Short-Term Effects of the Prone Positioning Maneuver on Lung and Chest Wall Mechanics in Patients with Acute Respiratory Distress Syndrome

To the Editor:

Little is known about changes in respiratory mechanics during the procedure of prone positioning in patients with acute respiratory distress syndrome (ARDS). This information is important to interpret changes in airway pressure that may occur in the lateral and prone positions during volume-controlled ventilation. Indeed, some changes may result from alterations in the chest wall elastance. We undertook the present study to assess lung and chest wall mechanics in a consecutive series of patients with ARDS during the procedure of prone positioning.

Methods

The study was approved by the local ethics committee (2014-AO-1714-43). Forty-one patients (26 men and 15 women, 66 ± 12 yr old) with moderate to severe ARDS (1), intubated and mechanically ventilated with volume-controlled ventilation, sedated, and paralyzed, were included once a clinician indicated prone positioning ($Pa_{O_2}/FI_{O_2} < 150$ mm Hg under positive end-expiratory pressure [PEEP] $\geq$ 5 cm H_2O) and after informed consent was obtained from the next of kin. The mean ± SD tidal volume was 6 ± 0.6 ml/kg ideal body weight, PEEP 11 ± 3 cm H_2O, inspiratory flow 1 ± 0 L/s (constant shape), and FI_{O_2} 73 ± 15%. Airway pressure (Paw) was measured proximal to the endotracheal tube, and airflow was measured with a Fleish II pneumotachograph inserted between the Paw port and Y-piece. Esophageal pressure (Pes) was measured with the use of an air-filled catheter (Nutrivent). Ventilator settings, except for FI_{O_2}, were kept unaltered during the whole study. In our ICU, the prone positioning procedure is performed routinely by three caregivers, with one staying at the patient's head to secure the endotracheal tube and avoid any kinking. Furthermore, the trachea is systematically suctioned before the procedure without disconnecting the patient. Pressure and flow signals were continuously recorded on a data logger (Biopac 150; Biopac Inc.) in the 0° supine position for 5–10 minutes, then in the transient 3-minute 90° lateral position (23 patients with left lateral), and then during the first 5–10 minutes in the 0° prone position. The patients remained prone in a 0–15° angulation for the next consecutive 16 hours. The reverse maneuver, from 0° prone to 0° supine via the same previous 90° lateral position, was also subjected to the same recordings.

Transpulmonary pressure was obtained by subtracting Pes from Paw. Lung resistance (R_L) and lung (E_L) and chest wall (Ecw) elastance were computed by fitting measurements with a resistance-elastance linear model. This procedure was done breath by breath using the classical least-square regression method (Figure 1). The data were analyzed by using linear mixed model to take into account the fact that serial measurements were obtained in the same patients. We investigated the effects of

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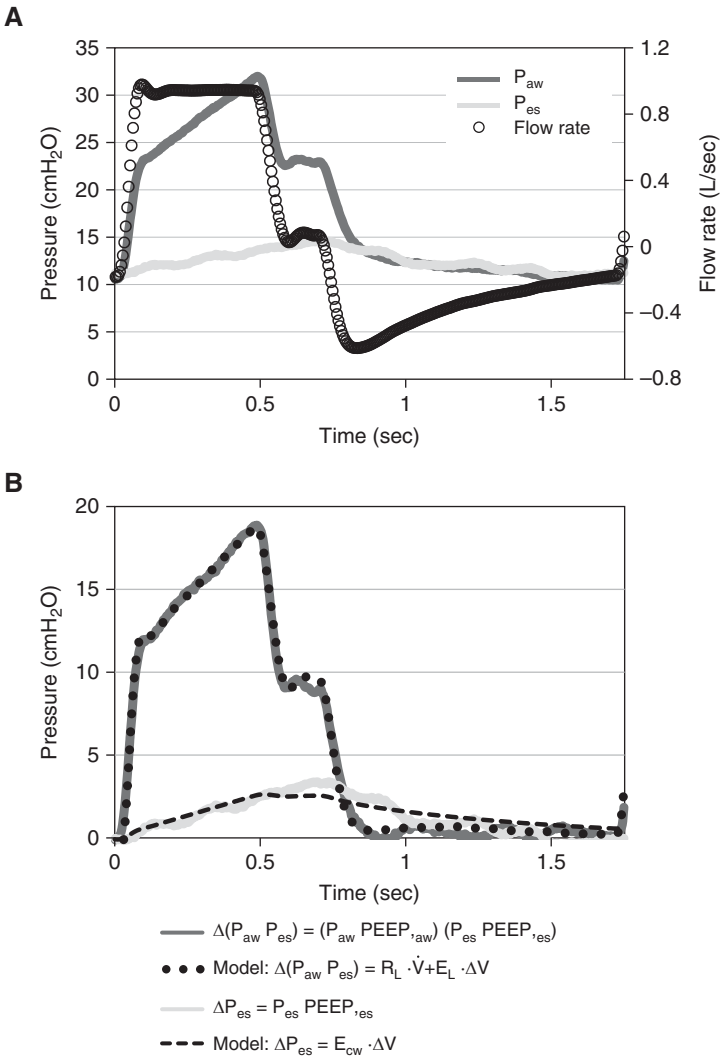

Figure 1. (*A*) Tracings superimposed over time of airway pressure (Paw, dark gray line), esophageal pressure (Pes, light gray line), and flow rate (open circles) during a single breath of mechanical ventilation in volume-controlled mode at constant-flow inflation. (*B*) Transpulmonary pressure (Paw−Pes) (dark gray line) and Pes (light gray line) above positive end-expiratory pressure (PEEP) for which the following models were tested (dotted and dashed dark lines, respectively): $\Delta(\text{Paw}-\text{Pes}) = R_L \times \text{Flow} + E_L \times \Delta V$, and $\Delta\text{Pes} = \text{Ecw} \times \Delta V$, where R_L is lung flow resistance, E_L is lung elastance, Ecw is chest wall elastance, and ΔV is tidal volume.

lateral and prone positions, first when turning the patient prone, and then when putting the patient back from prone to supine. The model included as fixed effects the position, the two sequences (turning the patient prone and back to supine) and the interaction between them, and the position by patient as a random effect. For each position, the mean value was compared with the mean of the corresponding reference.

Results

R_L and Ecw significantly increased in the lateral and prone positions from supine. E_L markedly increased in the lateral position, but did not differ between the prone and supine positions (Table 1). During the reverse procedure to put the patient back to supine, lateral positioning was associated with a significant decrease in E_L and no change in either R_L or Ecw, whereas supine repositioning was associated with a significant decrease in E_L and Ecw, and no change in R_L (Table 1). The corresponding raw values of Paw and absolute Pes used to determine respiratory mechanics are shown in Table 1.

Discussion

In this study, we primarily intended to describe how much respiratory mechanics changed during the procedure of prone positioning and in particular at the time of immediate installation in the prone position and back to supine when measurements were performed at a 0° inclination. We found that Ecw increased in the prone position, as previously observed (2–4). According to Pelosi and colleagues (2), an increase in Ecw triggers the redistribution of ventilation and improves oxygenation in the prone position. This effect would result from the limited expansion of the sternum, because in

Table 1. Respiratory, Lung, and Chest Wall Predicted Values Obtained from the Mixed Model during the Procedure of Turning the Patient to the Prone Position and Back to the Supine Position in 41 Patients with Acute Respiratory Distress Syndrome

	Supine (Reference)	Lateral	Prone	Prone (Reference)	Lateral	Supine
R_L, cm H_2O/L/s	14 (13 to 15)	16 (14 to 17)*	15 (14 to 16)*	15 (14 to 17)	16 (15 to 17)	14 (13 to 15)
E_L, cm H_2O/L	32 (28 to 37)	35 (30 to 40)*	32 (28 to 37)	33 (27 to 38)	35 (30 to 41)*	32 (26 to 37)*
Ecw, cm H_2O/L	10 (9 to 11)	12 (11 to 14)*	11 (10 to 13)*	11 (9 to 13)	12 (11 to 14)	9 (7 to 11)*
Maximal Paw, cm H_2O	35 (34 to 37)	38 (37 to 40)*	37 (35 to 39)*	37 (35 to 39)	39 (37 to 40)*	36 (34 to 37)
Plateau Paw, cm H_2O	24 (22 to 25)	26 (24 to 27)*	25 (24 to 27)*	25 (24 to 27)	26 (25 to 27)*	24 (22 to 25)*
PEEP,aw, cm H_2O	11 (10 to 12)	11 (10 to 12)	11 (10 to 12)*	11 (10 to 12)	11 (10 to 11)	11 (10 to 12)
Driving pressure of the respiratory system, cm H_2O	14 (12 to 15)	15 (14 to 17)*	14 (13 to 16)*	14 (13 to 16)	15 (14 to 17)*	13 (12 to 14)*
Maximal Pes, cm H_2O	15 (13 to 16)	14 (12 to 15)	14 (12 to 15)	14 (12 to 15)	14 (13 to 15)	14 (12 to 16)
Plateau Pes, cm H_2O	14 (13 to 15)	13 (12 to 15)	13 (12 to 15)	13 (12 to 15)	13 (12 to 15)	14 (12 to 16)
PEEP,es, cm H_2O	11 (10 to 12)	9 (8 to 10)*	9 (8 to 11)*	9 (8 to 11)	9 (8 to 10)*	11 (10 to 12)
Driving pressure of the chest wall, cm H_2O	3 (3 to 4)	5 (4 to 6)*	5 (4 to 5)*	4 (3 to 4)	4 (4 to 5)*	3 (2 to 4)*
Maximal transpulmonary pressure, cm H_2O	21 (19 to 23)	25 (23 to 27)*	23 (21 to 26)*	23 (21 to 25)	24 (23 to 26)*	21 (19 to 23)
Transpulmonary plateau pressure, cm H_2O	10 (9 to 11)	13 (11 to 14)*	12 (10 to 14)*	12 (11 to 14)	13 (11 to 14)*	10 (8 to 11)*
Transpulmonary PEEP, cm H_2O	0 (−1 to +1)	2 (0 to 3)*	2 (0 to 3)*	2 (1 to 3)	1 (0 to 2)*	−1 (−1 to +1)
Transpulmonary driving pressure, cm H_2O	11 (9 to 12)	11 (10 to 13)*	10 (9 to 12)	10 (9 to 12)	11 (10 to 13)*	10 (9 to 12)*

Definition of abbreviations: Ecw = chest wall elastance; E_L = lung elastance; Paw = airway pressure; Pes = esophageal pressure; PEEP = positive end-expiratory pressure; PEEP,aw = set PEEP at the ventilator; PEEP,es = PEEP at Pes; R_L = lung flow resistance.
Values are mean (95% confidence interval).
*$P < 0.05$ when comparing the mean value of the position with the mean value of the reference position in the sequence.

the prone position the lung operates between two rigid bars. This could be a mechanism whereby the distribution of tidal volume becomes more homogeneous, making the resulting overall lung stress (transpulmonary pressure) better distributed in the prone position. In this way, the prone position may contribute to lung protection. Regional pleural pressure and stress raisers (5), which in inhomogeneous lung parenchyma convert what is a safe level of transpulmonary pressure for a homogeneous lung into a locally injurious stress, play an important role in the distribution of lung stress. These factors were not assessed in the present study. We made the novel observation that the effect of the prone position on Ecw was immediate and did not vary over time during prone sessions as long as 16 hours. In our present cohort of patients with ARDS, the same E_L and higher Ecw in the prone position as compared with the supine would obviously result in a higher plateau pressure of the respiratory system, without any increase in the degree of alveolar stress. Actually, we found that the transpulmonary plateau pressure increased in the prone position, when a decrease would rather be expected. This raises a question as to the predominantly protective role of the increase in Ecw. It should be mentioned that the increase was very small and at any rate below the upper safety limit suggested by theoretical considerations (5). Our study showed that not only Ecw but also R_L increased in the prone position in patients with ARDS, a finding that has not been previously described. As the inspiratory flow was set to 1 L/s, the 1.2 cm H_2O/L/s increase in R_L corresponds to a 1.2 cm H_2O resistive pressure increase, which could contribute to a higher peak Paw in volume-controlled mode. Even if it was statistically significant, the clinical importance of this increase is doubtful. This increase in R_L could be due to a reduction in airway diameters and loss of lung volume (6). However, in studies where end-expiratory lung volume was measured, in general, prone positioning was not associated with a decrease (2, 3). It could be that the prolonged lateral position period resulted in some loss of aeration of the dependent lung and this effect carried over to the prone position, resulting in a possible loss of lung volume. Going back to supine from the prone position essentially offset the effect of the previous supine–prone steps, except for R_L.

In the present study, we found that R_L, E_L, and Ecw increased significantly from the supine to the lateral position. Previous observations showed a reduction in compliance of the respiratory system after 30 minutes in the lateral position (7) or during continuous rotating mobilization (8). Our study extends those findings by showing that compliance of both the lung and chest wall was impaired. Furthermore, our findings suggest that the increase in E_L and R_L observed with patients installed in the prone position took place at this early step of changing position. It should be mentioned that no kinking or massive tracheal secretions were present in the endotracheal tube at the time respiratory mechanics was measured in the lateral position.

Our study is limited by the short observation period and the lack of measurements of lung volume and gas exchange. This was as planned, because our primary aim was to describe respiratory mechanics during the routine procedure of prone positioning. Measurements of end-expiratory lung volume take time and would have prolonged the duration of the procedure beyond that required for routine care.

Further studies should explore the mechanism of these changes and in particular their relationship to end-expiratory lung volume.

In conclusion, during the prone positioning maneuver, R_L, Ecw, and E_L increased immediately in the lateral position.

R_L did not change further when patients were switched from the prone position back to supine. E_{cw} and E_L returned to baseline values when patients were returned to the supine position. ■

Author disclosures are available with the text of this letter at www.atsjournals.org.

Zakaria Riad, M.D.
Mehdi Mezidi, M.D.
Hospices Civils de Lyon
Lyon, France
and
Université de Lyon
Lyon, France

Fabien Subtil, Ph.D.
Hospices Civils de Lyon
Lyon, France
Université de Lyon
Lyon, France
and
Laboratoire de Biométrie et Biologie Evolutive UMR 5558
Villeurbanne, France

Bruno Louis, Ph.D.
INSERM U955
Créteil, France

Claude Guérin, M.D., Ph.D.
Hospices Civils de Lyon
Lyon, France
Université de Lyon
Lyon, France
and
INSERM U955
Créteil, France

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Inhaled Diesel Exhaust Decreases the Antimicrobial Peptides α-Defensin and S100A7 in Human Bronchial Secretions

To the Editor:

Inhaled air pollution has deleterious effects on human health. It is a known risk factor for chronic inflammatory respiratory diseases, exacerbation of allergic diseases, and increased susceptibility to pulmonary infections (1, 2). Susceptibility to infections during chronic airway inflammation is associated with decreased expression of antimicrobial peptides (AMPs) in the lungs (3). AMPs play a critical role in the resolution of infections and innate immune responses in the lungs (4). A recent *in vitro* study showed that diesel exhaust (DE), a paradigm of traffic-related air pollution (TRAP), decreases the expression of certain AMPs in bronchial epithelial cells (5). Although DE alters allergen-induced inflammatory mediators (2, 6), the effect of coexposure of DE and allergen on AMP expression remains unknown. Therefore, in this study we examined the levels of AMPs secreted in BAL in response to inhaled DE, in the presence and absence of allergen challenge, using a controlled human exposure study.

Methods

We performed a double-blind, randomized, crossover controlled study involving human exposure to DE and allergen as we previously described (2, 6). This study was approved by the institutional ethics review boards of the University of British Columbia and Vancouver Coastal Health Research Institute, and participants were enrolled with informed consent. Atopic human participants first inhaled either filtered air (FA) or DE (300 $\mu g/m^3$ particulate matter less than or equal to 2.5 μm in aerodynamic diameter) for 2 hours, after which one lung segment was challenged with either saline or allergen in saline (5 ml), and BAL was obtained 48 hours after challenge. Concentrations of allergens (house dust mite [*Dermatophagoides pteronyssinus*], birch, or Pacific grasses) were participant-adjusted based on wheal to skin prick. This procedure was repeated after 4 weeks with the opposite inhalation and new segmental challenge for allergen, thus resulting in BAL obtained from each participant under four different exposure conditions: filtered air and saline (FAS), DE and saline (DES), filtered air and allergen (FAA), and DE and

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