic positive end-expiratory pressure (PEEP) can significantly increase workload for ventilation. It has been suggested that, in the presence of expiratory flow limitation, application of low levels of PEEP by the ventilator can be used to reduce PEEP and therefore the magnitude of the inspiratory effort during assisted mechanical ventilation (or pressure support) and weaning. Clearly, pulmonary hyperinflation should not be further enhanced in order not to counteract the beneficial effect of removing PEEP by decreasing respiratory muscle length and force. This use of PEEP in COPD patients is supported not only by theory, but also by recent experimental work, although sufficient clinical information is not yet available to provide a guideline for titration of the PEEP level. Therefore, application of PEEP in COPD patients requires close monitoring of the end-expiratory lung volume. This can be accomplished, among other noninvasive ways (e.g., the inductive plethysmography), by inspection of flow/volume curves during application of increasing levels of PEEP. The shape of the expiratory limb of the flow/volume curve can also suggest the presence of dynamic hyperinflation and expiratory flow limitation.


Since the original description in 1967 of the adult respiratory distress syndrome (ARDS), mechanical ventilation with positive end-expiratory pressure (PEEP) has become one of the most widely used techniques to improve pulmonary oxygenation in ARDS patients [1]. It is well established that PEEP has neither a direct therapeutic action on the acutely injured lung nor a preventive effect in patients at risk of developing ARDS [2]. In ARDS patients, PEEP increases the functional residual capacity (FRC) and the respiratory compliance [3] by “recruiting” previously collapsed, unventilated, perfused airspaces [4, 5]. The level of PEEP to be applied to ARDS patients is chosen with more caution now than in the past, with a tendency to set the “minimal” PEEP as the “best” or “optimum” PEEP [6].

In the past, application of PEEP to acutely ill patients with chronic obstructive pulmonary disease (COPD) was not recommended, essentially for two reasons. First, the degree of hypoxaemia in COPD patients, even during respiratory failure, is generally mild and can be readily improved with oxygen-enriched air alone. Secondly, these patients are hyperinflated and any further increase in lung volume, for example with application of PEEP, would increase the risk of barotrauma.

Physiological basis for PEEP in COPD

Recent studies suggest that application of PEEP may be of benefit in COPD patients when used to improve respiratory muscle efficiency during assisted modes of mechanical ventilation or when weaning is being attempted [7]. The development of this concept can be better understood when considering the abnormalities in respiratory mechanics which occur, particularly the presence of dynamic pulmonary hyperinflation [8, 9]. Because of the increased airflow resistance, the time available for expiration is insufficient for complete exhalation to occur so that the end-expiratory lung volume (EELV) is greater than the elastic equilibrium volume of the respiratory system (Ve). This increase in EELV can be as much as 1.3 L [10]. In our studies, a 15-20 s period of relaxed expiration was often required in COPD patients, in order for the lung volume to reach Ve [10]. Obviously, such a long expiratory duration cannot be used in any ventilatory setting of critically ill patients. In the presence of dynamic pulmonary hyperinflation, the elastic recoil pressure at end-expiration (Pelrs) exceeds the pressure recorded at the airway opening [11, 12]. This positive end-expiratory Pelrs has been termed...
“auto” or “intrinsic” positive end-expiratory pressure (PEEP) and has been measured in COPD patients with acute respiratory failure (ARF) during mechanical ventilation [10–14] as well as spontaneous ventilation [15]; values ranged between a few cmH\(_2\)O and 20–22 cmH\(_2\)O. Recently, PEEP has also been measured in stable COPD patients, ranging between 1 and 7 cmH\(_2\)O [16]. PEEP has a number of important implications [7, 11, 12]. The adverse haemodynamic effects of PEEP have been discussed elsewhere [11].

In terms of respiratory muscle effort, PEEP acts as an “inspiratory threshold load” which has to be counterbalanced in order to inflate the lung [7]. During controlled mechanical ventilation, the pressure required to overcome PEEP is provided by the ventilator [12, 17]. In contrast, during assisted modes of mechanical ventilation, PEEP must be offset by the patient’s inspiratory muscles, which must generate a subatmospheric pressure in the central airways in order to trigger the assisted mechanical breath [7, 18]. This is true not only for conventional assisted mechanical ventilation, but also for other modes of assisted ventilation, such as synchronized intermittent mandatory ventilation and pressure support [19].

**PEEP: hyperinflation and inspiratory muscles**

The dynamic hyperinflation which occurs during mechanical ventilation in COPD patients is in addition to any increase in absolute lung volume due to the loss of lung elastic recoil. At high lung volume, the operational length of the inspiratory muscles is reduced and their strength and mechanical efficiency is significantly decreased [9]. Clearly, PEEP provides a significant burden for the inspiratory muscles, which can severely impair the ability to resume spontaneous ventilation. For example, with ventilatory modes requiring patient effort (e.g., assist-control ventilation and pressure support), PEEP is added to the “triggering” pressure (generally set at 1–2 cmH\(_2\)O) so that the total pressure which has to be developed by the inspiratory muscles to initiate the mechanical breath is markedly increased [7, 18]. Obviously, reducing PEEP will be of benefit.

Some recent data support the notion that application of low levels of positive end-expiratory pressure (PEEP) decreases PEEP and hence the work of breathing during assisted modes of mechanical ventilation [18, 19]. Similarly, continuous positive airway pressure (CPAP) is equally effective in reducing inspiratory effort in spontaneously breathing COPD patients being weaned from mechanical ventilation [20]. The ability of PEEP to reduce PEEP is critically dependent upon the presence of expiratory flow limitation. While it is generally accepted that flow limitation occurs during forced expiration, it is now well recognized to also occur in mechanically ventilated COPD patients [8, 9, 14, 21]. In the presence of expiratory flow limitation, an increase in the downstream impedance (e.g., the external application of PEEP) relative to the site of flow limitation should have little effect on the rate of lung emptying until the applied PEEP exceeds a critical level somewhat lower than the initial PEEP [17, 21, 22]. It has also been shown in two COPD patients during controlled mechanical ventilation, that cardiac output is not altered by application of PEEP lower than the original PEEP [17].

It should be noted that PEEP has also been observed in mechanically ventilated patients without COPD [12, 13, 23]. Expiratory flow can be impaired by factors other than air flow limitation, e.g., narrow bore endotracheal tubes, ventilator circuits, and other devices. The resistance of both endotracheal tubes and ventilator circuits is flow-dependent and can be as high as 13 cmH\(_2\)O·t\(^{-1}\)·s in a common ventilator setting [23]. However, values of PEEP higher than 5 cmH\(_2\)O are seldom found in patients without COPD [12, 13, 23]. In the absence of expiratory flow limitation, the application of PEEP through the external ventilator circuit will decrease driving pressure and hence expiratory flow. This will further increase EELV [21, 24].

**How much PEEP?**

The role of PEEP in mechanically ventilated COPD patients with acute respiratory failure is to provide support for the inspiratory muscles by offsetting PEEP, i.e., the inspiratory threshold load. Sufficient clinical information is not yet available to provide an exact guideline for the titration of the level of external PEEP in COPD patients. However, pulmonary hyperinflation should not be further enhanced by excessive amounts of PEEP [25]. In fact, this will tend to negate the beneficial effect of removing PEEP by decreasing inspiratory muscle length and force generating capacity. In addition, adverse haemodynamic effects and the risk of barotrauma will be increased [7, 24, 25].

Therefore, application of PEEP requires close monitoring of its effect on lung volume. This can be accomplished in a number of ways. For example, EELV can be monitored using respiratory inductance plethysmography (Respitrace) [18, 22, 26]. Alternatively, the expiratory PeIrs, i.e., PEEP, can be directly determined from the measurement of the difference between the value of the plateau in airway pressure during an end-expiratory occlusion and the pressure recorded at the airway opening at the end of the unoccluded expiration [18, 22]. This manoeuvre provides a simple way to check whether and to what extent PEEP replaces PEEP or adds to it. The end-expiratory occlusion can be performed easily during controlled mechanical ventilation, where the respiratory muscles are relaxed. However, it can present some problems when the patient’s respiratory muscles are active, for example during assisted mechanical ventilation and pressure support, i.e., when a reliable measurement of PEEP is required during application of increasing levels of external PEEP. Recent work has shown that PEEP can be measured by means of the end-expiratory occlusion method also when patients are ventilated with the assist mode or pressure support [18, 19]. In this regard, it should be noted that airway occlusion can be readily performed...
using the end-expiratory hold button of the Servo 900C Siemens ventilator [23]. Both respiratory inductive plethysmography and end-expiratory airway occlusion are noninvasive and are well suited to bedside monitoring during the application of PEEP in mechanically ventilated COPD patients.

A useful way to monitor the effects of the application of PEEP on respiratory mechanics in ICU patients is the analysis of the volume/flow (VF) relationship during a relaxed expiration [27]. Under those conditions, exhalation is passively driven by the elastic recoil of the total respiratory system, while flow resistance is the only opposing force. The method was originally used by McLaurin et al. [28] in awake human adults and has been modified and successfully applied for the “single breath” measurement of respiratory mechanics in anesthetized animals [29] and humans [30] and in infants [31]. The “single breath” method assumes that respiratory compliance is constant throughout expiration and that EELV corresponds to $V_t$. Since this is not always the case in ICU patients with ARF [14], the application of the “single breath” method in such patients is problematic. However, even simple inspection of the relaxed expiratory VF curves in mechanically ventilated patients can provide useful information [32]. In fact, when PEEP is absent, the expiratory flow decreases smoothly throughout expiration. By contrast, when EELV is above $V_t$ (i.e. PEEP is present), the expiratory flow is abruptly terminated by the next mechanical inflation, such that the expiratory VF curve has a characteristic “truncated” appearance (fig. 1). This particular information could be obtained also from the flow time profile [12, 16]. However, the shape of the VF curve is also important. In anesthetized animals, with the upper airway bypassed by a tracheal cannula, the relaxed expiratory VF relationship is linear [29]. In anesthetized humans it tends to be curvilinear, i.e. it exhibits a concavity toward the volume axis which mainly reflects the resistive properties of the endotracheal tubes [27, 30]. In critically ill patients, the VF relationship may be more complex. In the presence of dynamic expiratory flow limitation the VF curve is convex toward the volume axis either throughout expiration or during the late part of it [14, 32]. During mechanical ventilation, COPD patients with ARF in general exhibit an expiratory VF curve which is both “truncated” and convex toward the volume axis. This is indicative of expiratory flow limitation and dynamic pulmonary hyperinflation (fig. 1). In mechanically ventilated ARDS patients, after sudden removal of PEEP, the expiratory flows, in general, increase at all lung volumes because of the concomitant increase in expiratory driving pressure and the VF curve is not convex toward the volume axis (fig. 2). By contrast, in mechanically ventilated COPD patients the rate of lung emptying remains essentially unchanged after removal of PEEP (fig. 1). In fact, in the patient in figure 1, the applied PEEP (4 cmH$_2$O) was lower than PEEPi (11.5 cmH$_2$O) and did not affect expiration because of dynamic expiratory flow limitation. Thus, display of the VF curves during mechanical ventilation provides a simple, though qualitative, way to assess the presence of dynamic hyperinflation (“truncated” end-expiratory flow) and expiratory flow limitation (shape of VF curve) as well as to monitor the effects of applied PEEP on expiratory flow.

![Fig. 1. - Relaxed expiratory volume/flow curves in a mechanically ventilated chronic obstructive disease patient with positive end-expiratory pressure (PEEP) of 4 cmH$_2$O (smaller loop) and without PEEP (outer loop). With 4 cmH$_2$O of PEEP, the intrinsic PEEP was 7.5 cmH$_2$O. During expiration with PEEP of 4 cmH$_2$O, the volume/flow loop exhibited a characteristic “truncated” appearance due to the onset of the next mechanical inflation before expiration could be completed, i.e. the patient was dynamically hyperinflated. Complete relaxed expiration against atmospheric pressure resulted in a reduction of the end-expiratory lung volume, but during most of expiration the rate of lung emptying was unchanged due to pre-existing dynamic expiratory flow limitation, such that removal of PEEP did not affect the effective expiratory driving pressure.](image1)

![Fig. 2. - Expiratory volume/flow relationship in a mechanically ventilated adult respiratory distress syndrome patient. The smaller loop pertains to a positive end-expiratory pressure (PEEP) of 12 cmH$_2$O. At the end of a mechanical lung inflation, the airway is briefly occluded and PEEP removed, the larger loop representing the relaxed expiration to atmosphere. Removal of PEEP not only decreased the end-expiratory lung volume, but also increased the expiratory flows because of increased expiratory driving pressure. Note that in both instances the flow decreased smoothly throughout expiration, indicating absence of intrinsic PEEP.](image2)
Conclusions

In mechanically ventilated patients with PEEP and dynamic expiratory flow limitation, application of PEEP can be used to support the inspiratory muscles during "triggered" mechanical inflations and weaning, in order to reduce the amount of the inspiratory effort.

Although the theory and some experimental data are encouraging, at the present time more clinical research is required to investigate the benefits which can be obtained from the use of PEEP in COPD patients. Clearly, pulmonary hyperinflation should not be increased. Therefore, close monitoring of the EELV is needed during application of increasing levels of PEEP. This can be accomplished with some simple and noninvasive techniques, suitable for use at the bedside, which have also been discussed in this article.

References


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Revue brève. Le rôle de la pression positive en fin d'expiration (PEEP) chez les patients atteints de bronchopneumopathie chronique obstructive au cours de la ventilation assistée. A. Rossi, R. Brandolese, J. Milic-Emili, S.B. Gottfried.

RÉSUMÉ: Chez les patients développant une décompensation respiratoire aiguë (ARF) due à une exacerbation aiguë d'une bronchopneumopathie chronique obstructive (BPCO), la pression positive intrinsèque en fin d'expiration (PEEPi) peut augmenter significativement la charge de travail ventilatoire. L'on a suggéré que, en raison des limitations du débit expiratoire, l'application de bas niveaux de PEEP par le ventilateur pourrait être utilisée pour réduire la PEEPi, et dès lors l'amplitude de l'effort inspiratoire au cours de la ventilation assistée mécanique (ou aide de pression) et au cours du sevrage. Clairement, l'hyperinflation pulmonaire ne devrait pas être accentuée, afin de ne pas contrecarrer l'effet bénéfique du retrait de la PEEP en diminuant la longueur et la force des muscles respiratoires. Cette utilisation de la PEEP chez les patients BPCO est défendue, non seulement par la théorie, mais aussi par certains travaux expérimentaux, encore qu'une information clinique suffisante ne soit pas encore disponible au point de fournir des indications quant au dosage du niveau de PEEP. Dès lors, l'application de PEEP chez les patients BPCO exige un suivi attentif du volume pulmonaire en fin d'expiration. Ceci peut être obtenu parmi d'autres moyens non invasifs (par exemple la pléthysmographie d'induction), par la surveillance des courbes débits-volumes pendant l'application de niveaux croissants de PEEP. La forme de la boucle expiratoire de la courbe débit-volume peut également suggérer la présence d'une hyperinflation dynamique et d'une limitation du débit expiratoire.