Intraoperative Mechanical Ventilation

Subjects: Surgery
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Mechanical ventilation (MV) is still necessary in many surgical procedures; nonetheless, intraoperative MV is not free from harmful effects. Protective ventilation strategies, which include the combination of low tidal volume and adequate positive end expiratory pressure (PEEP) levels, are usually adopted to minimize the ventilation-induced lung injury and to avoid post-operative pulmonary complications (PPCs). Even so, volutrauma and atelectrauma may co-exist at different levels of tidal volume and PEEP, and therefore, the physiological response to the MV settings should be monitored in each patient.

Keywords: general anesthesia ; postoperative pulmonary atelectasis ; respiratory failure ; postoperative pulmonary complications ; risk assessment ; preoperative care ; intraoperative monitoring ; postoperative care ; positive end expiratory pressure ; precision medicine ; intraoperat

1. Introduction

Mechanical ventilation (MV) is still necessary in many surgical procedures to provide gas exchanges during general anesthesia (GA) [1][2]. The concept of ventilator-induced lung injury has long been known; indeed, inadequate MV settings can lead to both atelectasis and lung overdistention [3][4][5]. Most studies on protective mechanical ventilation are focused on acute respiratory distress syndrome (ARDS) patients, where low tidal volume (VT) and an adequate positive end expiratory pressure (PEEP) are useful to minimize the dangerous effect of MV [6][7][8][9].

As described in ARDS patients, also during GA, higher tidal volume produces inflammatory reaction and pulmonary damages; as a result, many studies have found that the use of higher VT in patients undergoing GA increases morbidity and mortality [10]. On the opposite side, the use of intraoperative low tidal volume can reduce postoperative pulmonary complications (PPCs) [7].

In the last decades, research focused on development of protective ventilation strategies to prevent PPCs; indeed, MV should provide gas exchanges while minimizing lung stress and strain [3][11]. From the clinical point of view, this purpose can be reached by coupling a deep physiological understanding of the different ventilatory parameters and a continuous monitoring of their effects on the lungs. Several randomized clinical trials (RCTs) failed to find a specific ventilation strategy able to reduce PPCs [12][13][14]. Patients' heterogeneity may be one of the main confounding factors leading to negative RCT.

This narrative review aims to provide a current knowledge regarding how to set mechanical ventilation in different type of surgery (i.e., open abdominal surgery, laparoscopy and thoracic surgery) in order to reduce the risk of PPCs.

2. Mechanical Power

Due to the complexity of the interaction between the many respiratory variables, many efforts have been made to achieve a comprehensive analysis of the energy given by the ventilator to the patients. Mechanical power (MP) is a summary variable including all the components which can possibly cause VILI. where RR is respiratory rate, VT is tidal volume, ELrs is respiratory system elastance, and Raw is airway resistance [15]. Higher values of MP have been associated lung injury; even so, studies performed in healthy lungs during general anesthesia are mostly conducted in animals [16][17][18].

The MP Formula can give to the anesthesiologist the ability to balance the effects of each respiratory parameter on the lungs. For example, the effect of tidal volume, which is squared in the Formula, is predominant. Further, it appears that the effect of PEEP is dichotomic: it increases the MP but also has the ability to reduce it through a reduction in ELrs. Finally, the MP Formula highlights that the respiratory rate, usually neglected when discussing the genesis of VILI, has a linear correlation with the amount of the energy delivered to the lungs.

Despite the robust physiological bases of MP, some limits should be considered. First, a validation of MP Formula in a large surgical population is still lacking, with only a small study performed in thoracic surgery [19]. Second, due to the complexity of the Formula, easier equations are being tested to allow an easier bedside calculation of MP [20][21]. Finally, despite low MP values, local damage is still possible in case of inhomogeneous ventilation with atelectasis and hyperinflation present at the same time.

3. Expiratory Flow Limitation

Expiratory flow limitation (EFL) is a pathological condition characterized by a sharp reduction of expiratory flow associated with increased risk of PPCs in patients undergoing general anesthesia [22]. In mechanically ventilated patients, EFL is usually defined by the lack of increasing in the expiratory flow when PEEP is decreased, also called PEEP test [23]. During anesthesia, FRC values may shift below the closing capacity, causing collapsible small airways and, consequently, the “opening-closing” phenomena.

This can contribute to PPCs through different pathways. Such cyclic closure results in a reduction on expiratory flow together with a physical stress to the airway wall, which promote inflammation [24]. Moreover, EFL can cause an enhance of regional overdistention [23], which is difficulty detectable during GA. Furthermore, the occurrence of EFL during mechanical ventilation may impair the efficacy of postoperative cough and the clearance of secretions in smaller airways [25][26][27].

Given the relationship between occurrence of EFL and PPCs, a routinely assessment of EFL is suggested; this is particularly relevant because intraoperative EFL is often at least partially reversible. In a study involving ARDS patients, extrinsic PEEP was able to reduce intrinsic PEEP in EFL patients [28]. Accordingly, an observational study demonstrated a “paradoxical” response to PEEP in EFL patients, i.e., the decrease of hyperinflation when PEEP was increased [29]. This is probably due to the fact that application of PEEP may stabilize small airways and consequently improve lung emptying.

4. From Protective to Personalized: The Future of Intraoperative Mechanical Ventilation

The continuous growing of monitoring tools available at bedside is challenging the actual concept of protective ventilation. EIT can give additional information to those given by respiratory mechanics. Respiratory mechanics can better asses the dynamic stress, whether EIT may help to optimize lung recruitment and homogeneity of ventilation [30]. Moreover, data regarding regional air trapping are gaining importance in EIT evaluation and may represent an important adding to intraoperative MV knowledge [25].

The same concept (i.e., coupling monitoring ability with clinical intervention) can be extended to the usefulness of intraoperative lung ultrasound assessment. Perioperative lung ultrasound has been used to dynamically detect the development of intraoperative atelectasis [31] or alveolar consolidation [32] as well as postoperative diaphragm dysfunction [33]. Given that lung ultrasound can assess PEEP-induced lung recruitment [34][35][36], its application could help to identify which patients could benefit from higher PEEP or recruiting maneuvers.

As resumed in this review, setting an adequate “personalized” MV able to optimize the lung function is far from being simple. Identifying the optimal MV strategy when considering the whole organism, and not only the lung, is even more challenging. Mechanical ventilation can affect the hemodynamic status of the patients in several ways, particularly with PEEP titration [35]. Briefly, the same PEEP value able to optimize lung function can impair cardiac output while resulting in lower arterial oxygen delivery (DO2) despite higher alveolar oxygen content; only few studies investigated the effects of different PEEP values on lung protection and DO2, showing that in a consistent percentage of patients, incremental PEEP appears to protect alveoli but resulted in lower DO2[36].

The different systemic consequences of PEEP underline that the ventilator-induced lung injury is only one of the putative adverse effect of MV; recently, it has been shown that two MV strategies with same lung-protection ability can affect in different ways the cardiovascular system [16]. How much is the acceptable fall in DO2, and how to balance the lung and hemodynamics effects of MV, are far from being demonstrated.

Finally, it is worth underlining that the microcirculatory effects of MV are not fully explainable with changes in cardiac output. For example, PEEP application can affect renal blood flow with a non-linear relationship difficult to predict [37]. Therefore, specific organ monitoring is recommended particularly in the high-risk setting; recently, intraoperative Doppler-determined renal resistive index (RRI) has been identified as a risk factor for postoperative acute kidney injury in patients undergoing cardiopulmonary bypass [38].

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