Determinants and Prevention of Ventilator-Induced Lung Injury

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KEYWORDS

- Mechanical ventilation • Ventilator-induced lung injury
- High-volume and high-pressure ventilation • Acute respiratory distress syndrome
- Mechanical power

KEY POINTS

- Mechanical ventilation has adverse side effects.
- Ventilatior-induced lung injury results from the interaction between the lung parenchyma and the mechanical forces applied on it.
- High PEEP may favor barotrauma, while lower PEEP may favor atelectrauma. Risks and benefits of PEEP in a range between 5 to 15 cm H_2O are equivalent, while at higher PEEP the risks of volutrauma outweight the benefits of reduces atelectrauma.

INTRODUCTION

As every powerful treatment, mechanical ventilation has its adverse side effects, which are classically referred to as ventilator-induced lung injury (VILI) and were first recognized—mainly as gross barotrauma—soon after the introduction of mechanical ventilation in patients with acute respiratory distress syndrome (ARDS). In the 1960s, the goal of mechanical ventilation was to maintain a normal gas exchange. The effort to limit the increase in CO_2 in patients with severely impaired lung compliance and increased dead space was obtained through high-volume and high-pressure ventilation, which often led to pneumothorax. This complication was so frequent that some authors suggested the preemptive positioning of chest drain in patients with ARDS.[1–3] Nowadays, this scenario seems to be hardly believable, but it must be pointed out that, back in the 1970s, the most feared complications of mechanical ventilation

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were those related to a high fraction of inspired oxygen. It has been forgotten, but the first applications of extracorporeal support were designed to reduce the fraction of inspired oxygen in patients with ARDS, and certainly not to allow less mechanically aggressive ventilation.[4] For years, therefore, barotrauma was considered an easily treatable complication (ie, drainage) and an unavoidable price to pay for keeping the patient alive. The remarkable conceptual change, however, was introduced by Dreyfuss and colleagues,[5] who emphasized the importance of volume—instead of airway pressure—in determining the ventilation-related lung damage. Actually, strictly speaking, volume and pressure are the 2 faces of the same coin, because they are linked by a proportionality constant: the total elastance of the respiratory system (ie, the sum of the chest wall and lung elastance). In cases of increased chest wall elastance, for the same high-pressure ventilation, lung damage was not observed, because most of the pressure was spent to displace the thorax instead of distending the lung. Obviously, the differences between volutrauma and barotrauma vanish when considering the *lung's* transpulmonary pressure and changes in *lung* volume. In an era in which the transpulmonary pressure was just a physiologic issue—remote from whatever clinical application—the concept of volutrauma represented an intellectual advance and pointed out that the lung lesions were due to excessive strain (ie, "movement" is required to promote damage). The concept of volutrauma paralleled the progressive attention to the decrease in tidal volume, first implemented in asthmatic patients. Hickling and colleagues[6] introduced the same concept of "permissive hypercapnia" as a tool for more gentle treatment of the ARDS lung. The landmark National Institutes of Health randomized trial documented the worse outcome of high tidal volume compared with the lower one. The next step toward a better understanding of the relationship between mechanical ventilation and lung damage was due to Slutsky's group in Toronto who, in an ex vivo rat lung model, showed that the damage resulting from mechanical ventilation was in large part due to the cyclic opening and closing of lung units, preventable by applying adequate positive end-expiratory pressure (PEEP).[7] This experiment was in line with the previous theoretic consideration of Mead and associates[8] and Lachmann,[9] and further reinforced by the clinical work of Amato and coworkers[10] and Ranieri and colleagues.[11] Indeed, Slutsky's experiments helped open the way to a new concept: to keep the lung open with PEEP may not only make mechanical ventilation safer, it might even promote lung recovery. In the last years, consequently, the effort to reduce mechanical ventilation-related lung damages converted into the widespread acceptance of the open lung strategy (ie, high PEEP associated with a low tidal volume) as the best way for treating patients with ARDS. However, several banks of clinical data seem to contrast with this belief. Therefore, despite decades of experimental and clinical research, which we briefly summarized, several issues remain open: (1) The definition and the assessment of VILI in the clinical setting seem, per se, to be questionable; (2) What is the mortality attributable to VILI in mechanically ventilated patients?; (3) Which are actual mechanical triggers of VILI?; and finally (4) Which are the lung conditions that favor it? Only when we will have answered these questions, we will be able to formulate a rational and, most likely, a predictably effective approach to VILI prevention.

DEFINITION OF VENTILATOR-INDUCED LUNG INJURY

The acronym VILI may express 2 concepts: *ventilator*-induced lung injury, stressing the importance of the ventilatory setting, or *ventilation*-induced lung injury, in which the emphasis is on the consequences of the forces acting on lung parenchyma during either spontaneous or mechanical ventilation. Indeed—regardless the origin of the