Dräger

Literature List
Electrical Impedance Tomography

2019

Electrical Impedance Tomography (EIT)
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Categories

CLIN = Clinical Study

ES = Experimental Study

REV = Review

CR = Case Report

CONS = Consensus Paper

Electrical Impedance Tomography (EIT)
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CLIN	Zhao Z, et al.	**Regional air trapping in acute exacerbation of obstructive lung diseases measured with electrical impedance tomography: a feasibility study**	*Minerva Anestesiologica* **2019 Dec**

Background: Since bronchial abnormalities often exhibit spatial non-uniformity which may be not correctly assessed by conventional global lung function measures, regional information may help to characterize the disease progress. We hypothesized that regional air trapping during mechanical ventilation could be characterized by regional end-expiratory flow (EEF) derived from electrical impedance tomography (EIT).

Methods: Twenty-five patients suffering from chronic obstructive pulmonary disease (COPD grade 3 or 4) or severe asthma with acute exacerbation were examined prospectively. Patients were ventilated under assist-control mode. EIT measurements were conducted before and one hour after inhaled combined corticosteroid and long-acting β2 agonist, on two consecutive days. Regional EEF was calculated as derivative of relative impedance for every image pixel in the lung regions. The results were normalized to global flow values measured by the ventilator.

Results: Regional and global EEF were highly correlated (P<0.00001) and regional effects of medication and disease progression were visible in the regional EEF maps. The sums of regional EEF in lung regions were 3.8 [2.0, 5.1] and 3.6 [1.9, 4.5] L/min in COPD patients before and after medication (median [lower, upper quartiles]; P=0.37). The corresponding values in asthma patients were 3.0 [2.5, 4.2] and 2.2 [1.7, 3.2] L/min (P<0.05). Histograms of regional EEF showed high spatial heterogeneity of EEF before medication. After one day of treatment, the histograms exhibited less heterogeneous and a decrease in EEF level.

Conclusion: Regional EEF characterizes air trapping and intrinsic PEEP, which could provide diagnostic information for monitoring the disease progress during treatment.

CLIN	Liu K, et al.	**PEEP guided by electrical impedance tomography during one-lung ventilation in elderly patients undergoing thoracoscopic surgery**	*Ann Transl Med.* **2019 Dec**

Background: To examine the influence of positive end-expiratory pressure (PEEP) settings on lung mechanics and oxygenation in elderly patients undergoing thoracoscopic surgery.

Methods: One hundred patients aged >65 years were randomly allocated into either the PEEP5 or the electrical impedance tomography (EIT) group ($PEEP_{EIT}$). Each group underwent volume-controlled ventilation (tidal volume 6 mL/kg predicted body weight) with the PEEP either fixed at 5 cmH_2O or set at an individualized EIT setting. The primary endpoint was the ratio of the arterial oxygen partial pressure to the fractional inspired oxygen (PaO_2/FiO_2). The secondary endpoints included the driving pressure, and dynamic respiratory system compliance (Cdyn). Other outcomes, such as the mean airway pressure (Pmean), mean arterial pressure (MAP), lung complications and the length of hospital stay were explored.

Results: The optimal PEEP set by EIT was significantly higher (range from 9-13 cmH_2O) than the fixed PEEP. PaO_2/FiO_2 was 47 mmHg higher (95% CI: 7-86 mmHg; P=0.021), Cdyn was 4.3 mL/cmH_2O higher (95% CI: 2.1-6.7 cmH_2O; P<0.001), and the driving pressure was 3.7 cmH_2O lower (95% CI: 2.2-5.1 mmH_2O; P<0.001) at 0.5 h during one-lung ventilation (OLV) in the $PEEP_{EIT}$ group than in the $PEEP_5$ group. At 1 h during OLV, PaO_2/FiO_2 was 93 mmHg higher (95% CI: 58-128 mmHg; P<0.001), Cdyn was 4.4 mL/cmH_2O higher (95% CI: 1.9-6.9 mL/cmH_2O; P=0.001), and the driving pressure was 4.9 cmH_2O lower (95% CI: 3.8-6.1 cmH_2O; P<0.001) in the $PEEP_{EIT}$ group than in the $PEEP_5$ group. PaO_2/FiO_2 was 107 mmHg higher (95% CI: 56-158 mmHg; P<0.001) in the $PEEP_{EIT}$ group than in the $PEEP_5$ group during double-lung ventilation at the end of surgery.

Conclusion: PEEP values determined with EIT effectively improved oxygenation and lung mechanics during one lung ventilation in elderly patients undergoing thoracoscopic surgery.

CLIN	Lehmann M, et al.	**Redistribution of pulmonary ventilation after lung surgery detected with electrical impedance tomography**	*Acta Anaesthesiol Scand.* **2019 Dec**

Background: Regional ventilation of the lung can be visualized by pulmonary electrical impedance tomography (EIT). The aim of this study was to examine the post-operative redistribution of regional ventilation after lung surgery dependent on the side of surgery and its association with forced vital capacity.

Methods: In this prospective, observational cohort study 13 patients undergoing right and 13 patients undergoing left-sided open or video-thoracoscopic procedures have been investigated. Pre-operative measurements with EIT and spirometry were compared with data obtained 3 days post-operation. The center of ventilation (COV) within a 32 × 32 pixel matrix was calculated from EIT data. The transverse axis coordinate of COV, COVx (left/right), was modified to COVx' (ipsilateral/contralateral). Thus, COVx' shows a negative change if ventilation shifts contralateral independent of the side of surgery. This enabled testing with two-way ANOVA for repeated measurements (side, time).

Results: The perioperative shift of COVx' was dependent on the side of surgery ($P = .007$). Ventilation shifted away from the side of surgery after the right-sided surgery (COVx'-1.97 pixel matrix points, $P < .001$), but not after the left-sided surgery (COVx'-0.61, $P = .425$). The forced vital capacity (%predicted) decreased from 94 (83-109)% (median [quartiles]; [left-sided]) and 89 (80-97)% (right-sided surgery) to 61 (59-66)% and 62 (40-72)% ($P < .05$), respectively. The perioperative changes in forced vital capacity (%predicted) were weakly associated with the shift of COVx'.

Conclusion: Only after right-sided lung surgery, EIT showed reduced ventilation on the side of surgery while vital capacity was markedly reduced in both groups.

CLIN	Yuan Z, et al.	**Oxygen Therapy Delivery and Body Position Effects Measured With Electrical Impedance Tomography**	*Respir Care.* **2019 Dec**

Background: The aim of this prospective randomized crossover study was to compare the short-term effects of high-flow nasal cannula (HFNC) therapy and a 45° head-up tilt to the short-term effects of conventional oxygen (O_2) therapy in post-abdominal surgery patients.

Methods: A total of 18 subjects who were successfully weaned from ventilator support after abdominal surgery were included in the study. The subjects were randomly assigned to 2 groups: conventional O_2 was applied in group A for 15 min, and HFNC (60 L/min) was applied in group B for 15 min. A 15-min washout period with conventional O_2 was performed before the interventions were switched in both groups. Heart rate, blood pressure, breathing frequency, ratio of arterial partial pressure of oxygen to the fraction of inspired oxygen (PaO_2 /FIO_2), and subject-reported comfort scores were recorded. Changes in end-expiratory lung impedance (EELI) were calculated with electrical impedance tomography.

Results: Results are presented as the percent change in lung volume compared to baseline during volume-controlled continuous mandatory ventilation before extubation. HFNC improved EELI in both the ventral (conventional O_2 vs HFNC, -48.2% ± 41.0 vs -30.0% ± 40.3, $P < .001$) and the dorsal (conventional O_2 vs HFNC, -37.0% ± 75.9 vs -26.5% ± 68.4, $P = .02$) regions of the lungs. Subjective subject-reported scores indicated that HFNC was more comfortable than conventional O_2 (conventional O_2 vs HFNC, 5.8 ± 1.5 vs 6.9 ± 1.9, $P = .02$). No differences were found in the other examined parameters. A head-up tilt position with conventional O_2 improved EELI in the dorsal regions (55.9% ± 100.1, $P < .001$) but not in the ventral regions (-37.9% ± 43.1%, $P = .38$) of the lungs compared to HFNC or conventional O_2 alone.

Conclusion: In post-abdominal surgery subjects who had been extubated, HFNC improved lung volume and patient comfort. A head-up tilt position introduced a heterogeneous increase in EELI in the dorsal regions of the lungs. HFNC therapy may be beneficial in this patient group.

CR	**Hansen G, et al.**	**Thoracic electrical impedance tomography to minimize right heart strain following cardiac arrest**	*Ann Pediatr Cardiol.* ***2019 Sep-Dec***

Abstract: Titrating ventilator settings to minimize pulmonary arterial pressures and optimize both ventilation and oxygen delivery can be challenging following cardiac arrest. Erroneous ventilator adjustments can lead to unnecessary strain on the right ventricle that may be particularly vulnerable during the acute recovery. We report a child with fulminant myocarditis who was mechanically ventilated using thoracic electrical impedance tomography to optimize regional lung inflation and possibly curtail right ventricular afterload following cardiac arrest.

REV	**Spinelli E, et al.**	**Electrical impedance tomography in perioperative medicine: careful respiratory monitoring for tailored interventions**	*BMC Anesthesiol.* ***2019 Aug***

Background: Electrical impedance tomography (EIT) is a non-invasive radiation-free monitoring technique that provides images based on tissue electrical conductivity of the chest. Several investigations applied EIT in the context of perioperative medicine, which is not confined to the intraoperative period but begins with the preoperative assessment and extends to postoperative follow-up.

Main Body: EIT could provide careful respiratory monitoring in the preoperative assessment to improve preparation for surgery, during anaesthesia to guide optimal ventilation strategies and to monitor the hemodynamic status and in the postoperative period for early detection of respiratory complications. Moreover, EIT could further enhance care of patients undergoing perioperative diagnostic procedures. This narrative review summarizes the latest evidence on the application of this technique to the surgical patient, focusing also on possible future perspectives.

Conclusion: EIT is a promising technique for the perioperative assessment of surgical patients, providing tailored adaptive respiratory and haemodynamic monitoring. Further studies are needed to address the current technological limitations, confirm the findings and evaluate which patients can benefit more from this technology.

REV	**Putensen C, et al.**	**Electrical Impedance Tomography for Cardio-Pulmonary Monitoring**	*J Clin Med.* ***2019 Aug***

Abstract: Electrical impedance tomography (EIT) is a bedside monitoring tool that noninvasively visualizes local ventilation and arguably lung perfusion distribution. This article reviews and discusses both methodological and clinical aspects of thoracic EIT. Initially, investigators addressed the validation of EIT to measure regional ventilation. Current studies focus mainly on its clinical applications to quantify lung collapse, tidal recruitment, and lung overdistension to titrate positive end-expiratory pressure (PEEP) and tidal volume. In addition, EIT may help to detect pneumothorax. Recent studies evaluated EIT as a tool to measure regional lung perfusion. Indicator-free EIT measurements might be sufficient to continuously measure cardiac stroke volume. The use of a contrast agent such as saline might be required to assess regional lung perfusion. As a result, EIT-based monitoring of regional ventilation and lung perfusion may visualize local ventilation and perfusion matching, which can be helpful in the treatment of patients with acute respiratory distress syndrome (ARDS).

CLIN	**Longhini F, et al.**	**Electrical impedance tomography during spontaneous breathing trials and after extubation in critically ill patients at high risk for extubation failure: a multicenter observational study**	*Ann Intensive Care.* ***2019 Aug***

Background: This study aims to assess the changes in lung aeration and ventilation during the first spontaneous breathing trial (SBT) and after extubation in a population of patients at risk of extubation failure.

Methods: We included 78 invasively ventilated patients eligible for their first SBT, conducted with low positive end-expiratory pressure (2 cm H_2O) for 30 min. We acquired three 5-min electrical impedance tomography (EIT) records at baseline, soon after the beginning (SBT_0) and at the end (SBT_30) of SBT. In the case of SBT failure, ventilation was reinstituted; otherwise, the patient was extubated and two additional records were acquired soon after extubation (SB_0) and 30 min later (SB_30) during spontaneous breathing. Extubation failure was defined by the onset of post-extubation respiratory failure within 48 h after extubation. We computed the changes from baseline of end-expiratory lung impedance (ΔEELI), tidal volume (ΔVt%), and the inhomogeneity index. Arterial blood was sampled for gas analysis. Data were compared between sub-groups stratified for SBT and extubation success/failure.

Results: Compared to SBT success (n = 61), SBT failure (n = 17) showed a greater reduction in ΔEELI at SBT_0 ($p < 0.001$) and SBT_30 ($p = 0.001$) and a higher inhomogeneity index at baseline ($p = 0.002$), SBT_0 ($p = 0.003$) and SBT_30 ($p = 0.005$). RR/Vt was not different between groups at baseline but was significantly greater at SBT_0 and SBT_30 in SBT failures, compared to SBT successes ($p < 0.001$ for both). No differences in ΔVt% and arterial blood gases were observed between SBT success and failure. The ΔVt%, ΔEELI, inhomogeneity index and arterial blood gases were not different between patients with extubation success (n = 39) and failure (n = 22) ($p > 0.05$ for all comparisons).

Conclusions: Compared to SBT success, SBT failure was characterized by more lung de-recruitment and inhomogeneity. Whether EIT may be useful to monitor SBT remains to be determined. No significant changes in lung ventilation, aeration or homogeneity related to extubation outcome occurred up to 30 min after extubation.

ES	**Haase J, et al.**	**Mechanical Ventilation Strategies Targeting Different Magnitudes of Collapse and Tidal Recruitment in Porcine Acid Aspiration-Induced Lung Injury.**	*J Clin Med.* ***2019 Aug***

Abstract: Reducing ventilator-associated lung injury by individualized mechanical ventilation (MV) in patients with Acute Respiratory Distress Syndrome (ARDS) remains a matter of research. We randomly assigned 27 pigs with acid aspiration-induced ARDS to three different MV protocols for 24 h, targeting different magnitudes of collapse and tidal recruitment (collapse&TR): the ARDS-network (ARDSnet) group with low positive end-expiratory pressure (PEEP) protocol (permissive collapse&TR); the Open Lung Concept (OLC) group, PaO_2/FiO_2 >400 mmHg, indicating collapse&TR <10%; and the minimized collapse&TR monitored by Electrical Impedance Tomography (EIT) group, standard deviation of regional ventilation delay, SDRVD. We analyzed cardiorespiratory parameters, computed tomography (CT), EIT, and post-mortem histology. Mean PEEP over post-randomization measurements was significantly lower in the ARDSnet group at 6.8 ± 1.0 cmH_2O compared to the EIT (21.1 ± 2.6 cmH_2O) and OLC (18.7 ± 3.2 cmH_2O) groups (general linear model (GLM) $p < 0.001$). Collapse&TR and SDRVD, averaged over all post-randomization measurements, were significantly lower in the EIT and OLC groups than in the ARDSnet group (collapse $p < 0.001$, TR $p = 0.006$, SDRVD $p < 0.004$). Global histological diffuse alveolar damage (DAD) scores in the ARDSnet group (10.1 ± 4.3) exceeded those in the EIT (8.4 ± 3.7) and OLC groups (6.3 ± 3.3) ($p = 0.16$). Sub-scores for edema and inflammation differed significantly (ANOVA $p < 0.05$). In a clinically realistic model of early ARDS with recruitable and nonrecruitable collapse, mechanical ventilation involving recruitment and high-PEEP reduced collapse&TR and resulted in improved hemodynamic and physiological conditions with a tendency to reduced histologic lung damage.

CLIN	Rosemeier I, et al.	Mechanical Ventilation Guided by Electrical Impedance Tomography in Children With Acute Lung Injury	*Crit Care Explor.* ***2019 Jul***

Objectives: To provide proof-of-concept for a protocol applying a strategy of personalized mechanical ventilation in children with acute respiratory distress syndrome. Positive end-expiratory pressure and inspiratory pressure settings were optimized using real-time electrical impedance tomography aiming to maximize lung recruitment while minimizing lung overdistension.

Design: Prospective interventional trial.

Setting: Two PICUs.

Patients: Eight children with early acute respiratory distress syndrome (< 72 hr).

Interventions: On 3 consecutive days, electrical impedance tomography-guided positive end-expiratory pressure titration was performed by using regional compliance analysis. The Acute Respiratory Distress Network high/low positive end-expiratory pressure tables were used as patient's safety guardrails. Driving pressure was maintained constant. Algorithm includes the following: 1) recruitment of atelectasis: increasing positive end-expiratory pressure in steps of 4 mbar; 2) reduction of overdistension: decreasing positive end-expiratory pressure in steps of 2 mbar until electrical impedance tomography shows collapse; and 3) maintaining current positive end-expiratory pressure and check regional compliance every hour. In case of derecruitment start at step 1.

Measurements and Main Results: Lung areas classified by electrical impedance tomography as collapsed or overdistended were changed on average by -9.1% (95% CI, -13.7 to -4.4; p < 0.001) during titration. Collapse was changed by -9.9% (95% CI, -15.3 to -4.5; p < 0.001), while overdistension did not increase significantly (0.8%; 95% CI, -2.9 to 4.5; p = 0.650). A mean increase of the positive end-expiratory pressure level (1.4 mbar; 95% CI, 0.6-2.2; p = 0.008) occurred after titration. Global respiratory system compliance and gas exchange improved (global respiratory system compliance: 1.3 mL/mbar, 95% CI [-0.3 to 3.0], p = 0.026; Pao2: 17.6 mm Hg, 95% CI [7.8-27.5], p = 0.0039; and Pao2/Fio2 ratio: 55.2 mm Hg, 95% CI [27.3-83.2], p < 0.001, all values are change in pre vs post).

Conclusions: Electrical impedance tomography-guided positive end-expiratory pressure titration reduced regional lung collapse without significant increase of overdistension, while improving global compliance and gas exchange in children with acute respiratory distress syndrome.

ES	**Reinartz S D, et al.**	**EIT monitors valid and robust regional ventilation distribution in pathologic ventilation states in porcine study using differential DualEnergy-CT**	*Sci Rep.* ***2019 Jul***

Abstract: It is crucial to precisely monitor ventilation and correctly diagnose ventilation-related pathological states for averting lung collapse and lung failure in Intensive Care Unit (ICU) patients. Although Electrical Impedance Tomography (EIT) may deliver this information continuously and non-invasively at bedside, to date there are no studies that systematically compare EIT and Dual Energy CT (DECT) during inspiration and expiration (ΔDECT) regarding varying physiological and ICU-typical pathological conditions such as atelectasis. This study aims to prove the accuracy of EIT through quantitative identification and monitoring of pathological ventilation conditions on a four-quadrant basis using ΔDECT. In a cohort of 13 pigs, this study investigated systematic changes in tidal volume (TV) and positive end-expiratory pressure (PEEP) under physiological ventilation conditions. Pathological ventilation conditions were established experimentally by single-lung ventilation and pulmonary saline lavage. Spirometric data were compared to voxel-based entire lung ΔDECT, and EIT intensities were compared to ΔDECT of a 12-cm slab of the lung around the EIT belt, the so called ΔDECTBelt. To validate ΔDECT data with spirometry, a Pearson's correlation coefficient of 0.92 was found for 234 ventilation conditions. Comparing EIT intensity with ΔDECT(Belt), the correlation r = 0.84 was found. Normalized cross-correlation function (NCCF) between scaled global impedance (EIT) waveforms and global volume ventilator curves was r = 0.99 ± 0.003. The EIT technique correctly identified the ventilated lung in all cases of single-lung ventilation. In the four-quadrant based evaluation, which assesses the difference between end-expiratory lung volume (ΔEELV) and the corresponding parameter in EIT, i.e. the end-expiratory lung impedance (ΔEELI), the Pearson's correlation coefficient of 0.94 was found. The respective Pearson's correlation coefficients implies good to excellent concurrence between global and regional EIT ventilation data validated by ventilator spirometry and DECT imaging. By providing real-time images of the lung, EIT is a promising, EIT is a promising, clinically robust tool for bedside assessment of regional ventilation distribution and changes of end-expiratory lung volume.

CLIN	**Coppadoro A, et al.**	**Event-triggered averaging of electrical impedance tomography (EIT) respiratory waveforms as compared to low-pass filtering for removal of cardiac related impedance changes**	*J Clin Monit Comput.* ***2019 Jul***

Abstract: Electrical impedance tomography (EIT) is used for bedside ventilation monitoring; cardiac related impedance changes represent a source of noise superimposed on the ventilation signal, commonly removed by low-pass filtering (LPF). We investigated if an alternative approach, based on an event-triggered averaging (ETA) process, is more effective at preserving the actual ventilation waveform. Ten paralyzed patients undergoing volume-controlled ventilation were studied; 30 breaths for each patient were identified to compare LPF and ETA. For ETA the identified breaths were temporally aligned on the beginning of inspiration; the values of the thirty curves at each time point were averaged. The analysis was conducted on the global EIT signal and on four ventral-to-dorsal regions of interest. Global tidal variations by ETA resulted higher than LPF (average difference 139 ± 88 arbitrary units, p = 0.004). Both for global and regional waveforms, minimum and maximum EIT slopes were steeper by ETA as compared to LPF (average difference respectively - 57 ± 60 mL/s and 144 ± 96 mL/s for global signal, p < 0.05); ventilator inspiratory peak airflow correlated with maximum slope measured by ETA (r = 0.902, p < 0.001), but not LPF (p = 0.319). Beginning of inspiration identified on the ventilator waveform and on the global EIT signal by ETA occurred simultaneously, (+ 0.04 ± 0.07 s, p = 0.081), while occurred earlier by LPF (- 0.26 ± 0.1 s, p < 0.001). Removal of cardiac related impedance changes by ETA results in a ventilation signal more similar to the waveforms recorded by the ventilator, particularly regarding the slope of impedance changes and time at the minimum values as compared to LPF.

CLIN	**Zhao Z, et al.**	**Detection of pulmonary oedema by electrical impedance tomography – validation of previously proposed approaches in a clinical setting**	*Physiol Meas.* ***2019 Jun***

Objective: The aim of the present study was to evaluate two previously proposed approaches based on electrical impedance tomography (EIT) to assess pulmonary oedema at the bedside.

Approach: Fourteen patients with acute respiratory distress syndrome were included and examined prospectively. Patients were rotated laterally along their longitudinal axis from supine to 45-degree left and right tilt to induce a gravity-dependent redistribution of pulmonary oedema. After a 20 min equilibration period at each of the three positions, 2 min EIT data were recorded and analyzed. Left-to-right lung and anterior-to-posterior ventilation ratios were calculated for each posture. The slopes of the regression lines in all three postures were then determined. The same examination was performed on the consecutive day. The EIT-derived parameters were compared with transcardiopulmonary thermodilution measurements.

Main Results: The correlations between the EIT and transcardiopulmonary thermodilution parameters were low (correlation coefficients $r < 0.4$) and not significant regardless of the examination days.

Significance: Despite previous clinical and experimental observations, left-to-right and anterior-to-posterior ventilation ratios derived from EIT examinations after postural changes did not reflect total extravascular lung water in our study population.

CR	**Yoshida, et al.**	**Regional Ventilation Displayed by Electrical Impedance Tomography as an Incentive to Decrease Positive End-Expiratory Pressure.**	*Am J Respir Crit Care Med.* ***2019 Jun***

Abstract: 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). When positive pressure successfully recruits atelectatic 'dorsal' lung, it is subsequently maintained open by positive end-expiratory pressure (PEEP); tidal recruitment is then diminished (7) and susceptibility of the ventral lung to inspiratory injury is less (6).
Ventilation using excessive PEEP, however, can also overinflate the aerated lung (1, 8) and worsen lung injury. A recent randomized clinical trial in ARDS (9) reported that a strategy combining lung recruitment and higher PEEP based on respiratory system compliance (Crs) increased barotrauma and mortality. 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.

CLIN	Sosio S, et al.	A Calibration Technique for the Estimation of Lung Volumes in Nonintubated Subjects by Electrical Impedance Tomography	*Respiration.* ***2019 Jun***

Background: Electrical impedance tomography (EIT) is a bedside monitoring technique of the respiratory system that measures impedance changes within the thorax. The close correlation between variations in impedance (ΔZ) and lung volumes (Vt) is known. Unless Vt is measured by an external reference (e.g., spirometry), its absolute value (in milliliters) cannot be determined; however, measurement of Vt would be useful in nonintubated subjects.

Objective: To validate a simplified and feasible calibration method of EIT, which allows estimation of Vt in nonintubated subjects.

Materials and Methods: We performed a prospective study on 13 healthy volunteers. Subjects breathed 10 times in a nonexpandable "calibration balloon" with a known volume while wearing the EIT belt. The relationship between ΔZ and the balloon volume was calculated (ΔZ/Vt). Subsequently, subjects were connected to a mechanical ventilator by a mouthpiece under different settings. Vt was calculated from EIT measurements (VtEIT) by means of the ΔZ/Vt coefficient and compared with the value obtained from the ventilator (Vtflow).

Results: There was a close correlation between Vtflow and VtEIT (r2 = 0.89). The fit equation was VtEIT = 0.9 × Vtflow +10.1. The highest correlation was found at positive endexpiratory pressure (PEEP) 0 (mean: VtEIT = 0.93 × Vtflow) versus PEEP 8 (mean: VtEIT = 0.8 × Vtflow), p = 0.01. No differences in the fit equation were found between pressure support ventilation (PSV) 0 and PSV 8, p = 0.50. Further analysis showed no statistically significant differences between sex, height, and BMI.

Conclusions: A simple and fast EIT calibration technique enables reliable, noninvasive monitoring of Vt in nonintubated subjects.

CLIN	Rowley DD, et al.	A Randomized Controlled Trial Comparing Two Lung Expansion Therapies After Upper Abdominal Surgery	*Respir Care.* ***2019 May***

Background: Lung expansion therapy is often ordered after surgery to improve alveolar ventilation and reduce risks of postoperative pulmonary complications. The impact of lung expansion therapy at altering ventilation in patients who are not intubated has not been described. The primary purpose of this study was to determine if there is a difference in dorsal redistribution of ventilation and incidences of postoperative pulmonary complications when comparing incentive spirometry (IS) with EzPAP lung expansion therapy after upper abdominal surgery. Our a priori null hypothesis was that there are no differences.

Methods: This randomized controlled trial enrolled adult human subjects after upper- abdominal surgery from January 2017 to November 2018. The subjects were allocated to receive IS or EzPAP 3 times a day on postoperative days 1-5. An electrical impedance tomography device was connected to the subjects for a single lung expansion therapy session on postoperative days 1, 3, and 5 to measure the change in post-lung expansion therapy dorsal end-expiratory lung impedance (ΔEELI%). Lung expansion therapy sessions with electrical impedance tomography included 2 min of normal breathing, 3 cycles of 10 breaths, and 2 min of normal breathing after cycle 3. Postoperative pulmonary complications were screened until hospital discharge. Mann-Whitney, chi-square, and Fisher exact tests were applied. Data were reported as count (n), percentage, and median (interquartile range) for primary and secondary outcomes. Alpha (2-tailed) was < 0.05.

Results: A total of 112 subjects were enrolled to receive IS (n = 56) or EzPAP (n = 56). Baseline characteristics were equal. Post-lung expansion therapy dorsal ΔEELI% increased for both groups, but the dorsal ΔEELI% for IS versus EzPAP on postoperative day 1 (16% versus 12%, P = .39), postoperative day 3 (6% versus 6%, P = .68), and postoperative day 5 (9% versus 6%, P = .46) was not significantly different. Hospital length of stay (4 d; P = .30) and incidence of postoperative pulmonary complications (3.6% versus 7.1%, P = .19) were similar.

Conclusions: There was no significant post-lung expansion therapy dorsal ΔEELI% or postoperative pulmonary complications among the adults who received IS or EzPAP 3 times a day after upper abdominal surgery.

CLIN	Fumagalli J, et al.	**Lung Recruitment in Obese Patients with Acute Respiratory Distress Syndrome.**	*Anesthesiology* ***2019 May***

Background: Obese patients are characterized by normal chest-wall elastance and high pleural pressure and have been excluded from trials assessing best strategies to set positive end-expiratory pressure (PEEP) in acute respiratory distress syndrome (ARDS). The authors hypothesized that severely obese patients with ARDS present with a high degree of lung collapse, reversible by titrated PEEP preceded by a lung recruitment maneuver.

Methods: Severely obese ARDS patients were enrolled in a physiologic crossover study evaluating the effects of three PEEP titration strategies applied in the following order: (1) PEEPARDSNET: the low PEEP/FIO2 ARDSnet table; (2) PEEPINCREMENTAL: PEEP levels set to determine a positive end-expiratory transpulmonary pressure; and (3) PEEPDECREMENTAL: PEEP levels set to determine the lowest respiratory system elastance during a decremental PEEP trial following a recruitment maneuver on respiratory mechanics, regional lung collapse, and overdistension according to electrical impedance tomography and gas exchange.

Results: Fourteen patients underwent the study procedures. At PEEPARDSNET (13 ± 1 cm H_2O) end-expiratory transpulmonary pressure was negative (-5 ± 5 cm H_2O), lung elastance was 27 ± 12 cm H_2O/L, and PaO_2/FIO_2 was 194 ± 111 mmHg. Compared to PEEPARDSNET, at PEEPINCREMENTAL level (22 ± 3 cm H_2O) lung volume increased (977 ± 708 ml), lung elastance decreased (23 ± 7 cm H_2O/l), lung collapse decreased (18 ± 10%), and ventilation homogeneity increased thus rising oxygenation (251 ± 105 mmHg), despite higher overdistension levels (16 ± 12%), all values P < 0.05 versus PEEPARDSnet. Setting PEEP according to a PEEPDECREMENTAL trial after a recruitment maneuver (21 ± 4 cm H_2O, P = 0.99 vs. PEEPINCREMENTAL) further lowered lung elastance (19 ± 6 cm H_2O/l) and increased oxygenation (329 ± 82 mmHg) while reducing lung collapse (9 ± 2%) and overdistension (11 ± 2%), all values P < 0.05 versus PEEPARDSnet and PEEPINCREMENTAL. All patients were maintained on titrated PEEP levels up to 24 h without hemodynamic or ventilation related complications.

Conclusions: Among the PEEP titration strategies tested, setting PEEP according to a PEEPDECREMENTAL trial preceded by a recruitment maneuver obtained the best lung function by decreasing lung overdistension and collapse, restoring lung elastance, and oxygenation suggesting lung tissue recruitment.

REV	Vasques F, et al.	**Monitoring of regional lung ventilation using electrical impedance tomography**	*Minerva Anestesiol.* ***2019 Apr***

Abstract: Among recent lung imaging techniques and devices, electrical impedance tomography (EIT) can provide dynamic information on the distribution regional lung ventilation. EIT images possess a high temporal and functional resolution allowing the visualization of dynamic physiological and pathological changes on a breath-by-breath basis. EIT detects changes in electric impedance (i.e., changes in gas/fluid ratio) and describes them in real time, both visually through images and waveforms, and numerically, allowing the clinician to monitor disease evolution and response to treatment. The use of EIT in clinical practice is supported by several studies demonstrating a good correlation between impedance tomography data and other validated methods of measuring lung volume. In this review, we will provide an overview on the rationale, basic functioning and most common applications of EIT in the management of mechanically ventilated patients.

CLIN	**Rahmel T, et al.**	**Evaluation of inhaled salbutamol effectiveness under supportive use of electrical impedance tomography in ventilated ICU patients: study protocol for a randomised controlled clinical trial**	*BMJ Open.* ***2019 Mar***

Introduction: The inhalative administration of drugs is a non-invasive application form that is regularly used in the treatment of ventilated patients in critical care setting. However, assessment of effectiveness or distribution of nebulised drugs is one of the lacking cornerstones of modern intensive care monitoring. Electrical impedance tomography (EIT) may provide a promising new monitoring and guiding tool for an adequate optimisation of mechanical ventilation in critically ill patients. EIT may assist in defining mechanical ventilation settings, assess distribution of tidal volume and evaluate associated pathologies at bedside. This study aims to elucidate the extent to which the effectiveness of inhaled salbutamol can be increased by the additional use of EIT for optimisation of respirator settings.

Methods and Analysis: This study is a randomised, open-label, superiority trial conducted on an intensive care unit of a German university hospital, comparing two groups of mechanically ventilated patients with an acute or chronic bronchial airway obstruction according to the effectiveness of inhaled salbutamol with (intervention) or without (control) additional use of EIT for optimising ventilator settings. The primary outcome is change in airway resistance 30 min after salbutamol inhalation.

Ethics and Dissemination: The study has received approval from the Ethics Committee of the Medical Faculty of Ruhr-University Bochum (17-6306). The results will be made available to critical care survivors, their caregivers, the funders, the critical care societies and other researchers by publication in a peer-reviewed journal.

REV	**Davies P, et al.**	**Clinical Scenarios of the Application of Electrical Impedance Tomography in Paediatric Intensive Care**	*Sci Rep. 2019* ***2019 Mar***

Abstract: EIT is a radiation-free functional modality that enables bedside imaging and monitoring of lung function and expansion. Clinical interest in this method has been driven by the need for bedside monitoring of the dynamics of the lungs and the effects of ventilatory manoeuvres, including changes in ventilator settings, suctioning, chest drains, positioning and physiotherapy. We aimed to describe the use of Electrical Impedance Tomography (EIT) as a clinical tool in a tertiary Paediatric Intensive Care unit. Children requiring intensive care with a variety of clinical conditions had an electrode belt with 16 electrodes wrapped around the chest, which sequentially applied a small alternating current from each electrode pair. The signal gives information on both real time, regional, global, and relative data. With the correct application, and understanding of the monitor, much clinical information can be gained, with potentially significant patient benefit. We present the clinical use of EIT in six conditions: Asthma, Ventilation weaning and expansion recoil, Sequential Lobar Collapse, Targeted Physiotherapy, Pleural Effusion assessment, and PEEP optimisation. Screenshots and analyses are offered displaying the pragmatic use of this technology. Electrical Impedance Tomography is a clinically useful tool on the Paediatric Intensive Care unit. It allows monitoring of a patient's respiratory function in ways which are not possible through any other means. An understanding of respiratory physiology will allow use of this information to improve patient outcomes.

CLIN	Becher T, et al.	**Changes in Electrical Impedance Tomography Findings of ICU Patients during Rapid Infusion of a Fluid Bolus: A Prospective Observational Study**	*Am J Respir Crit Care Med.* ***2019 Mar***

Introduction: Electrical impedance tomography (EIT) is a non-invasive, radiation-free imaging tool for critically ill patients suffering from acute respiratory failure. During bedside EIT monitoring, differences between end-expiratory lung impedance and end-inspiratory lung impedance, commonly referred to as "tidal impedance variation", are used to assess regional ventilation distribution, whereas changes in end-expiratory lung impedance over time are frequently used to track changes in end-expiratory lung volume (EELV).
However, despite being highly correlated to changes in air content, changes in pulmonary bioimpedance may also be influenced by intrathoracic fluid volume and electrolyte concentrations. This may affect the interpretation of changes in endexpiratory lung impedance and tidal impedance variation, which could be influenced by fluid and blood volume shifts.
The aim of this study was to assess the effects of routine clinical fluid administration on end-expiratory lung impedance and tidal impedance variation in critically ill patients requiring mechanical ventilation. Some results of this study have been previously reported in the form of abstracts.

CLIN	Zhao Z, et al.	**Positive end-expiratory pressure titration with electrical impedance tomography and pressure-volume curve in severe acute respiratory distress syndrome**	*Ann Intensive Care.* ***2019 Jan***

Background: The study objective was to compare titration of positive end-expiratory pressure (PEEP) with electrical impedance tomography (EIT) and with ventilator-embedded pressure-volume loop in severe acute respiratory distress syndrome (ARDS).

Methods: We have designed a prospective study with historical control group. Twenty-four severe ARDS patients (arterial oxygen partial pressure to fractional inspired oxygen ratio, $PaO_2/FiO_2 < 100$ mmHg) were included in the EIT group and examined prospectively. Data from another 31 severe ARDS patients were evaluated retrospectively (control group). All patients were receiving medical care under identical general support guidelines and protective mechanical ventilation. The PEEP level selected in the EIT group was the intercept point of cumulated collapse and overdistension percentages curves. In the control group, optimal PEEP was selected 2 cmH_2O above the lower inflection point on the static pressure-volume curve.

Results: Patients in the EIT group were younger ($P < 0.05$), and their mean plateau pressure was 1.5 cmH_2O higher ($P < 0.01$). No differences in other baseline parameters such as APACHE II score, PaO_2/FiO_2, initial PEEP, driving pressure, tidal volume, and respiratory system compliance were found. Two hours after the first PEEP titration, significantly higher PEEP, compliance, and lower driving pressure were found in the EIT group ($P < 0.01$). Hospital survival rates were 66.7% (16 of 24 patients) in the EIT group and 48.4% (15 of 31) in the control group. Identical rates were found regarding the weaning success rate: 66.7% in the EIT group and 48.4% in the control group.

Conclusions: In severe ARDS patients, it was feasible and safe to guide PEEP titration with EIT at the bedside. As compared with pressure-volume curve, the EIT-guided PEEP titration may be associated with improved oxygenation, compliance, driving pressure, and weaning success rate. The findings encourage further randomized control study with a larger sample size and potentially less bias in the baseline data.

REV	Shono A, Kotani T	**Clinical implication of monitoring regional ventilation using electrical impedance tomography**	*J Intensive Care.* ***2019 Jan***

Abstract: Mechanical ventilation can initiate ventilator-associated lung injury (VALI) and contribute to the development of multiple organ dysfunction. Although a lung protective strategy limiting both tidal volume and plateau pressure reduces VALI, uneven intrapulmonary gas distribution is still capable of increasing regional stress and strain, especially in non-homogeneous lungs, such as during acute respiratory distress syndrome. Real-time monitoring of regional ventilation may prevent inhomogeneous ventilation, leading to a reduction in VALI. Electrical impedance tomography (EIT) is a technique performed at the patient's bedside. It is noninvasive and radiation-free and provides dynamic tidal images of gas distribution. Studies have reported that EIT provides useful information both in animal and clinical studies during mechanical ventilation. EIT has been shown to be useful during lung recruitment, titration of positive end-expiratory pressure, lung volume estimation, and evaluation of homogeneity of gas distribution in a single EIT measure or in combination with multiple EIT measures. EIT-guided mechanical ventilation preserved the alveolar architecture and maintained oxygenation and lung mechanics better than low-tidal volume ventilation in animal models. However, careful assessment is required for data analysis owing to the limited understanding of the results of EIT interpretation. Previous studies indicate monitoring regional ventilation by EIT is feasible in the intensive care setting and has potential to lead to lung protective ventilation. Further clinical studies are warranted to evaluate whether monitoring of regional ventilation using EIT can shorten the duration of ventilation or improve mortality in patients with acute respiratory distress syndrome.