Influence of positive end-expiratory pressure on regional ventilation assessed by Electrical Impedance Tomography on healthy lungs

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***Abstract*— Electrical impedance tomography is a promising tool to evaluate lung function of mechanically ventilated patients at bedside. The aim of this study was to assess the relationship between regional ventilation and positive end-expiratory pressure (PEEP) on healthy subjects undergoing laparoscopy surgery. On a PEEP titration maneuver, regional ventilation of 14 patients was analyzed at each PEEP step, during a low flow maneuver, comparing four lung areas equally segmented: left and right halves of dependent and non-dependent regions. The ventilatory participation of non-dependent region decreased during PEEP decrement while dependent regions increased its participation, presenting difference only on PEEP lower than 12 cmH_2O (p <0.001). Except at 14cmH_2O PEEP step, there were no significant differences between ventilation on left and right quadrants. In conclusion, the results suggest that PEEP significantly influences regional ventilation on healthy lungs under mechanical ventilation.**

***Keywords*—EIT, regional ventilation, PEEP titration.**

I. Introduction

Ventilation and aeration are not spatially homogeneous on the lung having a significant dependence on gravity [1] as well as the mechanical properties of the tissue [2, 3], which in turn is influenced by ventilatory parameters adopted during mechanical ventilation. These characteristics can be assessed by imaging techniques such as computed tomography, positron emission tomography, electrical impedance tomography (EIT) and lung ultrasound [4]. EIT showed to be a valuable tool to the dynamic assessment of lung function at the bedside, contributing to individualization of ventilation parameters by assessing regional ventilation, since changes in impedance and lung volume are linear and highly correlated [5].

Adequate ventilatory settings have major importance for patients under mechanical ventilation as it has potential to induce injury even on healthy patients [6, 7]. In view of that risk, protective ventilation prioritizes a better gas exchange, but also, reducing the risk for ventilator-induced lung injury (VILI), through low tidal volumes and the usage of adequate positive end-expiratory pressure (PEEP), as it could represents a different response of alveolar recruitment and overdistension for different lung areas [8, 9]. A major strategy to identify the ideal PEEP is its titration, a systematic parameter evaluation during ascending or descending PEEP changes.

Therefore, this work aims to evaluate the relationship between PEEP and regional ventilation assessed by electrical impedance tomography on healthy individuals under mechanical ventilation.

II. Methods

A. Patients

After approval by an ethics committee, this study was performed on 14 healthy adult patients undergoing elective laparoscopic abdominal surgery, in supine Trendelenburg position and mechanically ventilated using an EVITA-XL ventilator (Dräger Medical, Germany).

B. Ventilatory Protocol

Baseline ventilation was performed on volume-controlled mode with constant inspiratory flow, tidal volume of 8 ml/kg, respiratory rate of 12 ipm and inspiratory to expiratory time ratio of 1:2.

The protocol begins with a recruitment maneuver followed by a decremental PEEP titration ranging from 20 to 4 cm H2O, decreasing 2 cm H2O steps every 100 seconds, approximately (Figure 1A). At each PEEP step it was performed a low flow inflation and deflation maneuver of 4 L/min until reaching a peak volume of 12 mL/kg body weight (Figure 1B).

C. Data Acquisition

Ventilatory variables, such as gas flow, volume and airway opening pressure, were measured by the mechanical ventilator and recorded. Electrical impedance tomography (EIT) data were collected synchronously with ventilatory signals, using a Pulmovista tomograph (Dräger Medical,Germany), containing 32 electrodes placed around the thorax at the xiphoid process level . It generated 64 by 64 elements matrices of estimated lung impedances at a minimum sampling frequency of 20 Hz for all subjects.

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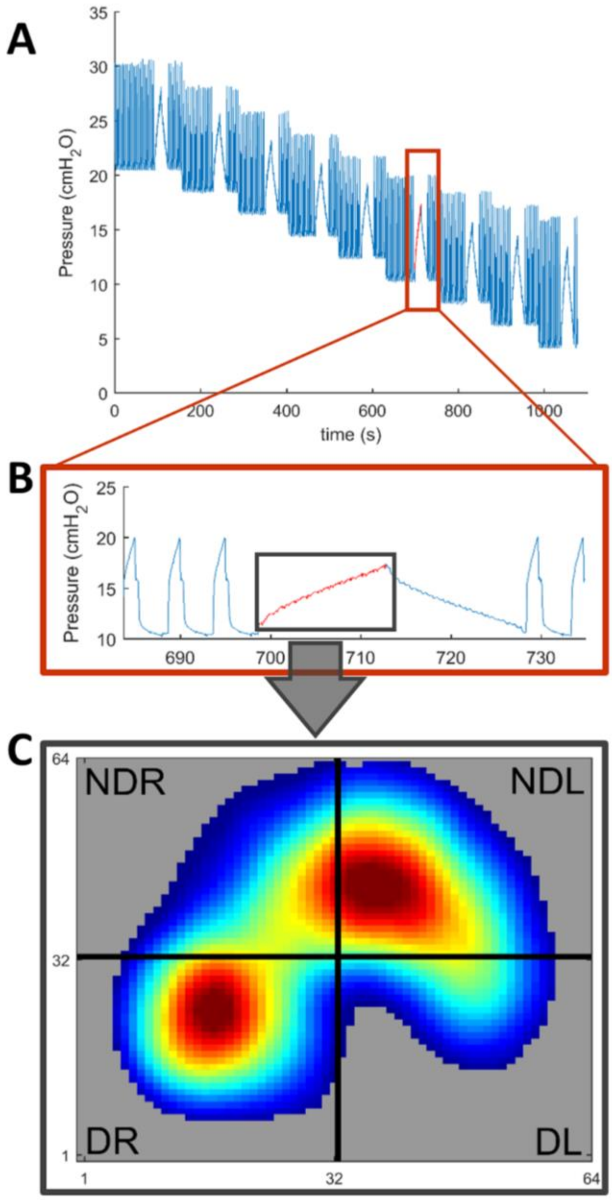

Fig. 1. Experimental protocol and image segmentation. A) Airway opening pressure of a representative patient showing the PEEP (positive end-expiratory pressure) titration with steps containing low-flow maneuvers and one of them highlighted by a red box, zoomed in B. B) Low-flow maneuver between tidal cycles with the inflation segment showed in red. The difference between impedance matrices estimated at the end and the start of the maneuver represented the regional ventilation. C) Map of changes in lung impedances, segmented in four equal size areas (32 by 32 elements) corresponding to the ventral (NDR - non-dependent right, NDL - non-dependent left) and dorsal regions (DR - dependent right, DL - dependent left). Elements with impedance change lower than 10% of the maximum change value were excluded (gray areas).

D. Data Processing

Considering the linear positive relationship between changes in lung impedance (ΔZ) and volume [5], regional ventilation was assessed from the difference between impedance values, for each matrix element, at the final and initial instants of the low flow inflation maneuver. The elements corresponding to lung tissue were functionally segmented in a region of interest (ROI) as those in which the tidal impedance change was at least 10% of the maximum change. ROI were calculated for each PEEP step and patient.

The ΔZ matrix was divided in 4 quadrants of equal size (32 by 32 elements), dependent (dorsal) and non-dependent (ventral), left and right, in order to evaluate the regional ventilatory mechanics (Figure 1C). The percentage of global ventilation correspondent to each quadrant (%ΔZq) was calculated as the sum of their ΔZ elements, divided by the sum of all ROI's elements, for each PEEP step. The regional ventilation trend during PEEP titration was assessed by the comparison of angular coefficients estimated from first-degree polynomial functions fitting %ΔZq versus PEEP for each subject, individually.

The spatial ventilatory variation coefficient, interquartile range divided by the median value, was calculated for every PEEP step of all ΔZ elements for each quadrant.

E. Statistical Analysis

Results were presented as median, first and third quartiles. Comparisons among quadrants were performed, for each PEEP step, by non-parametric ANOVA (Kruskal-Wallis test) with Bonferroni correction. The relationship between the interest variables (%ΔZq and variation coefficient) and PEEP was assessed by Pearson correlation coefficient of all subjects at once.

Data processing and statistics were performed on MATLAB 2017 (MathWorks Inc., USA) and Minitab 18 (Minitab Inc., USA).

III. RESULTS

Figure 2 shows the regional ventilation normalized by global ventilation - %ΔZq - for their respective PEEP steps, from all subjects. The comparison among quadrants did not revealed significative difference for this variable on PEEP steps from 20 to 16 cmH2O, while dependent and non-dependent regions were significantly different for PEEP below 12 cmH2O ($p < 0.001$), with the latter presenting higher ventilatory percentages. Left and right quadrants were not significantly different at most PEEP steps, considering dependent and non-dependent regions separately. The exception was 14 cmH2O PEEP step, where non-dependent left was significantly lower than its right counterpart and all other quadrants ($p< 0.01$).

There was a significative difference between the ventilatory trends of regions facing decremental PEEP change, as evidenced by Pearson correlation coefficient: 0.72, 0.47, -0.51 and -0.61, for dependent left and right and non-dependent left and right, respectively ($p<0.001$). As the former decreases the percentage of ventilation during the PEEP titration, the latter became more ventilated, without significant difference between right and left lung ($p < 0.01$). The same pattern was observed the %ΔZq/PEEP slope: 1.25 [0.71 1.65], 1.02 [0.85 1.21], -0.71 [-0.99 -0.48] and -1.13 [-1.66 -0.90] %/cmH2O for dependent left and right and non-dependent left and right, respectively ($p<0.01$).

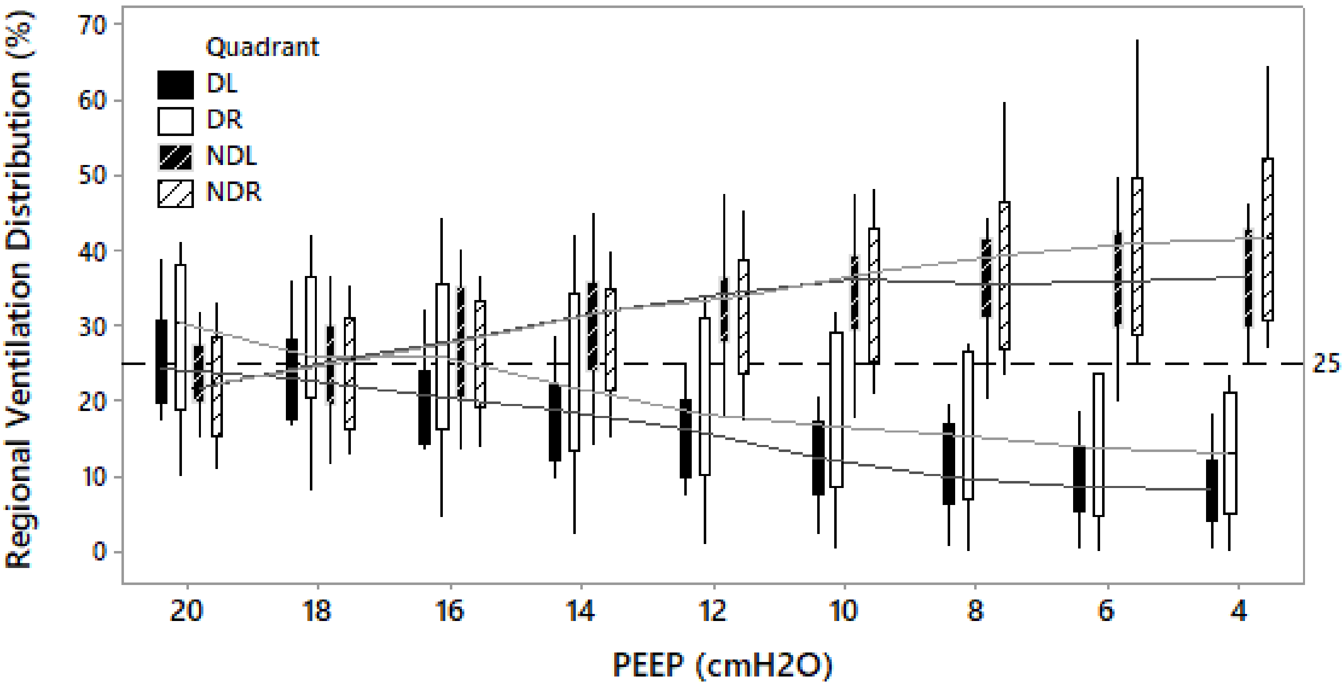

Fig. 2. Regional Ventilation Distribution per quadrant: percentage of the whole lung ventilation estimated for each quadrant - dependent left (DL), dependent right (DR), non-dependent left (NDL) and non-dependent right (NDR). As positive end-expiratory pressure (PEEP) decreases, it was observed an also decreased ventilatory participation of dependent quadrants and increase on non-dependent regions. This difference was statistically significative for PEEP lower than 12 cmH_2O.

Variation coefficient analysis showed difference among quadrants only for PEEP bellow 8 cmH2O, for which the left dependent region was significantly different from non-dependent regions ($p<0.05$) (Figure 3). Pearson correlation was significant only for the dependent quadrants ($\rho = 0.52$ and 0.40 for left and right, respectively).

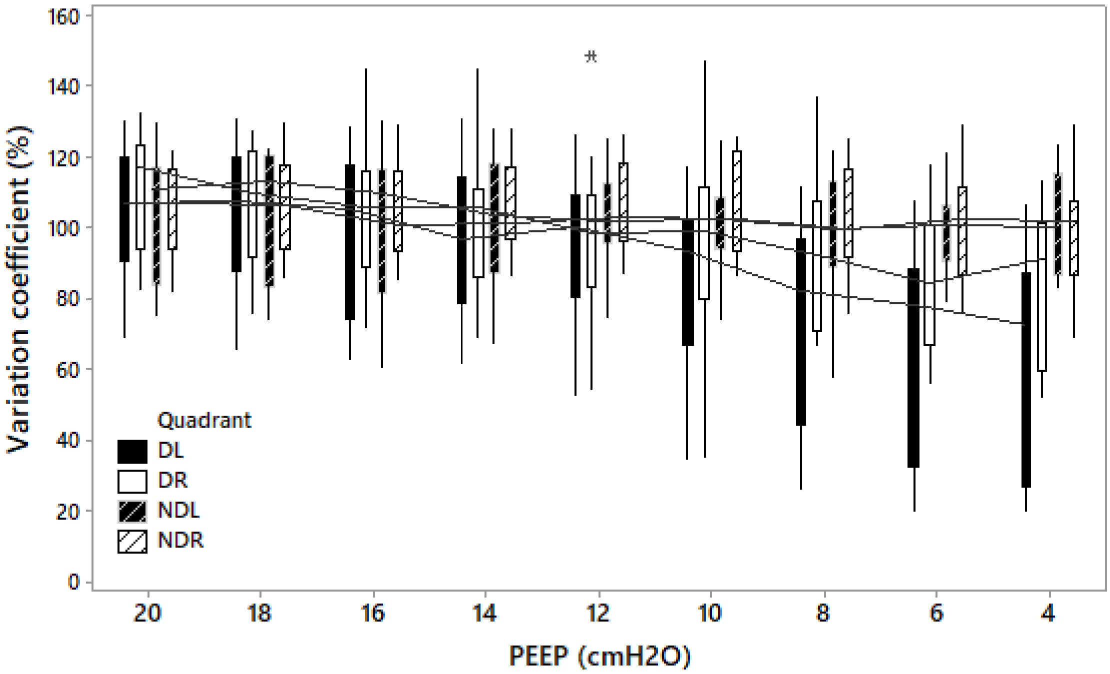

Fig. 3. Ventilatory variation coefficient per quadrant: spatial ventilation variability estimated for each quadrant - dependent left (DL), dependent right (DR), non-dependent left (NDL) and non-dependent right (NDR). Difference among quadrants was statistically significative only for PEEP below 8 cmH2O, with dependent left quadrant presenting lower values. Correlation between ventilation coefficient and PEEP was found only at dependent regions ($p < 0.001$).

IV. Discussion

The results showed that the lung regional ventilatory profile was significantly influenced by PEEP, presenting a more homogeneous participation on higher levels and a trend toward higher ventilatory participation of non-dependent regions as PEEP decreases.

These findings are in accordance with previous reports on the subject [10–15]. Blankman *et al.*, suggested that regional ventilation distribution could be modified by different levels of PEEP due to causes such as the tendency of the dependent region to collapse on low PEEP due to gravitational force [11] and to increase ventilation in high PEEP as a result of intratidal gas redistribution [10, 12]. On a non-dependent region, PEEP higher than 16cmH2O reduces the ventilation, probably due to overdistention.

In addition, our data did not show a significant difference between left and right areas for most PEEP steps, besides the 14 cmH2O. It is known that the right lung is slightly larger than the left one [16]. It may have influence on ventilation at the right side of the lung, also pointed by, due to the fact that in high PEEP the left side of the dependent region gains volume quickly than the right side [15], so the ventilation turns to be lower than the right side. This may explain why the DL region was different from DR on 14cmH2O PEEP and the only dependent quadrant with variation coefficient significantly different from the non-dependents at lower PEEP.

Despite EIT has been validated for regional ventilation assessment of large areas, by comparison to high resolution lung image techniques [5], its spatial resolution could be low enough to potentially result in bias at analysis that rely on correctly measuring small areas, as organ segmentation and spatial variability assessments. Another limitation of this study was the ventilation profile in which the signals were acquired. Although low flow was necessary to minimize pressure spatial heterogeneity on the lung, conventional ventilation requires higher flow rate. Considering the known significance of dynamic conditions on lung mechanics [17], this could limit the extrapolation of our findings to usual mechanical ventilation.

V. Conclusion

The lung regional ventilation, assessed by EIT, was significantly influenced by PEEP, with no significant difference among quadrants on high levels and a trend toward higher ventilatory participation of non-dependent regions as PEEP decreases.

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