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A 5-year observational study of lung-protective ventilation in the operating room: A single-center experience☆

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Abstract
Purpose: We assessed the evolution of lung-protective ventilation strategies during anesthesia and identified factors associated with the selection of a nonprotective ventilation strategy.
Methods: This retrospective observational study covered a 5-year period from March 2006 to March 2011. It included 45 575 adult patients who underwent intubation de novo in the operating room. We considered a tidal volume (V_T) greater than 10 mL/kg of ideal body weight (IBW) and/or positive end-expiratory pressure (PEEP) less than 5 cm H_2O as not lung protective. We evaluated the use of nonprotective ventilation strategies over time in men and women, by American Society of Anesthesiologists classification, and for elective vs emergent surgery.
Results: Over the duration of the study, there was a significant reduction in the percentage of patients receiving a V_T greater than 10 mL/kg IBW (28.5%-16.3%, $P < .001$), zero PEEP (27.5%-18.2%, $P < .001$), and V_T greater than 10 mL/kg IBW with PEEP less than 5 cm H_2O (13.4%-8.0%, $P < .001$). The odds of receiving nonprotective ventilation were greater for women than for men, in the first year compared with the last year, and for elective compared with emergent surgery.
Conclusion: Although use of nonprotective ventilation decreased over time, an important percentage of patients continue to receive nonprotective ventilation.

1. Introduction

Since publication of the ARDS Network study in 2000[1], lung-protective ventilation strategies are considered standard practice in patients with acute respiratory distress syndrome (ARDS). In patients with ARDS, minimizing overdistention by use of a tidal volume (V_T) of 6 mL/kg of ideal body

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weight (IBW) and a plateau pressure of 30 cm H_2O or less has a survival benefit. Positive end-expiratory pressure (PEEP) is also lung protective because it maintains alveolar recruitment, thus avoiding injury caused by cyclical alveolar opening and closing, as well as the high distending pressure that occurs at the junction of open and collapsed alveoli. Despite controversy about the best level of PEEP, it is generally accepted that a PEEP of 0 cm H_2O is harmful in patients with ARDS [2].

In mechanically ventilated patients in the intensive care unit (ICU), it has been shown that adoption of a strategy of limited V_T in all patients (<10 mL/kg IBW) resulted in a lower incidence of ARDS and higher survival [3]. Experts who reviewed this subject recommended a V_T less than 10 mL/kg and a PEEP of 5 cm H_2O for patients with healthy lungs [4]. In critically ill patients, the adoption of lung-protective ventilation strategies has been gradual, but Checkley et al [5] reported a significant reduction in V_T after publication of the ARDS Network trial in those hospitals that participated in the study.

It is not known whether the practice of lung-protective ventilation now commonly recommended in critically ill patients has been adopted during anesthesia. The primary aim of this observational study was to determine the evolution of lung-protective ventilation strategies during anesthesia in a large academic medical center. The secondary aim was to identify factors associated with the selection of a ventilation strategy considered not to be lung protective.

2. Methods

This study was conducted at the Massachusetts General Hospital in Boston, Mass. At the Massachusetts General Hospital, there are more than 50 operating rooms, 120 staff anesthesiologists, 70 anesthesia residents, and 40 certified registered nurse anesthetists. Some anesthesiologists are also board-certified intensivists and provide critical care coverage for the surgical ICU. In our operating rooms, all patients are supervised by an attending anesthesiologist, or the attending anesthesiologist delivers the anesthetic. The study was approved by the institutional review board of the Massachusetts General Hospital.

The anesthesia record is captured electronically by the Anesthesia Information Management System (AIMS). For this study, we extracted information from the AIMS database from March 1, 2006, to March 31, 2011. We restricted the population to those patients who underwent intubation de novo in the operating room at Massachusetts General Hospital and who were older than 18 years; this effectively eliminated patients with existing ARDS. Patients were excluded from analysis if data were missing for American Society of Anesthesiologists (ASA) classification, PEEP, peak inspiratory pressure (PIP), V_T, or height.

From the AIMS database, we collected intraoperative values for V_T, PEEP, PIP, ASA classification, height, weight, age, and sex. The ASA physical status classification system of the ASA assesses the fitness of patients before surgery. It ranges from a score of 1 for a normal healthy patient to 5 for a patient not expected to survive without the operation (6 is for a brain-dead patients whose organs are being removed for donor purposes). If the surgery is an emergency, the ASA classification is followed by "E."

Average PEEP for each case included all values (including zero values) starting at 15 minutes after induction of anesthesia until 15 minutes before emergence from anesthesia. Only PIP values greater than 3 cm H_2O occurring between 15 minutes postinduction and 15 minutes before emergence from anesthesia were used in calculating the average PIP. Similarly, V_T values were calculated using only values between 200 and 1500 mL inclusive, recorded 15 minutes postinduction up to 15 minutes before emergence from anesthesia. Although we did not determine the mode of ventilation in this study, most commonly volume-controlled ventilation is used in intubated patients during anesthesia in our hospital. Admission and discharge information was collected from the hospital's billing database.

Ideal body weight was calculated according to the following formulae:

$$\text{Male}: \text{IBW(kg)} = 50 + 2.3(\text{height [in.]}–60)$$

$$\text{Female}: \text{IBW(kg)} = 45.5 + 2.3(\text{height [in.]}–60)$$

We considered a V_T greater than 10 mL/kg IBW and/or PEEP less than 5 cm H_2O as *not* lung protective [4,6]. We evaluated the use of lung-protective ventilation strategies between the following groups: time (years 1-5 of the study), male and female patients, ASA class, and the need for emergent surgery.

Summary data are provided as median and interquartile range (IQR). For univariate analysis, we used the nonparametric Kruskal-Wallis test for comparison of median values between groups and the χ^2 test for evaluating the association between categorical variables, as appropriate. For multivariate analysis, we performed logistic regression analyses with a V_T greater than 10 mL/kg, PEEP less than 5 cm H_2O, PEEP of 0 cm H_2O, and nonprotective ventilation (V_T > 10 mL/kg IBW and a PEEP < 5 cm H_2O) as the dependent variables and age, sex, year, ASA class, and need for emergent surgery as the independent variables. Year was entered as a categorical variable, with 2010 as the reference year. All statistical analyses were performed using PASW Statistics 18.0 (IBM SPSS, Armonk, NY). $P < .05$ was considered significant.

3. Results

The study included 45 575 adult patients who received general anesthesia with an endotracheal tube during the time of the study. Summary data are provided in Table 1. The