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Pressure Characteristics of Mechanical Ventilation and Incidence of Pneumothorax Before and After the Implementation of Protective Lung Strategies in the Management of Pediatric Patients With Severe ARDS*

Michael P. Miller, MD, FCCP; and Mayer Sagy, MD, FCCP

Objective: **To compare pressure characteristics of mechanical ventilation and their impact on pediatric patients with severe ARDS in the pre-protective lung strategy (PLS) and post-PLS eras.**
Methods: **Medical records of 33 patients admitted to our pediatric ICU with ARDS from 1992 through 1994 (pre-PLS) and 52 patients with ARDS admitted from 2000 through 2003 (post-PLS) were retrospectively reviewed.**
Results: **Patient age and gender distribution were identical in both eras. Fifty-five percent of the patients in the pre-PLS era had pneumothorax, compared to 17% in the post-PLS era ($p < 0.05$). Overall mortality rates for patients in the pre-PLS and post-PLS eras were 42% and 25%, respectively ($p = 0.09$; not significant). Mean duration of exposure to peak inspiratory pressure (PIP) values > 40 cm H_2O was significantly longer in the pre-PLS era than in the post-PLS era. Pre-PLS patients with pneumothorax received mean maximum PIP of 72 ± 17 cm H_2O, mean maximum positive end-expiratory pressure (PEEP) of 20 ± 5 cm H_2O, and maximum mean airway pressure (MAP) of 46 ± 8 cm H_2O, while patients in the post-PLS era required mean maximum PIP of 42 ± 2 cm H_2O, mean maximum PEEP of 14 ± 2 cm H_2O, and maximum MAP of 30 ± 6 cm H_2O, respectively ($p < 0.05$ for all pressure parameters). There were no significant differences in mechanical ventilation pressure characteristics among patients who did not have pneumothorax during their course of management in both eras.**
Conclusions: **A significantly more aggressive use of ventilator pressure characteristics distinguished the pre-PLS era from the post-PLS era, and was found to be associated with a markedly higher incidence of pneumothorax. Outcome in both eras did not differ significantly, presumably due to insufficient statistical power.** ***(CHEST 2008; 134:969–973)***

Key words: ARDS; lung protective strategy; outcome, pediatric patients; pneumothorax; tube thoracostomy

Abbreviations: ARDSNet = National Institutes of Health ARDS Network; FIO_2 = fraction of inspired oxygen; HFOV = high-frequency oscillatory ventilation; MAP = mean airway pressure; NS = not significant; PEEP = positive end-expiratory pressure; PICU = pediatric ICU; PIP = peak inspiratory pressure; PLS = protective lung strategy/strategies; Pplat = plateau pressure

ARDS, as defined in 1994, is a disease characterized by hypoxemia and bilateral pulmonary infiltrates in the absence of left atrial hypertension.[1] The approach to mechanical ventilation of patients with ARDS prior to the institution of protective lung strategies (PLS) ensured adequate oxygenation with normal or close-to-normal $PaCO_2$ and pH. This approach resulted in a more liberal delivery of tidal volumes and positive end-expiratory pressure (PEEP), giving rise to higher peak inspiratory pressure (PIP) and mean airway pressure (MAP) within the diseased lung. Elevated transalveolar pressure has been implicated in the pathogenesis of ventilation-induced lung injury by causing a disruption of the alveolar membrane, activation of an inflammatory cascade, and barotrauma.[2–8] The current era of mechanical ventilation is remarkable for a PLS that aims at preventing ventilation-induced lung injury. This strategy advocates delivering adequate levels of PEEP to recruit lung parenchyma and limiting tidal volumes and/or PIP levels.[9–15] Hypercapnia with lower pH values than normal is permitted in this strategy, and the administration of a buffer is occasionally required to alleviate pronounced acidemia.[10,11,14,16]

The large ARDS Network (ARDSnet) study[11] demonstrated that lower tidal volumes of 6 mL/kg with low plateau pressure (Pplat) levels that do not exceed 30 cm H_2O were associated with a better outcome than were higher tidal volumes of 12 mL/kg with higher limits for Pplat ($\leq$ 50 cm H_2O). This beneficial effect of PLS has been corroborated by other studies[13,17] as well. However, the damaging effect of any tidal volume on lung parenchyma should also be linked to lung compliance. Since the mechanical properties of the lungs in ARDS could be homogeneous as well as heterogeneous, the effect of tidal volume of any size may be unpredictable because areas of overinflation may exist alongside areas of collapsed lung.[12,13] Studies[10,12,18–20] involving the use of a larger range of tidal volumes for ARDS patients failed to demonstrate any correlation with outcome. This raises the possibility that perhaps the pressure characteristics of mechanical ventilation that emanate from various ventilator settings play a significant role in the damage caused to the lungs and the ultimate outcome.

Our study compared pressure characteristics of mechanical ventilation in pediatric patients with severe ARDS in the era prior to PLS implementation with the current era of PLS in our Division of Pediatric Critical Care. We hypothesized that patients with severe ARDS in the previous era were exposed to much higher levels of PIP, PEEP, and MAP, and for longer periods than they were in the post-PLS era, irrespective of whether they received volume or pressure ventilation. We also hypothesized that the incidence of pneumothorax was significantly higher in the pre-PLS era, and that it was closely related to the pressure characteristics that these patients were exposed to.

*From the Division of Pediatric Critical Care Medicine, North Shore-Long Island Jewish Health System, Schneider Children's Hospital, New Hyde Park, NY.

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Correspondence to: Michael P. Miller, MD, FCCP, Division of Pediatric Critical Care Medicine, North Shore-Long Island Jewish Health System, Schneider Children's Hospital, New Hyde Park, NY 11040; e-mail: mmiller@nshs.edu

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Materials and Methods

The study met the criteria outlined in 45 CFR 46.110 and 21 CFR 56.110 for expedited review and was approved by the institutional review board of the hospital system. The medical records of ARDS patients admitted to our pediatric ICU (PICU) during the years 1992 through 1994 (pre-PLS) and those admitted during years 2000 through 2003 (post-PLS) were retrospectively reviewed. We included in the study all patients who had bilateral pulmonary infiltrates on chest radiograph without clinical evidence of cardiac failure. All of the patients required, at least at one point during their course of illness, mechanical ventilation with a minimum PEEP $\geq$ 8 cm H_2O to achieve adequate oxygenation (oxyhemoglobin saturation $\geq$ 90%) on nontoxic concentrations of supplemental oxygen (fraction of inspired oxygen [FIO_2] $\leq$ 0.60). All patients were also required to have a $PaO_2/FIO_2 < 200$ during their course in the PICU. Patients who received extracorporeal membrane oxygenation, patients with chronic lung diseases (cystic fibrosis or bronchopulmonary dysplasia), patients with an artificial airway (tracheostomy), and patients who had chest tubes inserted for pneumothorax or pleural effusions prior to the development of ARDS were excluded from the study. For patients who received high-frequency oscillatory ventilation (HFOV) in both eras, the pressure characteristics of mechanical ventilation were evaluated prior to HFOV and thereafter.

We compared the number of ARDS patients with pneumothorax and who required chest tube insertion in the two eras. We also compared maximum PIP, maximum PEEP, and maximum MAP used for patients in the two eras. We calculated the mean duration (hours) of exposure to PIP values > 40 cm H_2O in ARDS patients in the two eras. The number of patients who received HFOV in both eras was also compared. Patient outcome was evaluated by comparing the incidence of pneumothorax and mortality rates for patients in the two eras.

For nonparametric variables, such as mortality and incidence of pneumothorax and number of times HFOV was used, we used the χ^2 test to determine statistical significance among the data in the two eras. The unpaired *t* test was used to compare continuous data such as the age of patients treated in the two eras. We rejected the null hypothesis at $p < 0.05$.

Results

Thirty-three patients were enrolled in the study for the pre-PLS era and 52 patients for the post-PLS era. The distribution of age and gender was identical for both eras (Table 1). Fifty-five percent of patients (n = 18) enrolled in the pre-PLS era required chest tubes for pneumothorax, compared to 17% of patients (n = 9) in the post-PLS era ($p < 0.05$). Patients who had pneumothorax and patients who did not have pneumothorax during the pre-PLS era had similar mean lowest PaO_2/FIO_2 values as patients in the post-PLS era (Table 1). In contrast, patients who did not have pneumothorax had significantly higher mean lowest PaO_2/FIO_2 values compared to patients who did have pneumothorax; these values were 106 ± 36 vs 47 ± 13 and 86 ± 35 vs 63 ± 31 in both eras, respectively ($p < 0.05$). Overall mortality rates for pre-PLS and post-PLS eras were 42% and 25%, respectively ($p = 0.09$; not significant [NS]). Patients