Summarization of the article

Takeshi Yoshida, Thomas Piraino, Christiano A.S. Lima, Brian P. Kavanagh, Marcelo B.P. Amato, Laurent Brochard. "Regional Ventilation Displayed by Electrical Impedance Tomography as an Incentive to Decrease PEEP." AJRCCM Articles in Press (2019).

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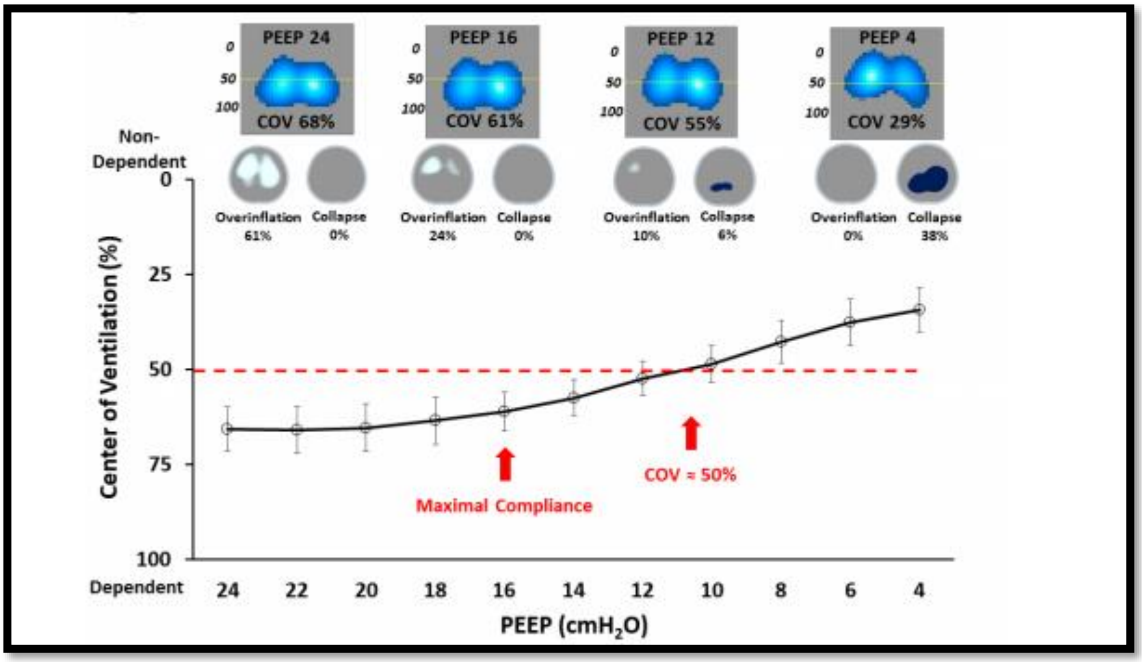

Representative EIT images illustrating COV and concomitant distribution of overinflation and collapse. Higher PEEP levels shifted COV to dependent lung because of non-dependent overinflation. Decreasing PEEP to 12 cmH2O achieved homogeneous ventilation, and this was associated with less hyperinflation. Further decreases in PEEP shifted COV to nondependent lung due to dependent lung collapse. The dotted red line indicates COV = 50%. Note: at PEEP 16 cmH2O, Crs is maximum, but the COV remains in dependent lung due to (non-dependent) overinflation.

Introduction

In the acute respiratory distress syndrome (ARDS), the aerated and non-dependent 'ventral' lung is the most susceptible to ventilator-induced lung injury [1-6].

A priority for clinicians should be to avoid unnecessarily high PEEP and to find a balance between its positive (i.e., decreased dependent atelectasis) and negative (i.e., non-dependent overinflation) effects.

We describe a new, intuitive, approach for avoiding excessive PEEP by using electrical impedance tomography (EIT); we report data from an experimental model and from three patients ventilated for ARDS since several days in which EIT 'visually' alerted the clinicians about this risk.

Methods and Material

Laboratory Study: We analyzed the data of six landrace pigs (37-44 kg) from a previous study: acute lung injury was induced by repeated surfactant depletion (10) and volume assist control ventilation was delivered (VT 5 mL·kg-1). Using EIT (Enlight1800®, Timpel SA, São Paulo, Brazil), we calculated the Center of Ventilation (COV), across PEEP levels decreasing from 24 to 4 cmH2O following lung recruitment.

The amount of lung overinflation and collapse was estimated by the proportion of pixel units in which compliance changed before/after passing the best levels of compliance over PEEP levels from 24 to 4 cmH2O (12).

Patients: Inclusion of patients' clinical data was approved by the research ethics board.

Patient 1: 60-year old male, with sepsis-induced ARDS (PaO2/FiO2 77 mmHg) on day 15 of ICU stay and mechanical ventilation. Patient 2: 50-year old male, with trauma induced ARDS (PaO2/FiO2 111 mmHg) on day 7. Patient 3: 74-year old female with ARDS following resection of ischemic small bowel (PaO2/FiO2 108 mmHg) on day 6. Ventilation was delivered in volume assist control (VT of 6 mL·kg-1 predicted body weight, PBW) at PEEP 9 cmH2O (Patient 1); pressure support 8 cmH2O (≈VT of 8 mL·kg1 PBW) and PEEP 14 cmH2O (Patient 2); and pressure assist control 20 cmH2O (≈VT of 6 mL·kg-1) and PEEP 14 cmH2O (Patient 3). PEEP was set clinically according to severity and physiological response (oxygenation, hemodynamic tolerance) (13). EIT (PulmoVista 500®; Dräger, Lübeck, Germany) was used at the bedside and COV calculated.

Results

- **Experimental Data:** The minimum level of PEEP required to maintain an 'open' lung (i.e. <1% atelectasis) and achieve the maximal Crs was 16cmH2O. Decreasing PEEP from 24 to 12 cmH2O resulted in the distribution of ventilation changing from predominantly dependent ('dorsal') to the midpoint of the lung due to less overinflation; below 12 cmH2O ventilation became predominant in non-dependent ('ventral') lung due to more lung collapse (Figure 1).

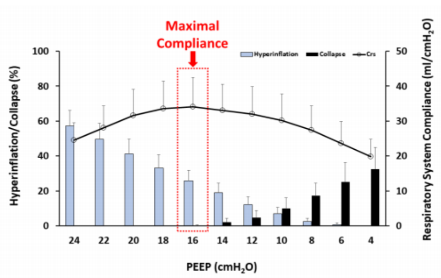

Figure 1 - Distribution of Lung Aeration and Respiratory Compliance in Experimental Injury

- **Patient 1:** On Day 1, PEEP was 9 cmH2O, and EIT showed major dependent atelectasis with COV of 19% (Figure 2A). PEEP was increased to 16 cmH2O, resulting in better oxygenation and more homogeneous of ventilation (COV 44%) (Figure 2B). On Day 2 PEEP was unchanged but a negative fluid balance was achieved; EIT indicated that ventilation occurred now predominantly in the dependent regions (COV 62%), suggesting the overinflation of 'ventral' lung (Figure 2C). PEEP was decreased to 10 cmH2O, which increased homogeneity of ventilation (COV 52%); the Crs improved and oxygenation was unchanged (Figure 2D).

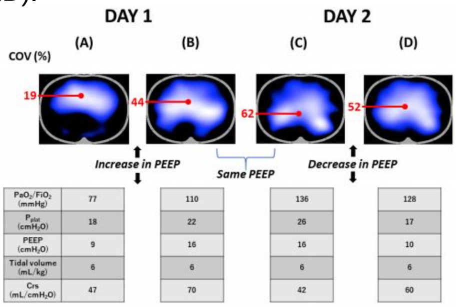

Figure 2 - EIT Images from a Patient with ARDS: (A) Low PEEP before Lung Recruitment; (B) High PEEP after Lung Recruitment; (C) One day later with the same high PEEP; and, (D) after decreasing PEEP.

- **Patient 2:** On Day 1, despite PEEP of 14 cmH2O, severe dependent atelectasis was present (COV 38%). PEEP was increased to 22 cmH2O: the ventilation became more homogeneous (COV 52%), and the PaO2/FiO2 and Crs increased (111 to 172 mmHg, 73 to 78 mL/cmH2O, respectively). On Day 2 a negative fluid balance was achieved: Page 5 of 13 AJRCCM Articles in Press. Published on 21-June-2019 as 10.1164/rccm.201904-0797LE Yoshida et al PaO2/FiO2 and Crs were largely unchanged but COV at 64% indicated predominance of dependent ventilation and 'ventral' overinflation. The PEEP was decreased to 16 cmH2O, and ventilation became more homogenous (COV 53%), increasing Crs (84 mL/cmH2O) without changing oxygenation.

- **Patient 3:** On Day 1, COV was 37% at PEEP 14 cmH2O due to dependent atelectasis. PEEP was increased to 20 cmH2O, and PaO2/FiO2 and Crs increased (108 to 209 mmHg, 21 to 26 mL/cmH2O, respectively) and distribution of ventilation became more homogeneous (COV 49%). On Day 2, PEEP was reduced to 18 cmH2O, reestablishing homogeneity of ventilation (COV 61% to 54%) and maintaining oxygenation (PaO2/FiO2 351 mmHg). Finally, on Day 3 after substantial fluid removal by dialysis (2.8 L) COV rose to 72% and Crs was unchanged (26 mL/cmH2O). PEEP was quickly reduced to 6 cmH2O and COV decreased to 61% (while Crs increased and PaO2/FiO2 remained stable).

Discussion

We describe a simple visual tool based on the ventral-to-dorsal distribution of ventilation to alert the clinician about potentially excessive PEEP. Our animal and patient data suggest that EIT (in conjunction with lung mechanics, e.g., Crs) may indicate excessive PEEP when a high COV (>50%) reflects predominantly dependent ventilation, indicating an overinflation of non-dependent 'ventral' lung.

When PEEP was titrated according to best Crs (9, 14), PEEP maintained an almost completely open lung experimentally (0.4±0.3% atelectasis at PEEP of 16 cmH2O; Figure 1), but this comes at the expense of overinflation; here, increased COV indicates ventilation shifted towards dependent 'dorsal' lung.

Our experimental data show that PEEP can markedly change the distribution of ventilation as visualized by EIT. If PEEP is insufficient and collapse remains high in dependent lung, then ventilation is predominantly non-dependent (COV 50%).

Our clinical observations are presented as a proof of concept. In the absence of regional ventilation information, there was no clear clinical indication to reduce the substantial levels of PEEP; indeed, PEEP could have even been increased aiming to improve oxygenation and as an attempt to increase Crs. COV in EIT seems a simple and rapid bedside guide to decrease PEEP. EIT in conjunction with lung mechanics can be used as visual tool at the bedside to detect a negative impact of PEEP.

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