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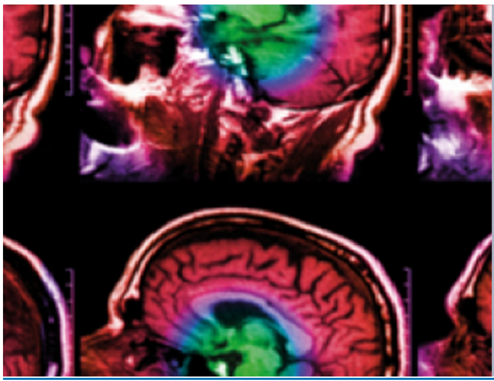

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TOPICAL REVIEW

Thoracic electrical impedance tomography in Chinese hospitals: a review of clinical research and daily applications

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Keywords: acute respiratory distress syndrome, electrical impedance tomography, intensive care units, mechanical ventilation, positive end-expiratory pressure, rehabilitation, surgery

Abstract

Chinese scientists and researchers have a long history with electrical impedance tomography (EIT), which can be dated back to the 1980s. No commercial EIT devices for chest imaging were available until the year 2014 when the first device received its approval from the China Food and Drug Administration. Ever since then, clinical research and daily applications have taken place in Chinese hospitals. Up to this date (2019.11) 47 hospitals have been equipped with 50 EIT devices. Twenty-three SCI publications are recorded and a further 21 clinical trials are registered. Thoracic EIT is mainly used in patients before or after surgery, or in intensive care units (ICU). Application fields include the development of strategies for protective lung ventilation (e.g. tidal volume and positive end-expiratory pressure (PEEP) titration, recruitment, choice of ventilation mode and weaning from ventilator), regional lung perfusion monitoring, perioperative monitoring, and potential feedback for rehabilitation. The main challenges for promoting clinical use of EIT are the financial cost and the education of personnel. In this review, the past, present and future of EIT in China are introduced and discussed.

1. Brief introduction of EIT history in China

Electrical impedance tomography (EIT) research in China can be dated back to the 1980s. EIT applications focus mainly on brain and breast imaging in the medical field and on industrial uses of EIT. Researchers from the Fourth Military Medical University and Chongqing University started to study EIT image reconstruction methods and hardware construction in the last century. Results were documented as publications and patents.

Thoracic EIT was rarely studied in China until the breakthrough of the first commercial device receiving its China Food and Drug Administration (CFDA) approval in 2014.04, but has experienced impressive growth since then. In the beginning, several ICUs in major hospitals, especially university hospitals, purchased thoracic EIT devices. Leading opinion leaders in the field were (and still are) conducting clinical EIT trials. With the collected experience and the progress of clinical studies, topics regarding EIT clinical applications have been presented in various domestic scientific conferences. More and more Chinese medical doctors have got to know about this technology and its correlative application fields. Chest imaging dominates current preclinical and clinical EIT research in China, reflecting the general trend that identified thoracic EIT as the most relevant use of EIT in the medical field. In this topical review, we therefore describe the clinical research and daily applications using thoracic EIT in Chinese research institutions and clinical departments.

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2. Status of clinical research and daily applications

Up to this date (2019.11) 47 hospitals have been equipped with 50 EIT devices in China (including Taiwan). These are tertiary hospitals at provincial or national levels with bed capacity exceeding 500, located in different regions of China (e.g. Peking Union Medical College Hospital, Beijing, Northern China; Sichuan Provincial People's Hospital, Western China; The First Affiliated Hospital of Guangzhou Medical University, Southern China; Shanghai Chest Hospital, Eastern China; Far Eastern Memorial Hospital, Taiwan Island). The departments that acquired EIT are mainly Critical Care Medicine and Anaesthesiology departments. The end-users of EIT include intensivists, anaesthesiologists, respiratory therapists, and rehabilitation physicians.

An article search was performed on PubMed (www.ncbi.nlm.nih.gov). The used keywords included 'electrical impedance tomography', 'EIT', 'China', 'Taiwan', 'lung', 'thoracic', 'pulmonary', 'airway', 'respiratory' (individually or in their combinations). Papers published in SCI Journals that were related to EIT technology and carried out by Chinese research teams were reviewed. The research activities focused on thoracic EIT with either animal or human subjects and are summarised in table 1 (only papers with full text in English were listed). After the launch of the first thoracic EIT device in China, the first SCI journal paper was published a year later in 2015 (Long *et al* 2015). Until November 2019, 20 SCI journal papers were published where Chinese clinical teams were involved and the data were collected in China (including 15 original research papers, three case reports, and two research letters). In addition, three papers were in press and in the phase of proofreading and were also summarised in table 1. Further, the search for new unpublished studies was performed on two clinical trial databases with similar search criteria. In total, 21 clinical trials were found in clinicaltrials.gov ($n = 11$) or the China Clinical Trials Register Center (www.chictr.org.cn, $n = 10$), which have not been published in English scientific journals. Their registration numbers and main objectives are described in table 2.

The applications mainly focused on adjusting ventilator settings (e.g. titration of positive end-expiratory pressure (PEEP) and tidal volume; comparing different ventilation modes), evaluation of treatment effectiveness (e.g. the effect of recruitment manoeuvre, suctioning or rehabilitation programme), monitoring patients with spontaneous breathing (e.g. ventilation distribution during support/assist ventilation, spontaneous breathing trial (SBT) and weaning from ventilator), perioperative monitoring and evaluation of surgery, and EIT technique development or validation. In the following, the application fields are discussed in detail and examples of the works from Chinese groups are described.

2.1. Guiding ventilator settings

An adequate PEEP is recommended for patients with acute respiratory distress syndrome (ARDS) to keep the alveoli open and prevent atelectasis (Ferguson *et al* 2012). Insufficient PEEP cannot maintain alveoli open while inappropriately high PEEP may lead to various lung damages (Brower *et al* 2004). Individualising PEEP is a common consensus but the superior method is still under debate. EIT-guided PEEP titration is one of the well-accepted applications of thoracic EIT (Frerichs *et al* 2017). Different individualised EIT titration methods have been proposed. In a study from the Netherlands with 12 post-cardiac surgery patients, these EIT-derived measures did not differ from each other (Blankman *et al* 2014). However in a recent study with 30 ARDS patients, it was found that in about 10% of the patients the EIT-derived measures exhibited high differences when analysing the same patients (Zhao *et al* 2019d). The patient groups were different between these two studies (post-surgery vs. ARDS), and some of the titration methods and the sample sizes were different. Since the EIT-derived parameters capture various aspects of lung function and ventilation, it was proposed that the existence of differences in the recommended PEEP among the EIT measures might be a good indicator of functional lung status (Zhao *et al* 2019d). The authors recommended calculating more than one EIT measure at a time to confirm the selected PEEP level.

Retrospective clinical studies and prospective animal experiments demonstrated the use and superiority of EIT for PEEP titration (Meier *et al* 2008, Wolf *et al* 2013, Hochhausen *et al* 2017). The group from the Far Eastern Memorial Hospital conducted the first prospective outcome study using PEEP titration with EIT in ARDS patients (Zhao *et al* 2019a). As compared with the retrospective group in which PEEP was titrated with quasi-static pressure–volume (PV) curve (lower inflection point plus 2 cmH_2O as selected PEEP), the EIT-based PEEP titration was associated with improved oxygenation, compliance, driving pressure, and weaning success rate (Zhao *et al* 2019a). In this study, regional respiratory compliance was computed at each PEEP level using the EIT method proposed previously (Costa *et al* 2009). The PEEP levels ($PEEP_{max\text{-}C}$) of individual maximum regional compliance were identified during decremental PEEP trials (figure 1). At PEEP levels higher than $PEEP_{max\text{-}C}$, overdistension percentages were estimated. At PEEP levels lower than $PEEP_{max\text{-}C}$, the collapse percentages were calculated. The optimal PEEP level selected for the patients was the intercept point of cumulated collapse and overdistension percentage curves, which is postulated to provide the best compromise between collapsed and overdistended lung. If the intercept point occurred between two

Table 1. Summary of EIT publications related to Chinese teams and animal/human subjects.

Publication year	Subjects	Study type	Main finding of EIT
2015 (Long *et al* 2015)	18 ARDS patients	Observational	PEEP titration significantly affected regional gas distribution in the lungs, which could be monitored with EIT
2016 (Liu *et al* 2016)	ARDS model in 10 pigs	Experimental	Method developed and evaluated to identify regional overdistension, recruitment and cyclic alveolar collapse
2016 (Hsu *et al* 2016)	19 ARDS patients	Observational	EIT was able to identify slow recruitment associated with late improvements in oxygenation following PEEP change
2016 (He *et al* 2016)	50 OP patients	Randomised-control	EIT-guided PEEP titration led to a better oxygenation and ventilation distribution in patients undergoing laparoscopic abdominal surgery
2016 (Yun *et al* 2016)	20 ARDS patients	Observational	The discrepancy between lung tissue reopening and oxygenation improvement after recruitment manoeuvre was identified with EIT
2017 (Hsu *et al* 2017)	16 patients with PMV	Observational	Ventilation redistribution and ventilation delay based on EIT can help to identify respiratory muscles reactivation
2017 (Sun *et al* 2017a)	15 AECOPD patients	Crossover	EIT could be used to identify better support ventilation mode in regard to ventilation distribution
2017 (Sun *et al* 2018)	1 ARDS patient	Case	Regional airway closure could be confirmed with EIT
2017 (Zhao *et al* 2017)	30 patients during SBT	Observational	Regional ventilation distribution patterns during inspiration were associated with weaning outcomes, and may be used to predict the success of extubation
2018 (Zhao *et al* 2018c)	3 ICU and 1 OP patients	Cases	Various methods of functional EIT imaging were compared under clinical settings
2018 (Zhang *et al* 2018)	41 healthy and 67 obstructive	Observational	EIT could be used to evaluate the degree of obstruction in patients with obstructive ventilatory defects on the global and regional levels
2018 (Zhao *et al* 2018b)	24 patients with OLV	Observational	It is feasible to titrate tidal volume and PEEP at the bedside during OLV using EIT in combination with PaO_2
2018 (Gong *et al* 2018)	1 ARDS patient	Case	EIT reconstruction method improvement
2018 (Wang *et al* 2018)	9 patients with OLV	Observational	EIT can monitor ventilation during minimally invasive thoracic surgery without intrusion in the surgical field
2018 (Zhao *et al* 2018a)	1 MMA patient	Case	The use of EIT to select a suitable method for inspiratory muscle training was possible and useful
2018 (Su *et al* 2018)	23 ARDS patients	Observational	PEEP titration with EIT was explored
2019 (Zhao *et al* 2019a)	55 ARDS patients	Current vs. historical cohorts	As compared with pressure-volume curve, the EIT-guided PEEP titration may be associated with improved oxygenation, respiratory compliance, driving pressure, and weaning success rate
2019 (Zhao *et al* 2019b)	1 PMV patient	Case	Patient immediate responses to IMT can be measured with EIT. Individual IMT strategies can be developed
2019 (Zhao *et al* 2019c)	14 ARDS patients	Observational	Two previously proposed EIT-based methods were not able to assess pulmonary oedema in the clinical settings
2019 (Zhao *et al* 2019d)	30 ARDS patients	Observational	Differences exist in the recommended PEEP among various EIT measures, which might be an indicator of non-recruitable lungs and heterogeneous airway resistances
2019 (Liu *et al* 2019)	100 surgical patients over 65 years old	Randomised-control	PEEP setting with EIT effectively improved oxygenation and lung mechanics during one-lung ventilation compared to a fixed PEEP of 5 cmH_2O in elderly patients undergoing thoracoscopic surgery
2019 (Zhao *et al* 2020)	18 COPD and 7 asthma patients	Observational	Assessing regional air trapping by calculating the regional end-expiratory flow, which could provide diagnostic information for monitoring the disease progression during treatment

Table 1. (Continued)

Publication year	Subjects	Study type	Main finding of EIT
2020 (Yuan *et al* 2020)	18 post-OP patients	Crossover	The change of EELI measured by EIT showed the effects of therapy and body position changes

AECOPD, acute exacerbation of chronic obstructive pulmonary disease; ARDS, acute respiratory distress syndrome; COPD, chronic obstructive pulmonary disease; EELI, end-expiratory lung impedance; IMT, inspiratory muscle training; MMA, methylmalonic acidemia; OLV, one-lung ventilation; PaO_2, arterial partial pressure of O_2; PEEP, positive end-expiratory pressure; PMV, prolonged mechanical ventilation; SBT, spontaneous breathing trial.

Table 2. Registered clinical trials that have not been published yet.

Planned study completion year	Registration number	Investigator	Study type	Main objective
2015	NCT02292992	Lee Chao-Hsien	Crossover	The difference of EELI detected by EIT between nasal pillow mask and HFNC after extubation
2019	NCT02361398	Yun Long	Randomised	PEEP titration with EIT vs. best oxygenation
2018	NCT03112512	Chang Mei Yun	Randomised	PEEP titration with EIT vs. maximal hysteresis
2018	NCT03118804	Liu Songqiao	Observation	Weaning from ventilator guided by EIT
2018	NCT03244761	Jian-Xin Zhou	Crossover	Comparing standard and modified T-HFO in change of PEEP and EELI
2019	NCT03498807	Hou T Chang	Randomised	PEEP titration with EIT vs. PV loop
2019	NCT03738345	Jie Li	Observation	Different flow settings of HFNC for healthy and hypoxemia subjects
2020	NCT03763890	Haibo Qiu	Crossover	Evaluating the impact of PEEP on alveolar heterogeneity
2019	NCT03830099	Jian-Xin Zhou	Observation	Evaluating ventilation distribution in patients after neurosurgery
2019	NCT04081142	Yun Long	Observation	Regional perfusion measurement with EIT plus saline for ICU patients
2019	NCT04081155	Yun Long	Observation	Evaluating the effect of PEEP on regional ventilation and perfusion
2018	ChiCTR-ROC-17011321	Wang Yuguang	Observation	EIT-guided body position selection on clinical outcomes
2019	ChiCTR1800015680	Weng Yibing	Case-control	Weaning strategy development with EIT
2020	ChiCTR1800016754	Hai-rui Liu	Randomised	EIT-guided PEEP titration vs. fixed PEEP in patients under intracranial tumor surgery
2019	ChiCTR1800019359	Meiying Xu	Randomised	EIT-guided PEEP titration vs. fixed PEEP in elderly under lung resection
2019	ChiCTR1900021119	Jingxiang Wu	Randomised	EIT-guided PEEP titration vs. fixed PEEP in elderly under thoracoscopic surgery
2019	ChiCTR1900021649	Hairui Liu	Randomised	Comparing two RM on ventilation distribution and clinical outcomes
2020	ChiCTR1900023897	Tianzuo Li	Randomised	EIT-guided ventilator settings in prolonged general anaesthesia during abdominal surgery
2019	ChiCTR1900025184	Huisheng Xu	Observation	Ventilation distribution during ESD of upper gastrointestinal mucosa
2020	ChiCTR1900025656	Chen Xiaoping	Randomised	Effect of EIT-guided PEEP on right ventricular function

ESD, endoscopic submucosal dissection; HFNC, high flow nasal cannula; RM, recruitment manoeuvre; T-HFO, high-flow oxygen therapy applied to the tracheostomy cannula.

PEEP levels, the selected PEEP corresponded to the PEEP step toward the lowest global inhomogeneity index, which indicated the degree of homogeneity of ventilation distribution (Zhao *et al* 2009). The same group had just completed a prospective randomised study comparing the same EIT-based PEEP with maximal hysteresis of the quasi-static PV curve in moderate-to-severe ARDS patients. Preliminary results for 87 randomised patients were presented at the annual EIT conference in 2019 (Hsu *et al* 2019), suggesting a better survival rate in the EIT group.

Individual PEEP titration may be needed not only for ARDS patients in the ICU but also for patients under surgery. The current practice is that a fixed PEEP of 5 cmH_2O or no PEEP is applied in surgery patients without lung diseases. Liu *et al* have conducted a prospective randomised study comparing

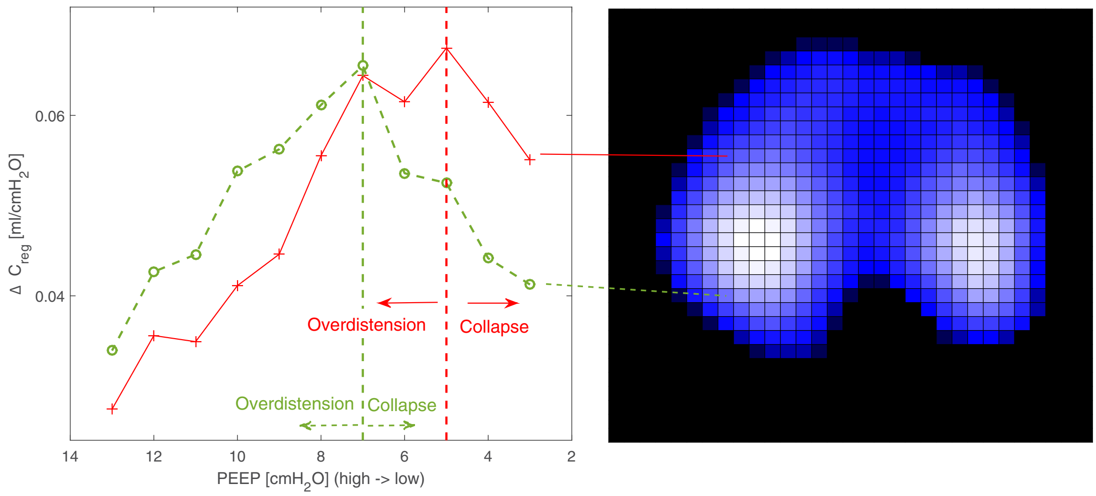

Figure 1. Illustration of overdistension and collapse estimated with regional respiratory compliance. Left: Regional compliance curves towards dependent (green circles) and non-dependent (red pluses) regions during decremental PEEP titration. Right: Tidal variation of relative impedance showing ventilation distribution. At PEEP levels higher than the value where regional compliance reached its maximum, corresponding regions were defined as overdistended. At lower PEEP levels, the corresponding regions were defined as collapsed.

outcomes of EIT-guided PEEP and a fixed PEEP of 5 cmH_2O in 100 elderly patients undergoing thoracoscopic surgery. The results indicated that individual PEEP settings might improve lung mechanics and oxygenation, but not other outcomes such as lung complications and duration of hospitalisation (Liu *et al* 2019). Besides the use of PEEP, small tidal volume is recommended for ARDS during mechanical ventilation (Ferguson *et al* 2012). However, no guideline is given for surgery patients (e.g. for cardiac surgery patients during one-lung ventilation; figure 2). The same research group examined different tidal volumes in nine patients (Wang *et al* 2018), and examined the combination of various PEEP levels in 24 patients under thoracic surgical procedures (Zhao *et al* 2018b). The ventilation distribution and the corresponding oxygenation differed significantly among various tidal volume and PEEP steps. One of the findings of these studies was that it was feasible to titrate tidal volume at the bedside by using EIT in combination with PaO_2.

2.2. Evaluation of treatment effectiveness

It is known that not all regions within the lungs are recruitable in patients with ARDS (Gattinoni *et al* 2006). We might 'guess' whether the lungs are recruitable by considering the oxygenation after the recruitment manoeuvre. However, if the oxygenation is not improved, does it necessarily mean the lungs were not recruited? Should higher recruitment pressure be applied? To answer these questions, Long and his colleagues conducted a study on 20 ARDS patients undergoing a recruitment manoeuvre (Yun *et al* 2016). It was found that even when remarkable lung tissue reopening was detected (confirmed via EIT), the oxygenation did not necessarily increase. The authors suspected that lung ventilationperfusion mismatch could be significant in such patients. Therefore, a workflow evaluating the effect of recruitment manoeuvre was proposed, which required bedside monitoring of ventilation distribution and oxygenation (figure 3).

To evaluate lung perfusion, on the other hand, one may use mathematical methods to analyse the cardiac-related signal in the EIT data. However, the accuracy was shown not to be as high as with the method based on hypertonic saline bolus injection (Borges *et al* 2012). Up to now, no studies have been published on human subjects using EIT with saline bolus injection. Again, Long and his group from the Peking Union Medical College Hospital are conducting a study on lung perfusion detection using EIT and saline bolus injection on various patients (NCT04081142). Preliminary results indicated that with 10 ml 10% saline bolus during end-inspiration or end-expiration hold, lung perfusion could be detected with EIT. No side effects were observed so far. Diagnosis and evaluation of treatment efficacy could be demonstrated in patients with acute pulmonary embolism.

2.3. Monitoring patients with spontaneous breathing

One of the treatment objectives for patients under mechanical ventilation is to resume spontaneous breathing and reduce ventilation support as soon as possible, to minimise the risk of ventilator-associated pneumonia, airway trauma, atrophy and diaphragm dysfunction (Petrof and Hussain 2016). However, spontaneous breathing effort during mechanical ventilation may cause pendelluft, which results in lung damage (Yoshida *et al* 2013). Therefore, it is important to monitor patients with spontaneous breathing to

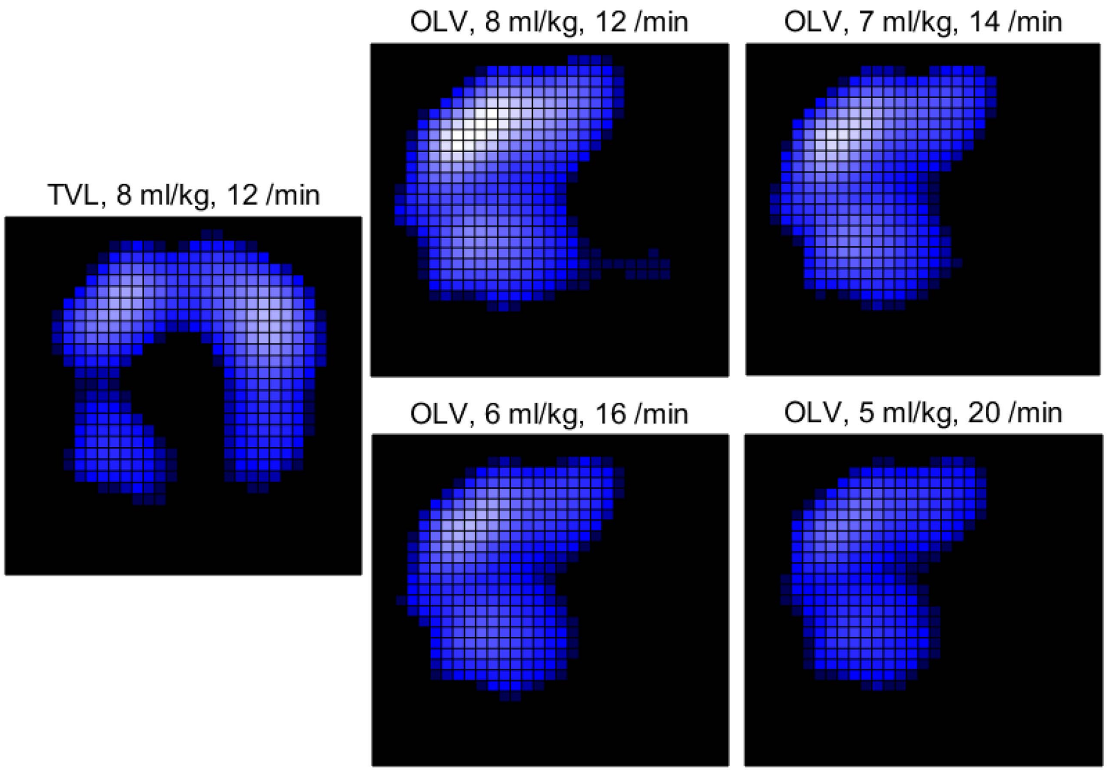

Figure 2. Tidal ventilation distribution in a patient measured with EIT during ventilation of two lungs (TLV) and one lung (OLV). Highly ventilated regions are coded in light blue. Pixel values are relative impedances in arbitrary units. All sub-figures have the same colour scale. The tidal volume and breathing rate are indicated above each image.

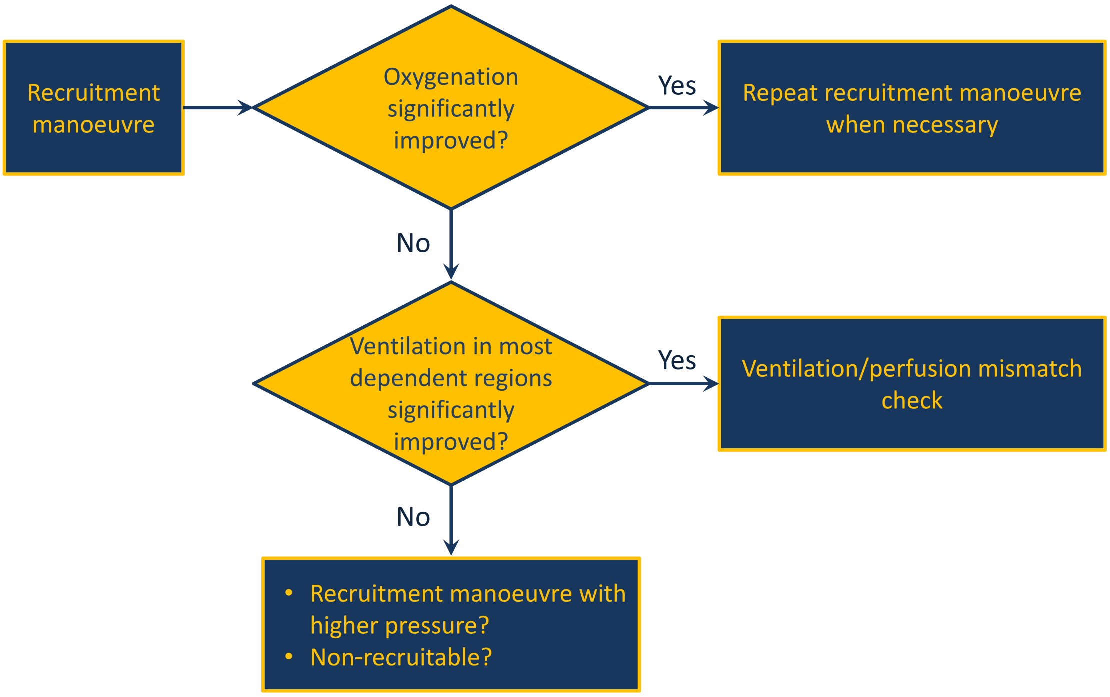

Figure 3. Illustration of the workflow evaluating the effect of a recruitment manoeuvre by means of EIT and oxygenation, based on the information given in the publication (Yun *et al* 2016).

identify potential risks. Sun *et al* compared neurally-adjusted ventilator-assist (NAVA) with pressure support ventilation in 15 COPD patients and found that NAVA increased ventilation distribution in the most dependent regions and reduced dead space (2017a). However, to capture the pendelluft during spontaneous breathing, which usually happens during the beginning of inspiration, intratidal gas distribution should be

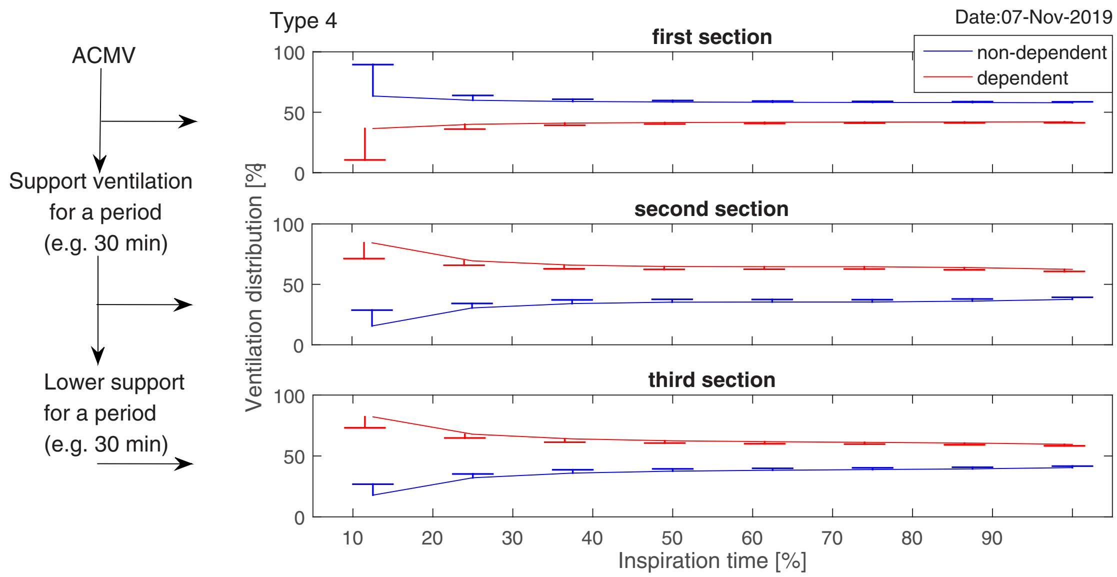

Figure 4. Customised software to evaluate weaning outcome at the bedside. The spontaneous breathing trial is divided into two parts. The first part is with higher support level (lower patient load); the second half is with lower support level (higher patient load). At the end of each period, EIT data are recorded and analysed by the software. The weaning pattern is automatically identified. For the definition and identification of the weaning pattern types please refer to Zhao *et al* (2017). ACMV, assist-control mechanical ventilation mode.

calculated (Lowhagen *et al* 2010). Zhao *et al* analysed 30 patients under prolonged mechanical ventilation. Four different intratidal gas distribution patterns were found, corresponding to different weaning success rates (Zhao *et al* 2017). Following this study, customised software was developed which is now available to end-users to further evaluate whether the method can be used to guide spontaneous breathing trial and to predict weaning outcome (figure 4).

2.4. Perioperative monitoring and evaluation of surgery, and EIT technique development or validation

Anaesthesiologists are interested in ventilation distribution during various types of surgery. Before the era of EIT, no bedside tool could achieve this task. At the moment, several studies are being conducted in this field. For example, the group from the People's Hospital of Quzhou is interested in ventilation distribution during endoscopic submucosal dissection of upper gastrointestinal mucosa (ChiCTR1900025184). The measurement time points during surgery are important, since monopolar or bipolar surgical diathermy may create strong interference to EIT measurement. In the extreme case, EIT hardware could be damaged. Harmonic scalpel use would not influence EIT measurement but it is not widely used compared to diathermy. In another study, the authors have compared post-operative ventilation distribution in cardiac surgical patients after traditional full sternotomy or minimally invasive thoracotomy in 40 patients. While the data are still being analysed, preliminary results show large variations in regional ventilation recovery. The findings indicated that EIT might identify inter-individual differences in postoperative lung function recovery among the patients, enabling personalised therapy and care of patients after extubation.

EIT was also proposed to detect pulmonary oedema (Kunst *et al* 1999, Trepte *et al* 2016). The validation of this approach was carried out in a clinical setting on 14 ARDS patients (Zhao *et al* 2019c). Unfortunately, simple left-to-right and anterior-to-posterior ventilation ratios derived from EIT examinations after postural changes did not reflect total extravascular lung water in the study population. Further advanced measures have to be developed and evaluated to assess the level of pulmonary oedema. In another study, several commonly-used functional EIT (fEIT) images, quantifying tidal ventilation distribution, were evaluated in a clinical setting. The pros and cons of those functional EITs were discussed (Zhao *et al* 2018c). A more thorough and deeper understanding of the examined approaches to fEIT image generation was provided. It was confirmed that fEIT based on standard deviation calculation is subject to baseline drift and influenced by signals other than respiration. Therefore, it is rarely used in clinical practice. However, in the case of pendelluft, the phase differences in respiratory signals of various regions cannot be captured by other common fEIT images (i.e. using tidal variation and regression) and the ventilation in certain regions might be underestimated (figure 5).

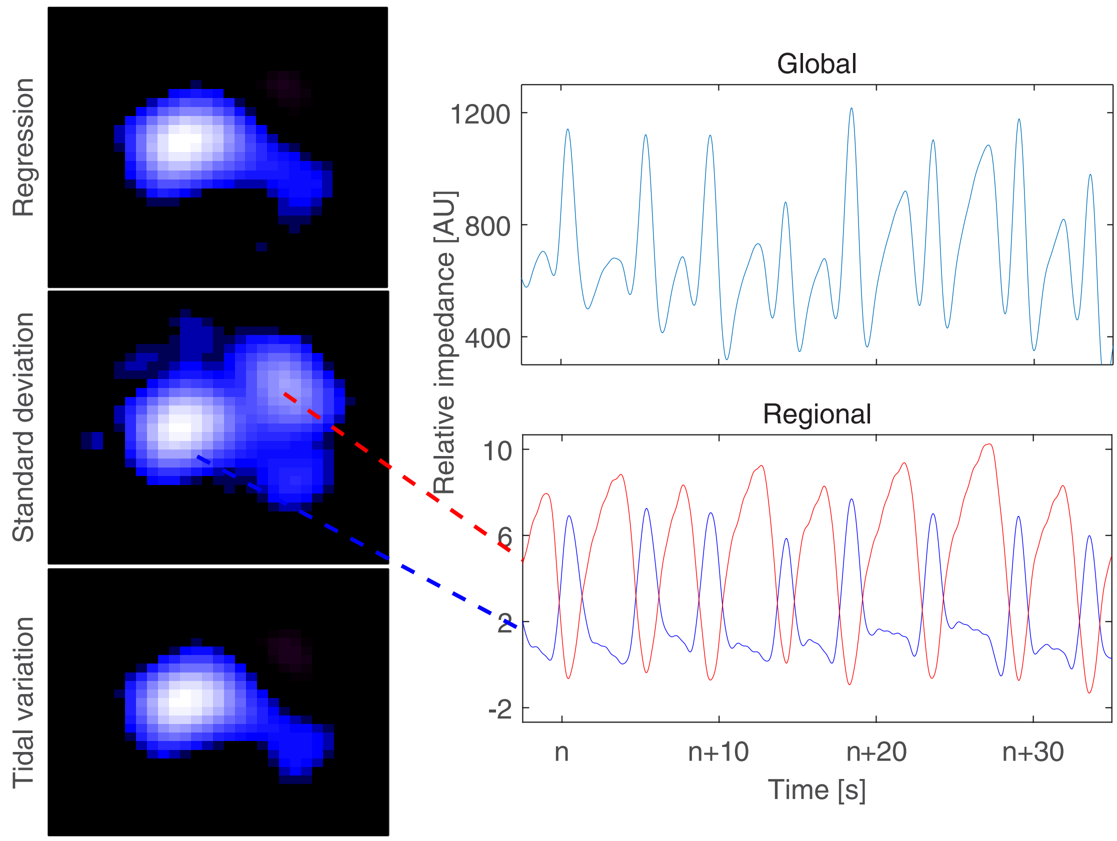

Figure 5. EIT data from a patient with pendelluft. Left: Various functional EIT images. Right: Global and regional relative impedance time curves. AU, arbitrary unit.

3. The challenges of chest EIT in China

Chest EIT provides unique information that no other established techniques can substitute. Before the EIT era, physicians assessed lung function at the bedside, based on global lung mechanics, hemodynamics, blood gas analysis, ultrasound and x-ray images. With EIT, different measures of lung function can be determined on a regional level and their distribution within the chest can be visualized. Thus, in contrast to the other mentioned methods, only EIT reveals the exact spatial distribution of regional lung function. Although the acceptance of chest EIT in hospitals is increasing after 5 years of promotion, there are challenges identified in clinical practice. The challenges we are facing in China at the moment include acquisition and maintenance costs of EIT devices, end-user motivation and workload, and consensus and guidelines for particular applications.

3.1. Acquisition and maintenance costs of EIT devices

EIT data acquisition and device maintenance cost money. Because EIT is only a monitoring tool, not a diagnosis or life-support tool, its necessity relative to investment is often under debate. At this moment, only two hospitals in Taiwan have managed to pass the local regulations and charge patients for their usage of EIT. Many hospitals have expressed their interest in equipping their departments with EIT devices but the reimbursement of the device and measurement costs is their biggest concern. We can imagine, once this issue is solved countrywide, that the number of Chinese hospitals equipped with EIT devices would rapidly increase within a short period.

3.2. End-user motivations and workload

As mentioned at the beginning of the paper, the typical end-users are intensivists, anaesthesiologists, respiratory therapists and rehabilitation physicians. However, these healthcare professionals might potentially have conflicts of interest about other personnel taking care of the patients. In an operation theatre scenario, when an anaesthesiologist wants to add EIT to the routine, this would introduce issues such as additional preparation time or potentially limiting the operation field. Under such circumstances, surgeons might oppose the extra measurement. In an ICU scenario, respiratory therapists are only available in a few ICUs. In most of the ICUs intensivists need to adjust ventilator settings among many other activities. They might be reluctant to add an additional measurement to their routine. ICU nurses could also complain about the EIT measurement procedure, which might be performed during their work on patients. We have met these issues in the early promotion of EIT in the hospital. We consider these to be influenced by a lack of education on EIT technology, which can be eliminated: an embedded EIT educational program in traditional education could be helpful in the long term.

3.3. Consensus and guidelines for particular applications

A consensus paper on chest EIT was recently published (Frerichs *et al* 2017). However, due to a lack of prospective randomised studies at the time of writing that document, specific guidelines for particular applications of exact procedures could not be provided. To use EIT in daily clinical routine, clear guidelines are required on how EIT should be used for predefined applications and how the information should be interpreted. We have summarised terminology and various data analysis methods in the consensus paper (Frerichs *et al* 2017) but an automatic interpretation of the results and ready-to-use software are still warranted. With more upcoming prospective randomised studies, we will be more confident to formulate our guidelines on the daily use of EIT in the future.

3.4. Technical limitations in present EIT systems (hardware and software)

Currently, only one EIT system is available commercially in China, which is PulmoVista 500 from Dräger Medical, Lübeck, Germany. Another major vendor of EIT technology, Timpel, São Paulo, Brazil with the Enlight 1800, plans to introduce the device to the Chinese market in 2021. No further information from other vendors was available at the moment of this review. As of February 2020, no original papers using those devices in Chinese hospitals have been published.

PulmoVista 500 is equipped with electrode belts designed for use in lying patients in intensive care units and operation theatres. Applications for subjects in the sitting position or for women with large breasts are not ideal due to possible bad electrode contact. Certain electrodes with insufficient skin contact would need to be pressed (manually or by leaning on a back rest) or fixed with duct tape. Electrode movement introduces baseline shifts, which could be an issue for long-term monitoring. Besides, ICU patients already have many cables connected to various monitoring devices and the EIT cable may add an extra burden. Wireless electrodes with local analog-to-digital converters could be a solution.

Current online software displays impedance trend, ventilation distribution in different regions of interest, and several indices for PEEP titration. As the clinical application scenarios of EIT dramatically increase, many analyses have to be done offline with customized software for particular applications. Further development of online software should be scenario-based.

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Conflict of interest

Zhanqi Zhao receives a consulting fee from Dräger Medical. Inéz Frerichs reports funding by the European Union's 7th Framework Program for Research and Technological Development (WELCOME, Grant No. 611223), the European Union's Framework Program for Research and Innovation Horizon2020 (CRADL, Grant No. 668259 and WELMO, Grant No. 825572) and reimbursement of speaking fees, congress and travel costs by Dräger Medical. Feng Fu declares no conflict of interest.

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