



The Role of *Electrical Impedance Tomography* in Lung Imaging

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ABSTRACT

Lung imaging in certain conditions, such as in patients with Acute Respiratory Distress Syndrome (ARDS), poses its challenges. Heterogeneity of lung damage in ARDS can only be detected by CT scan, causing treatment delay and increased mortality. Difficulty to perform standard imaging such as CXR in such patients also contributes to the increasing incidence of VALI (Ventilator-Associated Lung Injury) due to diagnosis delay. EIT (Electrical Impedance Tomography) is a novel imaging method that uses electrical impedance modality. EIT is a bedside, continuous imaging method which can depict both solids and fluids (including air) in body cavities, both statically and dynamically. EIT carries the potency to be the primary lung imaging method for patients in intensive care in the future.

Keywords: ARDS, electrical impedance tomography, lung imaging

ABSTRAK

Pencitraan paru mempunyai tantangan tersendiri pada beberapa kondisi pasien, misalnya pada sindrom distres pernapasan akut (*Acute Respiratory Distress Syndrome/ARDS*). Heterogenitas kerusakan paru pada ARDS hanya bisa dideteksi menggunakan *CT scan*, mengakibatkan keterlambatan penanganan serta meningkatnya mortalitas. Kesulitan melakukan pencitraan standar seperti foto polos toraks juga turut berkontribusi dalam meningkatnya insidens VALI (*Ventilator-Associated Lung Injury*) karena keterlambatan diagnosis. EIT (*Electrical Impedance Tomography*) merupakan metode pencitraan baru menggunakan modalitas impedansi listrik. EIT dapat mencitrakan benda padat ataupun fluida (termasuk udara) dalam rongga tubuh dengan baik, baik secara statis maupun dinamis, secara kontinu (*bedside*). EIT berpotensi menjadi metode utama pencitraan paru pasien-pasien di perawatan intensif. **Anthony Christanto. Peran *Electrical Impedance Tomography* pada Pencitraan Paru.**

Kata kunci: ARDS, *electrical impedance tomography*, pencitraan paru

Introduction

Acute Respiratory Distress Syndrome (ARDS) is an acute, life-threatening form of respiratory failure. The newest criteria describe bilateral opacities as a classical finding in chest imaging among patients with ARDS;¹ however, it is a well-known fact that ARDS is a heterogeneous lung injury, with regions of consolidations, normal lung parenchyma, and markedly overdistended lung units.² These heterogeneous injuries imply the difference in lung functions, which is marked by a difference in ventilation. These differences in ventilation are undetectable in the intensive care setting, and this often leads to sub-optimal ventilator settings, leading to the incidence of ventilator-associated lung injury (VALI).³

Electrical Impedance Tomography (EIT) is a novel imaging method that uses electrical

impedance as its modality. Despite its limitations, EIT poses a unique, specific benefit: the real-time capability to perform as a good tool to monitor body functions. Its unusual high temporal resolution makes EIT ideal to be used in fast-acting settings with a need for fast decision making, such as in intensive care units (ICUs).³⁻⁵ It is undoubtedly clear that EIT may pose as the primary imaging tool for ARDS in intensive and critical care settings.⁵

History of EIT

EIT device is first introduced in the 1980s and quickly regained interest between scientific communities. However, it is not until the mid-1990s that modern EIT has been developed and recognized for its potential capability to monitor lung function.³ It was thus described as a potential long-awaited 'holy grail' of lung ventilation management, as EIT usage would

lead to an increased understanding of regional differences of lung ventilation and, therefore, a tailored, effective mechanical ventilation setting (the so-called protective ventilation).⁶

However, despite its staggering claim of benefits, EIT has not found its place in clinical practice. Compared to CT scan, which quickly rose as a well-established diagnostic imaging modality (despite only being about ten years older than EIT), EIT usage has been limited. It is proposed that this was due to 'bad experiences of those who had used it in 'real world,' clinical settings in the very early phase in its development when the EIT were still not capable. The development of EIT has peaked in the 2000s and is now ready for real-world usage, with the emerging of modern EIT devices and their supporting devices (i.e., the electrodes belt). Both devices are now widely



used in intensive care units around the globe and are used as aids in clinical decision-making processes related to patients with ARDS.⁷ EIT has been regarded as an 'ideal' imaging tool; EIT is portable, low cost, completely non-invasive, and non-radioactive, and can work in fast-paced settings.

Principles of EIT

EIT reconstructs the electrical impedance of the test objects using voltage current measurements measured on the objects' surface. To achieve this, EIT uses a series of electrodes placed along the object's surface, with a set of current-emitting electrodes (called 'driving' or 'current' electrodes) commonly a voltage controlled current source (VCCS), and 'sensing' electrodes connected to a voltmeter, which acts as the voltage measurement device.⁸ Traditional EITs use 16 electrocardiography-styled electrodes placed circularly in the chest, just below the nipples. However, this was time-consuming and might be problematic in several patients, such in those unconscious in intensive care settings. Therefore, modern EIT incorporates these electrodes unto a belt-shaped attire, which greatly reducing its preparation time and its difficulty.

To initiate the measurement, the belt is placed similarly to the electrodes (just below the nipple). Then, the electrodes on the belt will alternately act as 'current' and 'sensing' electrodes in a circulate manner. Following Ohm's Law, the impedance of test objects (R) can be determined using both given current (I) applied in the current electrodes and surface potentials (V) measured in the remaining sensing electrodes by the formula $V=IR$. These roles will successively rotate around the entire chest, and thus in one rotation, 208 obtained values (13 values each on 16 electrode positions) are used to reconstruct one cross-sectional EIT image (also called a *frame*).³

Whenever a disturbance arises, such as a regional change of impedance, a regional change of voltage will always occur. As an example, when there is a regional increase of impedance, then the voltages measured behind the affected region will also be increased. This can be explained simply by looking to the formula $V=IR$. As impedance (R) is proportional to voltage (V), regardless of the value of current (I) given, increase of

impedance will always result in increased voltage. After successive measurements and reconstruction algorithms, this area of abnormality will eventually appear as a region of deviation in the EIT frames.

This method is effective for analyzing simple-shaped anomaly; however, for complex shapes, more sophisticated analysis methods are needed. Some examples include finite volume and finite difference approaches with regular grids. Modern EITs utilize the finite element method (FEM)-based linear reconstruction algorithm (using triangle-shaped grids on a mesh-shaped frame) as opposed to Sheffield back-projection algorithm used in traditional EITs. This greatly reduces traditional EITs' limitations, which include reconstruction of non-round-shaped subjects, flexibility in measurements, and ability to suppress corrupt data.^{3,12}

EIT as An Imaging Tool

EIT possesses a particularly high temporal resolution (frame rate) which can reach up to 0.1 milliseconds (10 MHz). This is significantly higher than those of CT or MRI (10 Hz)⁹ and even higher than typical ultrasounds, the cornerstone of temporal imaging.¹⁰ This means that EIT can produce up to 10,000 images per second, which makes it ideal to be used as a bedside, real-time monitoring tool. However, the major disadvantage of EIT compared to modern imaging modalities is its poor spatial resolution. Modern EIT utilizes several support systems, including active surface electrodes to reduce cables-related signal loss, artifacts, and interferences to optimize its spatial resolution.^{5,7,11} However, it is thought that EITs in the future will not be able to achieve significantly higher spatial resolution than today EITs, despite their advancements.³

EIT is particularly useful in evaluating lung function (ventilation), due to high impedance of lung tissue (about five times higher than other soft tissues of the chest). There is also significant increase in lung impedance (around 300%) between inspiration and expirations. For comparison, cardiac activity between systole and diastole gives only 3% change in thoracic impedance. Thus, EIT is very useful in monitoring lung functions without interferences from cardiac activity,³ and ventilation monitoring is currently the most promising clinical application of EIT. This

application of EIT is called the functional EIT (f-EIT) and is the most widespread and well-known use of EIT.

Currently, there are three methods of EIT measurements; these include absolute EIT (a-EIT), time-difference EIT (td-EIT), and frequency-difference or multi-frequency EIT (mf-EIT). Absolute EIT is the simplest and oldest method in which EIT images were produced at any point in time, without the need of reference calculations. In time-difference EIT, time is used as a reference calculation, and images are reconstructed based on the differences of voltage measurements between a given time. In multi-frequency EIT, frequency is used as the reference, following the basic principle that every tissue has a unique frequency, thus giving out different impedance profile. One measurement is used as a reference and other is taken at different frequency to be reconstructed later by specific algorithm.¹²

Functional EIT as a dynamic imaging or monitoring tool uses time-difference EIT as its method to monitor ventilation and its regional distribution, including its corresponding abnormalities including lung collapse, recruitment, and hyperdistension.¹³

The Role of EIT in Chest Imaging

Despite its established use as an excellent monitoring tool for lung ventilation, EIT also carries potency as an excellent lung imaging tool. Modern absolute EIT techniques do not only create an image from a single measurement; Instead, they take several measurements and incorporate them into a single image to be interpreted later (just as conventional imaging method).¹⁴ With this, EIT can also function not only as a monitoring tool, but also as a fast-acting imaging method in the bedside. Modern functional EIT is also able to give intensive care physicians clues regarding early lung abnormalities (VALI or not VALI-related), including pneumothorax, pleural effusion, and lung collapse (atelectasis).³ EIT is even shown to be able to detect as small as 100 mL artificially-induced pneumothorax and pleural effusion in test animals.¹³

Modern EITs are equipped with 'filters', which is used to distinguish several frequencies found in test objects. As such, EIT is able to display an image based on certain frequency,



based on the physician preference (following the basic principle of multi-frequency EIT). As an example, a 'ventilation window' can be used to show areas of ventilation throughout the lung, and a 'perfusion window' to show perfusion of the lung areas. Using these data, combined with conventional imaging (i.e. CXR) and physical examination, physician can determine the diagnosis more accurately; for example, unventilated and unperfused area in EIT is highly suggestive of lung collapse, while unventilated and hypoperfused area is suggestive of pleural effusion. Both cases would have shown similarly in CXR as a 'white lung' appearance.¹⁵

EIT use in critically ill patients, particularly with ARDS, is very promising. Despite the lower spatial resolution of EIT, EIT produces comparable results with CT scan in identifying lung collapse and hyperdistention in those patients. EIT is also very sensitive in detecting pneumothorax with the 'aeration change' window, which will display pneumothorax as a bright, white area of increased impedance, due to air having much higher impedance than lung and its surrounding tissues.¹³ EIT also has a unique capability to measure total lung volumes, which can only be done before using CT scan; EIT can also measure perfusion/ventilation ratio,¹⁵ which is very helpful for clinician in determining further management plan.

Lung Protective Ventilation and EIT

It has been stated before that the aim of EIT usage is to improve the efficacy of the so-called 'protective ventilation'. Traditional definition defines protective ventilation is a low tidal volume ventilation (4-8 mL/kg) with permissive hypercapnia. Several studies showed that low tidal volume ventilation reduces the incidence of VALI.¹⁶ However, this standardized protocol does not necessarily address the basic problem in ARDS, which is reduced functional residual capacity (the volume of functional lung which receives ventilation) as the result of the presence of non-aerated areas.¹⁷ This may explain why up to one third of patients with acute lung injury (ALI), including ARDS, still develop tidal hyperinflation even with low tidal ventilation (LTV).¹⁸

This overdistension, previously only detectable only by CT, is determined based on anatomical, static parameters, with the assumption that these changes will occur just the same throughout the breathing cycle. EIT, in the other hand, revealed that these changes occur dynamically in accordance with positive end expiratory pressure (PEEP) changes. This makes EIT so unique as it enables frequent adjustment of ventilator settings, depending on up-to-date information obtained from the EIT.¹⁸ In fact, the modern, 'new' lung protective ventilation utilizes EIT ('EIT-guided ventilation')

to achieve optimal tidal ventilation, involving lung recruitment manoeuvres associated with body fluids and regional ventilation shifts, easily detected by EIT.¹⁹

EIT in the Future

Currently, td-EIT (functional EIT) is the most widely understood method of EIT, used as ventilation monitoring tool in the intensive care settings as stated before. It is also proposed to be the main lung imaging method for pediatric patients.⁸ Absolute EIT is currently trending in research, with new advancements being made in order to improve a-EIT usage as a diagnostic imaging tool.¹⁴ Aside from its usage in chest imaging, It is now being developed as main screening tool for breast cancer.²⁰ EIT is also proposed to be used as a mobile diagnostic tool to diagnose chest abnormalities on-site.²¹

Conclusion

Despite its limitations, EIT may be considered as a serious alternative method for lung imaging. EIT may not yet replace current standard of lung imaging, such as CT scan, in term of diagnostic imaging. However, EIT holds a place in functional imaging, its usage is crucial for survival in patients with ARDS. The potential of EIT is still not clearly understood and further researches and trials are needed.

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