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EDITORIAL

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Turn the ARDS patient prone to improve oxygenation and decrease risk of lung injury

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Since 1976, when Piehn and Brown [1] reported that the prone position improves oxygenation in patients with acute respiratory failure, more than 200 articles have been published concerning the effect of proning on gas exchange in patients with acute respiratory distress syndrome (ARDS). Based on these reports, the prone position is now an accepted method for improving oxygenation in severely hypoxemic ARDS patients [2].

In this issue of *Intensive Care Medicine*, Vieillard-Baron et al. [3] have studied the effect of the prone position in a subgroup of ARDS patients who, during controlled mechanical ventilation in the supine position on ZEEP, exhibited dynamic hyperinflation and intrinsic PEEP (PEEPi). With proning, both dynamic hyperinflation and PEEPi were essentially abolished with a concurrent increase in oxygenation and decrease in $PaCO_2$. As in a previous study on supine ARDS patients on ZEEP [4], dynamic hyperinflation and PEEPi were presumably due to tidal expiratory flow limitation. Tidal flow limitation is said to be present when expiratory flow at a given lung volume cannot be augmented in spite of further increases of the transpulmonary and alveolar pressure [5]. The latter is commonly seen in mechanically ventilated ARDS patients at ZEEP because their expiratory flow reserve is diminished by decreased functional residual capacity (FRC) and the reduced number of functional lung units [4, 6]. As a result, in order to satisfy their ventilatory needs, they have to breathe at a higher lung volume than the relaxation volume of the respiratory system (Vr) [7]. Tidal expiratory flow limitation implies sequential dynamic compression of the peripheral airways during expiration with consequent inhomogeneous regional lung emptying (the dependent lung zones achieve flow limitation earlier due to the vertical pleural pressure gradient). Inhomogeneous lung emptying promotes regional differences of PEEPi within the lung and dynamic hyperinflation. In the presence of regional PEEPi inequality, lung inflation does not start synchronously in all lung regions since the short-time constant units can start filling while the long-time constant units are still emptying [8]. This causes impaired distribution of ventilation and gas exchange (decreased PaO_2 and increased $PaCO_2$). Under such conditions, the application of external PEEP by reducing PEEPi inequality [9] increases PaO_2 and decreases $PaCO_2$. The present study of Vieillard-Baron et al. [3] suggests that proning has the same effect as PEEP because in this position dynamic hyperinflation and PEEPi are reduced with a concurrent reduction in PEEPi inequality. Furthermore, the prone position increased oxygenation and decreased $PaCO_2$. The reduction of dynamic hyperinflation and PEEPi with proning was probably due largely to abolishment or reduction of the extent of tidal flow limitation [6]. In this connection it should be stressed that tidal flow limitation is a risk factor for low-volume lung injury during mechanical ventilation [10, 11]. It is evident, therefore, that assessment of expiratory flow limitation should be mandatory in the management of ARDS [6] and other mechanically ventilated patients [12, 13].

In another study of ARDS patients mechanically ventilated on ZEEP, in whom there was little or no dynamic hyperinflation and PEEPi in the supine position [14], when shifting from supine to prone position the $PaCO_2$ remained unchanged while PaO_2 increased. Since in these patients there was little PEEPi inequality in the supine position, the improvement in PaO_2 was due to other mechanisms (alveolar recruitment, redistribution of blood flow, etc).

In line with previous results [14], Vieillard-Baron et al. [3] found that in both the supine and prone position the application of PEEP improved oxygenation but not $PaCO_2$. With PEEP, however, the oxygen delivery either did not change or decreased [14], suggesting that in these terms the benefits of PEEP are questionable. In this context, it should also be noted that the prone position does not affect outcomes such as mortality or length of hospital stay and is associated with higher incidence of pressure sores, selective intubation, and endotracheal tube obstruction [15, 16].

Vieillard-Baron et al. [3] found that the reduction in $PaCO_2$ with the prone position correlated significantly with the reduction in expiratory time constant (τ) assessed as the time required to exhale 63% of the total expired volume during a prolonged expiration to the relaxation volume of the respiratory system [17]. This analysis assumes that the lung of ARDS patients behaves as a single-compartment model such that the volume-time curve during a relaxed expiration can be described by the following mono-exponential equation:

$$V(t) = A \cdot \exp(-t/\tau) \qquad (1)$$

where V(t) is the time-course of volume during passive deflation to the relaxation volume of the respiratory system, A is initial volume, and t is time during deflation. However, Chelucci et al. have shown that in both normal subjects [18] and ARDS patients [19] a double-compartment model has to be used:

$$V(t) = A_1 \cdot \exp(-t/\tau_1) + A_2 \cdot \exp(-t/\tau_2) \qquad (2)$$

where A_1, A_2, and τ_1, τ_2 are the corresponding initial volumes and time constants of fast and slow compartments.

Vieillard-Baron et al. also stated that the additional volume exhaled by prolonging the expiratory time beyond baseline is a measure of the "slow compartment" of the lung. This is surprising because their τ was based on a single-compartment model (Eq. 1). Even with the two-compartment model (Eq. 2) the "slow compartment" assessed by Vieillard-Baron et al. [3] underestimates the magnitude of the actual slow compartment (A_2) because this compartment empties throughout expiration. In this connection it should be noted that the "slow compartment" is usually labeled as ΔFRC, i.e., the difference between the end-expiratory lung volume and the relaxation volume of the respiratory system [20]. In a complex area such as respiratory mechanics, standard terms should be used. Finally, it should be noted that Eq. 2 applies only in the absence of flow limitation during the passive expiration. Thus, assessment of slow and fast time constants and compartments in ARDS patients with tidal flow limitation is problematic.

In spite of these shortcomings, the paper of Vieillard-Baron et al. is important because it provides new evidence that in ARDS patients who exhibit dynamic hyperinflation and PEEPi at ZEEP in the supine position, these are essentially abolished in the prone position, with concurrent improvement in PaO_2 and $PaCO_2$.

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