Electrical Impedance Tomography to Titrate PEEP at Bedside in ARDS

PEEP titration in ARDS is still a challenge at the bedside, applied with varying techniques such as PEEP/F_{IO_2} table, lowest-distending pressure, best respiratory-system compliance during decremental PEEP trials, PEEP titration by the low inflection point of pressure-volume curve, PEEP titration by electrical impedance tomography (EIT), PEEP titration by computed tomography (CT), and PEEP titration by transpulmonary end-expiratory pressure. Different gas exchange and lung mechanics can be achieved during experimental and clinical studies, but the impact on hard, clinically meaningful outcomes remains to be determined.[1]

EIT is a promising, noninvasive, radiation-free, continuous bedside imaging technique that measures the distribution of tidal variations in air content inside the lungs during assist-controlled ventilation.[2] He and colleagues[3] analyzed 117 subjects with ARDS receiving mechanical ventilation randomly assigned to EIT ($n = 61$; PEEP adjusted based on ventilation distribution) or control group ($n = 56$; low PEEP/F_{IO_2} table). The primary outcome was 28-d mortality. They observed no statistically significant difference in the value of PEEP between the EIT versus the control group. There was no significant difference in mortality rate (21% vs 27%, EIT vs control, $P = .63$), ICU length of stay (13.0 d vs 10.0 d, $P = .17$), and ventilator-free days (14.0 vs 19.0, $P = .55$) between the 2 groups. However, significantly lower ΔD1-Sequential Organ Failure Assessment (SOFA) and ΔD2-SOFA were found in EIT group ($P < .001$) in a post hoc comparison.

Hsu and colleagues[4] randomized 87 subjects to either EIT-PEEP titration group ($n = 42$) or pressure-volume (PV) PEEP titration group ($n = 45$). The authors observed that PEEP was significantly higher in PV ± group (17.4 ± 1.7 cm H_2O vs 16.2 ± 2.6 cm H_2O, $P = .02$). Driving pressure was significantly lower in EIT group (10.9 ± 2.5 cm H_2O vs 12.4 ± 3.6 cm H_2O, $P = .04$). The survival rate was higher in EIT group (69.0% vs 44.4%, $P = .02$).

EIT can also provide information about the global and regional distribution of ventilation, allowing the calculation of global and regional compliance, as well as some other promising indexes like EIT-based global inhomogeneity index, the center of ventilation, and SD of regional delayed ventilation. All those indexes have shown to reflect physiological lung properties that were previously inaccessible at the bedside, also detected in children.[5]

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The most promising method to set PEEP according to EIT is the Costa[6] method, which searches for the PEEP level resulting in the least amount of collapse and overdistention simultaneously. When using the Costa[6] method, the physiological consequences of a PEEP titrated by EIT correlate best with results of a PEEP resulting in slightly positive (0–2 cm H_2O) transpulmonary pressures, producing homogeneous distribution of tidal ventilation (according to ventral to dorsal distribution). Van der Zee and colleagues reported a case series of 15 subjects with COVID-19 and moderate-to-severe ARDS in whom EIT was applied as a "personalized PEEP." They compared this EIT-based PEEP with the PEEP that could have been set according to the lower or higher PEEP-F_{IO_2} table from the ALVEOLI trial. They observed that the $PEEP_{set}$ corresponded better with the higher PEEP-F_{IO_2} table than the lower PEEP-F_{IO_2} table and was positively correlated with the body mass index of these subjects.[7] This result has been consistent. EIT has also be used to titrate PEEP at bedside in subjects with ARDS and COVID-19 ARDS during venovenous extracorporeal membrane oxygenation,[8] producing important physiological benefits.

Suggesting a further potential benefit of EIT for optimizing protective ventilation, in this issue of RESPIRATORY CARE, Gogniat and colleagues[9] report the possibility of calculating lung strain (the tidal deformation of lung parenchyma normalized by the functional residual capacity [FRC]; strain = tidal volume [V_T]/FRC) using EIT. More precisely, they could measure the changes in regional strain caused by a change in PEEP. The calculus was performed in a pixel-wise fashion, and the authors could display a map of strain-changes, called dynamic relative regional strain.

Dr Amato has disclosed relationships with Covidien/Medtronic, Orange Medical, Nihon Kohden, and Timpel. Dr Barbas has disclosed no conflicts of interest.

Correspondence: Carmen S V Barbas, Pulmonary Division, Heart Institute – INCOR, FMUSP, University of São Paulo, São Paulo, Brazil; and Adult Intensive Care, Albert Einstein Hospital, São Paulo, Brazil. E-mail: carmen.barbas@gmail.com.

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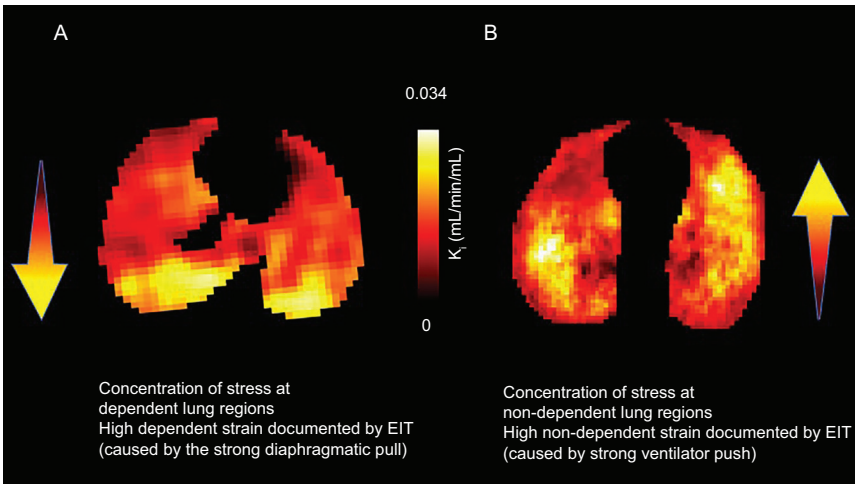

Fig. 1. Cross-sectional PET images (fluorodeoxyglucose) in pigs taken at the fifth intercostal space. A: Spontaneous ventilation during pressure support. The animal was ventilated for 24 h during pressure support ventilation at low PEEP = 5 cm H_2O, with tidal volume (V_T) maintained at 6 mL/kg, and global transpulmonary driving pressures 18 cm H_2O (measured with an esophageal balloon). A pressure transducer placed at surface of diaphragm revealed local concentration of transpulmonary driving pressures at 30 cm H_2O. Electrical impedance tomography (EIT) revealed a localized strain equivalent to that produced by V_T 15 mL/kg. The diaphragmatic pull produced higher inflammation in the dependent lung zones. B: Controlled mechanical ventilation during volume controlled ventilation (VCV) and PEEP = 5 cm H_2O. The animal was ventilated for 24 h during VCV at low PEEP (5 cm H_2O), with V_T strictly set at 6 mL/kg, and global driving pressures 22 cm H_2O (probably causing global transpulmonary driving pressures ~18 cm H_2O, as in animal A). EIT revealed a localized strain in the non-dependent lung regions, with regional V_T 12 mL/kg (the strain in the non-dependent region was 3 times the one in dependent regions). The ventilator produced higher ventilation and inflammation in the non-dependent lung zones. From reference 11, with permission.

For instance, by decreasing PEEP from 15 to 5 cm H_2O, the authors detected a 3-fold increase in strain in most ventral lung areas. The approach was simple and required a reference PEEP to be computed. The method produced a quantification that was consistent with other physiological parameters and confirms the results of a recent study by Cornejo and colleagues.[10] Cornejo et al validated their findings against a sophisticated calculus of CT-based strain. This latter calculus required 2 complete CT acquisitions (at end inspiration and end expiration) and could never be performed at the bedside. In contrast, EIT-based strain could be calculated continuously and at the bedside, producing real-time maps along multiple PEEP steps. Gogniat et al[9] ingeniously used 2 parameters that can be calculated in a pixel-by-pixel fashion and that were proven to change linearly with dynamic changes in air content: the δ-Z (air-volume changes related to V_T) and the EELI (air-volume changes related to changes in end-expiratory lung volume [EELV]). The EIT-strain method can only compute changes in regional strain but not yet absolute strain. Very likely, future studies will prove that dynamic changes in strain will be more relevant than absolute strain calculations. This can be easily inferred from the physiological effects of PEEP: When V_T is kept constant, PEEP will cause a decrease in strain in most regions of the lung (by increasing the denominator, EELV or EELI); and yet, this cannot be assumed as necessarily protective. On the other hand, any change in PEEP that produces an increase in regional strain must cause some concern. Very likely, this change must be analyzed in conjunction with some measure of cyclic stress like driving pressure. The worst scenario would be a change in PEEP that produces both, an increase in driving pressure and increase in regional strain. This latter could indicate a dangerous concentration of stresses, magnifying the potential danger associated with a certain level of driving pressure. This situation was already well documented during the original description of the pendelluft phenomenon[11] (see Fig. 1).

Excessive lung strain and stresses are considered key mechanisms of ventilator-induced lung injury (VILI). Up to now, the cyclic stress globally expressed by driving pressures has been the most consistent predictor of VILI.[12] The possibility of measuring dynamic relative regional strain maps continuously by EIT seems to be a step forward in detecting situations of concentrated, hidden stress, providing us with new tools to personalize and optimize protective ventilation.

Carmen S V Barbas
Pulmonary Division
Heart Institute – INCOR
FMUSP
University of São Paulo
São Paulo, Brazil

Adult Intensive Care
Albert Einstein Hospital
São Paulo, Brazil

Marcelo BP Amato
Pulmonary Division
Heart Institute – INCOR
FMUSP
University of São Paulo
São Paulo, Brazil

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