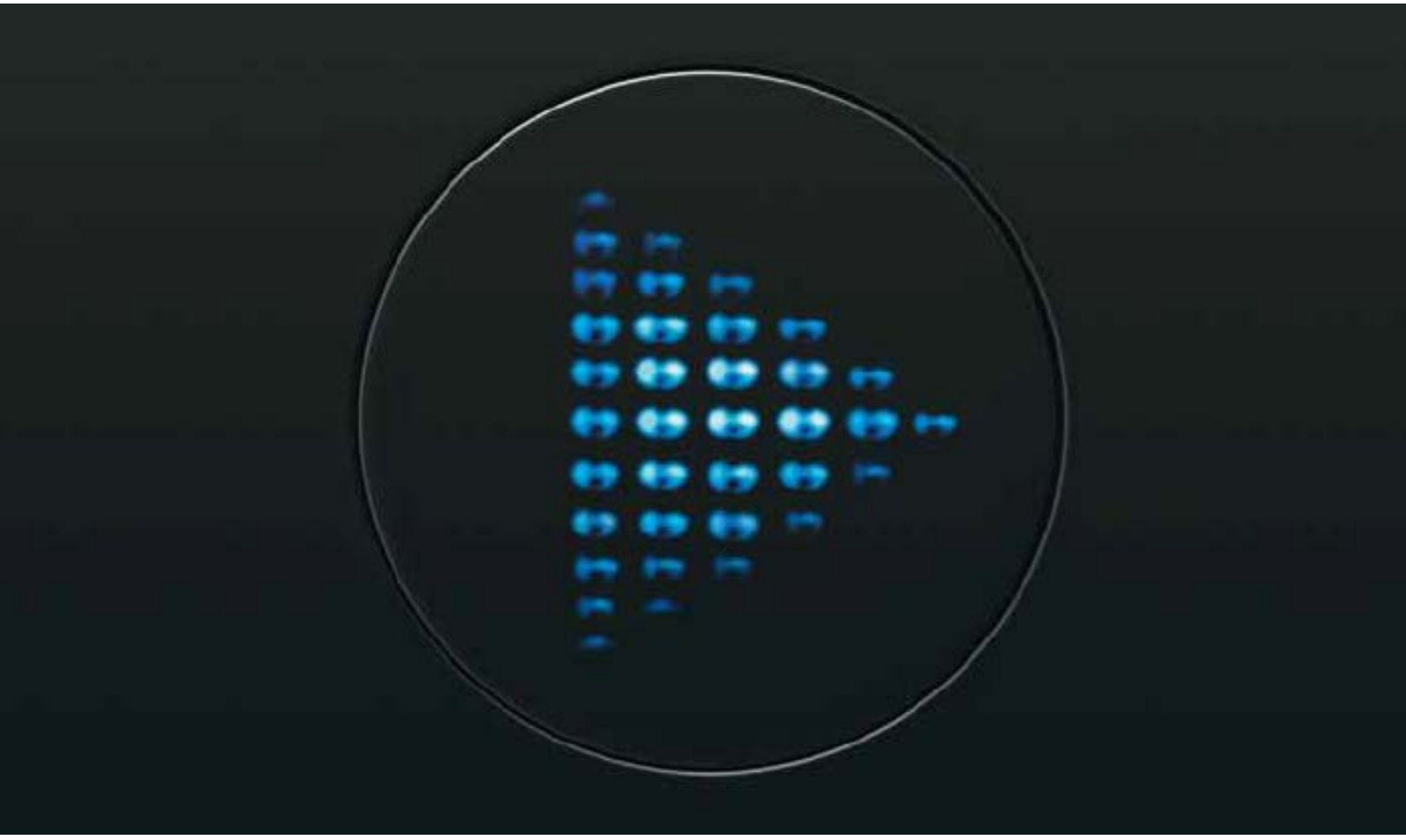

Literature List
Electrical Impedance Tomography

2014

Electrical Impedance Tomography (EIT)
Literature List

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Categories

CLIN = Clinical Study

ES = Experimental Study

REV = Review

TEN = Technical Note

EDIT = Editorial

CR = Case Report

Electrical Impedance Tomography (EIT)
Literature List

CR	**van der Burg PS et al.**	**Unilateral atelectasis in a preterm infant monitored with electrical impedance tomography: a case report**	*Eur J Pediatr. 2014 Dec; 173(12); 1715-7*
Abstract: Electrical impedance tomography (EIT) is a non-invasive, radiation-free tool to monitor regional changes in ventilation. This report describes, for the first time, that unilateral atelectasis in an extremely low birth weight infant results in a loss of regional ventilation measured by EIT in the affected lung.			
Conclusion: EIT is currently the most promising technique to monitor regional lung aeration continuously at the bedside in this vulnerable population.			
ES	**Bodenstein M et al.**	**Hints for cyclical recruitment of atelectasis during ongoing mechanical ventilation in lavage and oleic acid lung injury detected by SpO_2 oscillations and electrical impedance tomography**	*Exp Lung Res. 2014 Nov; 40(9); 427-38*
Purpose of the Study: Detection of cyclical recruitment of atelectasis after induction of lavage (LAV) or oleic acid injury (OAI) in mechanically ventilated pigs. Primary hypothesis is that oxygen oscillations within the respiratory cycle can be detected by SpO_2 recordings (direct hint). SpO_2 oscillations reflect shunt oscillations that can only be explained by cyclical recruitment of atelectasis. Secondary hypothesis is that electrical impedance tomography (EIT) depicts specific regional changes of lung aeration and of pulmonary mechanical properties (indirect hint). **Materials and Methods:** Three groups (each n = 7) of mechanically ventilated pigs were investigated applying above mentioned methods before and repeatedly after induction of lung injury: (1) sham treated animals (SHAM), (2) LAV, and (3) OAI. **Results:** Early oxygen oscillations occurred in the LAV group (mean calculated amplitude: 73.8 mmHg reflecting shunt oscillation of 11.2% in mean). In the OAI group oxygen oscillations occurred hours after induction of lung injury (mean calculated amplitude: 57.1 mmHg reflecting shunt oscillations of 8.4% in mean). The SHAM group had no relevant oxygen oscillations (<30 mmHg, shunt oscillations < 1.5%). Synchronously to oxygen oscillations, EIT depicted (1) a decrease of ventilation in dorsal areas, (2) an increase in ventral areas, (3) a decrease of especially dependent expiratory impedance, 3) an increase in late inspiratory flow especially in the dependant areas, (4) an increase in the speed of peak expiratory flow (PEF), and (5) a decrease of dorsal late expiratory flow.			
Conclusions: SpO2 and EIT recordings detect events that are interpreted as cyclical recruitment of atelectasis.			
CR	**Guerin C, Frerichs I**	**Getting a better picture of the correlation between lung function and structure using electrical impedance tomography**	*Am J Respir Crit Care Med. 2014 Nov; 190(10); 1186-7*
The authors report the case of a 56-year-old woman with lymphangioleiomyomatosis, which received a single left lung transplant from a cadaveric donor on October 10, 2004. As per the authors, EIT is considered to be potentially useful for monitoring regional ventilation in mechanically ventilated patients. The main benefit of the EIT examination in the presented case was the information obtained regarding the functional status of the native and transplanted lungs.			

CLIN	**Hough J et al.**	**Lung recruitment and endotracheal suction in ventilated preterm infants measured with electrical impedance tomography**	*J Paediatr Child Health. 2014 Nov; 50(11); 884-9*

Aims: Although suctioning is a standard airway maintenance procedure, there are significant associated risks, such as loss of lung volume due to high negative suction pressures. This study aims to assess the extent and duration of change in end-expiratory level (EEL) resulting from endotracheal tube (ETT) suction and to examine the relationship between EEL and regional lung ventilation in ventilated preterm infants with respiratory distress syndrome.

Methods: A prospective observational clinical study of the effect of ETT suction on 20 non-muscle-relaxed preterm infants with respiratory distress syndrome (RDS) on conventional mechanical ventilation was conducted in a neonatal intensive care unit. Ventilation distribution was measured with regional impedance amplitudes and EEL using electrical impedance tomography.

Results: ETT suction resulted in a significant increase in EEL post-suction ($P < 0.01$). Regionally, anterior EEL decreased and posterior EEL increased post-suction, suggesting heterogeneity. Tidal volume was significantly lower in volume-guarantee ventilation compared with pressure-controlled ventilation ($P = 0.04$).

Conclusions: ETT suction in non-muscle-relaxed and ventilated preterm infants with RDS results in significant lung volume increase that is maintained for at least 90 min. Regional differences in distribution of ventilation with ETT suction suggest that the behaviour of the lung is heterogeneous in nature.

CLIN	**Spooner AJ et al.**	**Head-of-bed elevation improves end-expiratory lung volumes in mechanically ventilated subjects: A prospective observational study**	*Respir Care. 2014 Oct; 59(10); 1583-9*

Background: Head-of-bed elevation (HOBE) has been shown to assist in reducing respiratory complications associated with mechanical ventilation; however, there is minimal research describing changes in end-expiratory lung volume. This study aims to investigate changes in end-expiratory lung volume in a supine position and 2 levels of HOBE.

Methods: Twenty postoperative cardiac surgery subjects were examined using electrical impedance tomography. End-expiratory lung impedance (EELI) was recorded as a surrogate measurement of end-expiratory lung volume in a supine position and at 20° and then 30°.

Results: Significant increases in end-expiratory lung volume were seen at both 20° and 30° HOBE in all lung regions, except the anterior, with the largest changes from baseline (supine) seen at 30°. From baseline to 30° HOBE, global EELI increased by 1,327 impedance units (95% CI 1,080-1,573, $P < .001$). EELI increased by 1,007 units (95% CI 880-1,134, $P < .001$) in the left lung region and by 320 impedance units (95% CI 188-451, $P < .001$) in the right lung. Posterior increases of 1,544 impedance units (95% CI 1,405-1,682, $P < .001$) were also seen. EELI decreased anteriorly, with the largest decreases occurring at 30° (-335 impedance units, 95% CI -486 to -183, $P < .001$).

Conclusions: HOBE significantly increases global and regional end-expiratory lung volume; therefore, unless contraindicated, all mechanically ventilated patients should be positioned with HOBE.

CR	**Dostal P et al.**	**Assessment of regional ventilation with the electrical impedance tomography in a patient after asphyxial cardiac arrest**	*Resuscitation 2014 Aug; 85(8); e115-7*

The authors report the case of a 61-year-old man admitted after successful resuscitation from asystolic out-of-hospital cardiac arrest (OHCA) following a short period of severe dyspnoea. In this patient, an EIT was used to visualize and quantify the distribution of ventilation, which helped the authors to recognize the cause of cardiac arrest.

CLIN	**Krause U et al.**	**Monitoring of regional lung ventilation using electrical impedance tomography after cardiac surgery in infants and children**	*Pediatr Cardiol. 2014 Aug; 35(6); 990-7*

Abstract: Electrical impedance tomography (EIT) is a noninvasive method to monitor regional lung ventilation in infants and children without using radiation. The objective of this prospective study was to determine the value of EIT as an additional monitoring tool to assess regional lung ventilation after pediatric cardiac surgery for congenital heart disease in infants and children. EIT monitoring was performed in a prospective study comprising 30 pediatric patients who were mechanically ventilated after cardiac surgery. Data were analyzed off-line with respect to regional lung ventilation in different clinical situations. EIT data were correlated with respirator settings and arterial carbon dioxide (CO_2) partial pressure in the blood. In 29 of 30 patients, regional ventilation of the lung could sufficiently and reliably be monitored by means of EIT. The effects of the transition from mechanical ventilation to spontaneous breathing after extubation on regional lung ventilation were studied. After extubation, a significant decrease of relative impedance changes was evident. In addition, a negative correlation of arterial CO_2 partial pressure and relative impedance changes could be shown. EIT was sufficient to discriminate differences of regional lung ventilation in children and adolescents after cardiac surgery. EIT reliably provided additional information on regional lung ventilation in children after cardiac surgery. Neither chest tubes nor pacemaker wires nor the intensive care unit environment interfered with the application of EIT. EIT therefore may be used as an additional real-time monitoring tool in pediatric cardiac intensive care because it is noninvasive.

CR	**Lehmann S et al.**	**Monitoring of lobectomy in cystic fibrosis with electrical impedance tomography – a new diagnostic tool**	*Biomed Tech (Berl). 2014 Aug; 4 pages*

Abstract: Electrical impedance tomography (EIT) is a radiation-free technique generating cross-sectional images of the lung. EIT visualizes global and regional ventilation by illustrating the distribution of electrical bioimpedance. With an electrode belt around the patient's thorax, rotating injection-couples of a harmless alternating current allow voltage measurement of the remaining electrodes. This enables the reconstruction of a tomogram with highly dynamic changes within ventilation. We report on a female six-year-old patient with cystic fibrosis and complete destruction of the upper and middle lobe of the right lung. Lobectomy, a rare therapeutic option in patients with cystic fibrosis that needs to be considered in cases of severe localized destruction, was performed. We show a pre- and postoperative documentation of static (radiology) and dynamic investigation tools (spirometry) in correlation with EIT as a new non-invasive and radiation-free diagnostic tool for this patient group.

EDIT	**Constantin JM et al.**	**Electrical impedance tomography: so close to touching the holy grail**	*Crit Care. 2014 Jul; 18(4):164*

Abstract: Electrical impedance tomography is a new technology giving us lung imaging that may allow lung function to be monitored at the bedside. Several applications have been studied to guide mechanical ventilation at the bedside with electrical impedance tomography. Positive end-expiratory pressure trials guided by electrical impedance tomography are relevant in terms of recruited volume or homogeneity of the lung. Tidal impedance variation is a new parameter of electrical impedance tomography that may help physicians with ventilator settings in acute respiratory distress syndrome patients. This parameter is able to identify the onset of overdistention in the nondependent part and recruitment in the dependent part. Electrical impedance tomography presents a big step forward in mechanical ventilation.

CLIN	**Bläser D et al.**	**Unilateral empyema impacts the assessment of regional lung ventilation by electrical impedance tomography**	*Physiol. Meas. 2014 Jun; 35(6); 975–83*

Abstract: Several studies have shown the ability of electrical impedance tomography (EIT) to assess regional ventilation distribution in human lungs. Fluid accumulation in the pleural space as in empyema, typically occurring on one chest side, may influence the distribution of ventilation and the corresponding EIT findings. The aim of our study was to examine this effect on the assessment of regional ventilation by EIT. Six patients suffering from unilateral empyema and intubated with a double-lumen endotracheal tube were studied. EIT data were acquired during volume-controlled ventilation with bilateral (tidal volume (V_T): 800 ml) and unilateral ventilation (V_T: 400 ml) of the right and left lungs. Mean tidal amplitudes of the EIT signal were calculated in all image pixels. The sums of these values, expressed as relative impedance change (rel. ΔZ), were then determined in whole images and functionally defined regions-of-interest (ROI). The sums of rel. ΔZ calculated during the two cases of one-lung ventilation either on the affected or unaffected side were significantly smaller than during bilateral ventilation. However, in contrast to previous findings in patients with no pleural pathology, very low values of rel. ΔZ were found when the lung on the affected side was ventilated. ROI-based analysis rendered higher values than the whole-image analysis in this case, nonetheless, the values were significantly smaller than when the unaffected side was ventilated in spite of identical V_T. In conclusion, our results indicate that the presence of empyema may affect the quantitative evaluation of regional lung ventilation by EIT.

REV	**Frerichs I et al.**	**Electrical impedance tomography imaging of the cardiopulmonary system**	*Curr Opin Crit Care. 2014 Jun; 20(3) ;323-32*

Purpose of review: This review article summarizes the recent advances in electrical impedance tomography (EIT) related to cardiopulmonary imaging and monitoring on the background of the 30-year development of this technology.

Recent findings: EIT is expected to become a bedside tool for monitoring and guiding ventilator therapy. In this context, several studies applied EIT to determine spatial ventilation distribution during different ventilation modes and settings. EIT was increasingly combined with other signals, such as airway pressure, enabling the assessment of regional respiratory system mechanics. EIT was for the first time used prospectively to define ventilator settings in an experimental and a clinical study. Increased neonatal and paediatric use of EIT was noted. Only few studies focused on cardiac function and lung perfusion. Advanced radiological imaging techniques were applied to assess EIT performance in detecting regional lung ventilation. New approaches to improve the quality of thoracic EIT images were proposed.

Summary: EIT is not routinely used in a clinical setting, but the interest in EIT is evident. The major task for EIT research is to provide the clinicians with guidelines how to conduct, analyse and interpret EIT examinations and combine them with other medical techniques so as to meaningfully impact the clinical decision-making.

CLIN	**van der Burg PS et al.**	**Cross-sectional changes in lung volume measured by electrical impedance tomography are representative for the whole lung in ventilated preterm infants**	*Crit Care Med. 2014 Jun;42(6):1524-30*

Objective: Electrical impedance tomography measures lung volume in a cross-sectional slice of the lung. Whether these cross-sectional volume changes are representative of the whole lung has only been investigated in adults, showing conflicting results. This study aimed to compare cross-sectional and whole lung volume changes using electrical impedance tomography and respiratory inductive plethysmography.

Design: A prospective, single-center, observational, nonrandomized study.

Setting: The study was conducted in a neonatal ICU in the Netherlands.

Patients: High-frequency ventilated preterm infants with respiratory distress syndrome.

Interventions: Cross-sectional and whole lung volume changes were continuously and simultaneously measured by, respectively, electrical impedance tomography and respiratory inductive plethysmography during a stepwise recruitment procedure. End-expiratory lung volume changes were assessed by mapping the inflation and deflation limbs using both the pressure/impedance and pressure/inductance pairs and characterized by calculating the inflection points. In addition, oscillatory tidal volume changes were assessed at each pressure step.

Measurements and Main Results: Twenty-three infants were included in the study. Of these, eight infants had to be excluded because the quality of the registration was insufficient for analysis (two electrical impedance tomography and six respiratory inductive plethysmography). In the remaining 15 infants (gestational age 28.0 ± 2.6 wk; birth weight 1,027 ± 514 g), end-expiratory lung volume changes measured by electrical impedance tomography were significantly correlated to respiratory inductive plethysmography measurements in 12 patients (mean $r = 0.93 \pm 0.05$). This was also true for the upper inflection point on the inflation ($r = 0.91$, $p < 0.01$) and deflation limb ($r = 0.83$, $p < 0.01$). In 13 patients, impedance and inductance data also correlated significantly on oscillatory tidal volume/pressure relationships (mean $r = 0.81 \pm 0.18$).

Conclusions: This study shows that cross-sectional lung volume changes measured by electrical impedance tomography are representative for the whole lung and that this concept also applies to newborn infants.

CLIN	**Blankman P et al.**	**Detection of 'best' positive end-expiratory pressure derived from electrical impedance tomography parameters during a decremental positive endexpiratory pressure trial**	*Crit Care 2014 May; 18(3); R95*

Introduction: This study compares different parameters derived from electrical impedance tomography (EIT) data to define 'best' positive end-expiratory pressure (PEEP) during a decremental PEEP trial in mechanically-ventilated patients. 'Best' PEEP is regarded as minimal lung collapse and overdistention in order to prevent ventilator-induced lung injury.

Methods: A decremental PEEP trial (from 15 to 0 cm H_2O PEEP in 4 steps) was performed in 12 postcardiac surgery patients on the ICU. At each PEEP step, EIT measurements were performed and from this data the following were calculated: tidal impedance variation (TIV), regional compliance, ventilation surface area (VSA), center of ventilation (COV), regional ventilation delay (RVD index), global inhomogeneity (GI index), and intratidal gas distribution. From the latter parameter we developed the ITV index as a new homogeneity parameter. The EIT parameters were compared with dynamic compliance and the PaO_2/FiO_2 ratio.

Results: Dynamic compliance and the PaO_2/FiO_2 ratio had the highest value at 10 and 15 cm H_2O PEEP, respectively. TIV, regional compliance and VSA had a maximum value at 5 cm H_2O PEEP for the non-dependent lung region and a maximal value at 15 cm H_2O PEEP for the dependent lung region. GI index showed the lowest value at 10 cm H_2O PEEP, whereas for COV and the RVD index this was at 15 cm H_2O PEEP. The intratidal gas distribution showed an equal contribution of both lung regions at a specific PEEP level in each patient.

Conclusion: In post-cardiac surgery patients, the ITV index was comparable with dynamic compliance to indicate 'best' PEEP. The ITV index can visualize the PEEP level at which ventilation of the non-dependent region is diminished, indicating overdistention. Additional studies should test whether application of this specific PEEP level leads to better outcome and also confirm these results in patients with acute respiratory distress syndrome.

CLIN	**Corley A et al.**	**Lung volume changes during cleaning of closed endotracheal suction catheters: a randomized crossover study using electrical impedance tomography**	*Respir Care. 2014 Apr; 59(4); 497-503*

Background: Airway suctioning in mechanically ventilated patients is required to maintain airway patency. Closed suction catheters (CSCs) minimize lung volume loss during suctioning but require cleaning post-suction. Despite their widespread use, there is no published evidence examining lung volumes during CSC cleaning. The study objectives were to quantify lung volume changes during CSC cleaning and to determine whether these changes were preventable using a CSC with a valve in situ between the airway and catheter cleaning chamber.

Methods: This prospective randomized crossover study was conducted in a metropolitan tertiary ICU. Ten patients mechanically ventilated via volume-controlled synchronized intermittent mandatory ventilation (SIMV-VC) and requiring manual hyperinflation (MHI) were included in this study. CSC cleaning was performed using 2 different brands of CSC (one with a valve [Ballard Trach Care 72, Kimberly-Clark, Roswell, Georgia] and one without [Portex Steri-Cath DL, Smiths Medical, Dublin, Ohio]). The maneuvers were performed during both SIMV-VC and MHI. Lung volume change was measured via impedance change using electrical impedance tomography. A mixed model was used to compare the estimated means.

Results: During cleaning of the valveless CSC, significant decreases in lung impedance occurred during MHI (-2563 impedance units, 95% CI 2213-2913, P < .001), and significant increases in lung impedance occurred during SIMV (762 impedance units, 95% CI 452-1072, P < .001). In contrast, cleaning of the CSC with a valve in situ resulted in non-significant lung volume changes and maintenance of normal ventilation during MHI and SIMV-VC, respectively (188 impedance units, 95% CI -136 to 511, P = .22; and 22 impedance units, 95% CI -342 to 299, P = .89).

Conclusion: When there is no valve between the airway and suction catheter, cleaning of the CSC results in significant derangements in lung volume. Therefore, the presence of such a valve should be considered essential in preserving lung volumes and uninterrupted ventilation in mechanically ventilated patients.

ES	**Czaplik M et al.**	**Setting ventilation parameters guided by electrical impedance tomography in an animal trial of acute respiratory distress syndrome**	*Proc. SPIE 9038, Medical Imaging 2014 Mar; 90381Y*

Abstract: Since mechanical ventilation can cause harm to lung tissue it should be as protective as possible. Whereas numerous options exist to set ventilator parameters, an adequate monitoring is lacking up to date. The Electrical Impedance Tomography (EIT) provides a non-invasive visualization of ventilation which is relatively easy to apply and commercially available. Although there are a number of published measures and parameters derived from EIT, it is not clear how to use EIT to improve clinical outcome of e.g. patients suffering from acute respiratory distress syndrome (ARDS), a severe disease with a high mortality rate. On the one hand, parameters should be easy to obtain, on the other hand clinical algorithms should consider them to optimize ventilator settings. The so called Global inhomogeneity (GI) index bases on the fact that ARDS is characterized by an inhomogeneous injury pattern. By applying positive endexpiratory pressures (PEEP), homogeneity should be attained. In this study, ARDS was induced by a double hit procedure in six pigs. They were randomly assigned to either the EIT or the control group. Whereas in the control group the ARDS network table was used to set the PEEP according to the current inspiratory oxygen fraction, in the EIT group the GI index was calculated during a decremental PEEP trial. PEEP was kept when GI index was lowest. Interestingly, PEEP was significantly higher in the EIT group. Additionally, two of these animals died ahead of the schedule. Obviously, not only homogeneity of ventilation distribution matters but also limitation of over-distension.

CLIN	**Karsten J et al.**	**The suitability of EIT to estimate EELV in a clinical trial compared to oxygen wash-in/wash-out technique**	*Biomed Tech (Berl). 2014 Feb; 59(1); 59-64*

Introduction: Open endotracheal suctioning procedure (OSP) and recruitment manoeuvre (RM) are known to induce severe alterations of end-expiratory lung volume (EELV). We hypothesised that EIT lung volumes lack clinical validity. We studied the suitability of EIT to estimate EELV compared to oxygen wash-in/wash-out technique.

Methods: Fifty-four postoperative cardiac surgery patients were enrolled and received standardized ventilation and OSP. Patients were randomized into two groups receiving either RM after suctioning (group RM) or no RM (group NRM). Measurements were conducted at the following time points: Baseline (T1), after suctioning (T2), after RM or NRM (T3), and 15 and 30 min after T3 (T4 and T5). We measured EELV using the oxygen wash-in/wash-out technique (EELVO2) and computed EELV from EIT ($EELV_{EIT}$) by the following formula: $EELV_{EIT}T_{x,y...}=EELV_{O2}+\Delta EELI\times V_T/\Delta Z$. $EELV_{EIT}$ values were compared with $EELV_{O2}$ using Bland-Altman analysis and Pearson correlation.

Results: Limits of agreement ranged from -0.83 to 1.31 l. Pearson correlation revealed significant results. There was no significant impact of RM or NRM on $EELV_{O2}$-$EELV_{EIT}$ relationship (p=0.21; p=0.23).

Discussion: During typical routine respiratory manoeuvres like endotracheal suctioning or alveolar recruitment, EELV cannot be estimated by EIT with reasonable accuracy.