Dräger medical

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# Electrical Impedance Tomography

## Committed to guiding daily respiratory therapy and helping prevent lung damage

MEDICAL INSIGHT

**Electrical Impedance Tomography (EIT) has received increasing attention from the scientific community for more than 20 years. Its documented contribution to monitoring, quantification and the evaluation of therapeutic measures effectively complements other tools for respiratory monitoring.**

Various research groups have developed EIT prototypes and performed dozens of experimental and clinical studies. Validation of EIT data was a fundamental part in most of these studies. Most found good correlation with other techniques. Regional distribution of ventilation has been compared to CT[1], EBCT[2], SPECT[3], changes of end expiratory lung volume with multibreath nitrogen-washout technique[4], and mass spectrometry[5].
Lung perfusion has been compared to radionuclide imaging[6] and EBCT[7]. Many studies also concluded that EIT implicates the potential to emerge as a useful bedside monitoring tool [1, 8, 9, 10, 11, 12, 17].

Fig. 1: EIT monitoring at the acute point of care.

### EIT research at Dräger

Dräger Medical has always believed in the huge potential offered by EIT. More than five years ago, Dräger established a research project to address a very basic question: Will EIT emerge as a clinical tool for daily routine or will it rather remain a research tool due to the limitations that have been associated with EIT up to now?

Today, one result from this research project is clear: Dräger Medical is on the verge of designing an EIT system that can be used quickly, reliably, and effectively in normal clinical practice on just about any patient. In fact, due to this progress, Dräger Medical believes that EIT systems can be almost as simple to use as a basic cardiac monitor.

**The ability to monitor and quantify both distribution of ventilation and lung volume changes indicates that EIT could be an extremely valuable clinical bedside tool. Dräger Medical is currently defining the requirements for a commercial product in order to solidify this emerging technology as a viable bedside tool for day-to-day use in the ICU.**

This article refers to a technology in general. It does not refer to a commercially available product.

Currently, various clinical cooperation partners are performing studies with Dräger EIT prototypes to evaluate the reliability of the EIT measurements, clinical handling, representation of data, and the usability of EIT for the online assessment of the lungs, as well as for guiding respiratory therapy.

Dräger Medical expects that the clinical value of EIT data will be even higher when intelligently linked to other respiratory and hemodynamic parameters in the critical care workplace. Eventually, EIT should prove to be another key piece in developing a more complete clinical picture of ventilated patients.

## How EIT works

It is well-known that the bioelectric properties of lung tissue are affected by the air content. Consequently, changes in lung volume due to ventilation result in changes of the thoracic impedance.

To monitor thoracic impedance changes, electrodes have to be placed around the patient's chest wall, tiny electrical currents are applied to the body through one electrode pair and the resulting voltages are measured simultaneously at other electrode pairs (Fig. 2).

In EIT, the location of the current application is rotated around the body and thus the current is successively applied to all electrode pairs. After each complete rotation, a cross-sectional image can be calculated by superimposing the voltage profiles of each location (Fig. 3, 4).

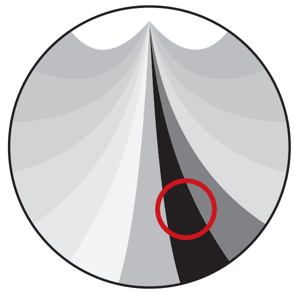

Fig. 3: Voltage profile of a homogeneous object with the current application at the upper position. The red circle represents an area of increased impedance, resulting in higher voltages (dark gray) "behind" that area.

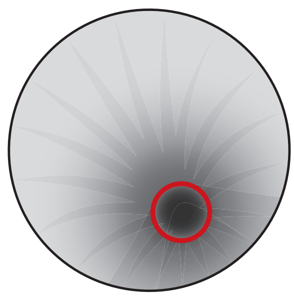

Fig. 4: EIT images are generated by superimposing the 16 voltage profiles into one single image, which displays the area of increased impedance.

## A therapy optimization tool

Currently, CXR or CT scans are the only widely available technologies which can achieve regional information on the lung. While those techniques provide snapshots of morphologic structures with a high spatial resolution, EIT provides functional images with a fairly low spatial, but very high temporal, resolution (Fig. 5). This means that after the assessment of radiological images the clinician can follow the response of the lung to any therapeutic measures on a breath-by-breath basis. Thus, EIT could be used as a complementary tool to radiological techniques in order to monitor the patient's lung function.

## Non-invasive approach supports continuous bedside monitoring

EIT is non-invasive and has no known hazards or adverse effects associated with it. This combination makes EIT well-suited for continuous respiratory monitoring of intensive care patients right at the bedside.

## Breath-by-breath assessment of therapy measures

Today, clinicians use radiological images on a regular basis to assess the regional distribution of ventilation, which largely affects the capability of the lung to exchange gases. For many therapeutic measures, such as adjustments of ventilator settings, recruitment maneuvers, patient positioning, lung suction, and lung puncture, it is highly beneficial to get immediate feedback on a breath-by-breath basis to assess the efficiency of the measure. Besides EIT images, real-time impedance curves and derived parameters also allow easy quantification.

Having this information available at the bedside could also make it easier and more efficient, for example, to optimize PEEP settings[1, 17]. In addition, EIT can allow you to follow the contribution of spontaneous breathing to more homogeneous ventilation.

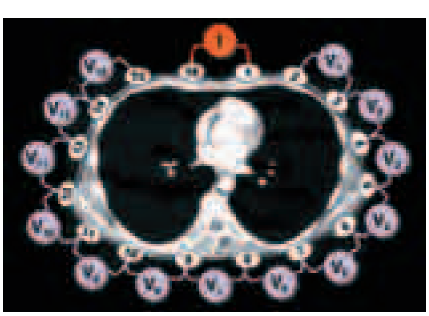

Fig. 2: A first pair of electrodes applies a very small current into the thorax while the remaining 13 electrode pairs measure the resulting voltage signals and their changes.

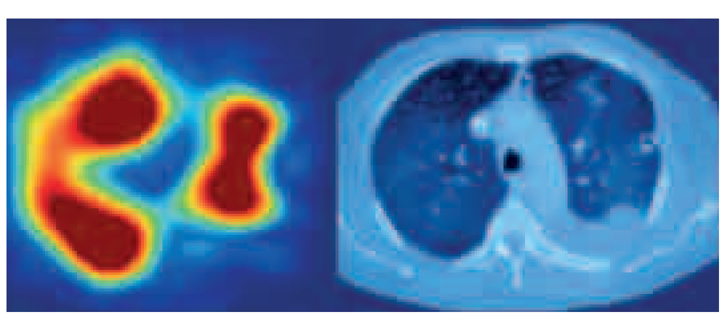

Fig. 5: Functional EIT image (left) and CT scan from a patient with a pleural effusion after rupture of the diaphragm, resulting in a significantly reduced ventilation of the lower left lung. The red color represents regions with the highest volume changes, the non-ventilated regions are displayed in deep blue.

## Regional compliance

Amato et al suggested that the use of a protective ventilatory strategy guided by PV curves may result in a better survival of mechanically ventilated patients[13]. If EIT data are linked with pressure values from the ventilator during slow inflation maneuvers, the regional compliance can be determined. In mechanically ventilated patients suffering from inhomogeneous lung mechanics, the regional pressure volume relationship can differ markedly from conventional global pressure volume curves, which represent the whole lung. The knowledge of those varying mechanical properties, represented by regional inflection points (Fig. 6)[14], could help clinicians guide ventilatory strategy more precisely, all with the goal of avoiding regional lung damage.

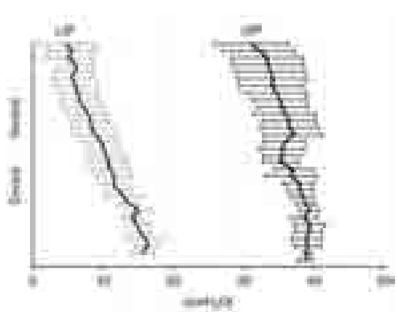

Fig. 6: Regional lower (LIP) and upper (UIP) inflection points of nine mechanically ventilated patients in the dorsal to ventral direction in an approximate 3 cm slice of the thorax measured by electrical impedance tomography (EIT) (mean and standard deviation).

## Lung perfusion

If EIT data are filtered in the bandwidth of the heart rate, changes of lung perfusion and cardiac activity can be displayed and quantified by EIT[15] as well. For example, the reduction of lung perfusion due to a recruitment maneuver could be directly monitored and quantified by EIT. The distribution of lung perfusion could be related to the distribution of ventilation, thus providing the ventilation/perfusion ratio. Such an image, combined with numeric parameters, could provide clinicians with even more insight into why the gas exchange of the patient might be compromised.

## Avoiding complications

Once clinicians have gathered sufficient experience with the online interpretation of EIT data, this technology could emerge to be a significant diagnostic method for the treatment of ICU patients with respiratory complications.

Based on this information, the physician may get useful feedback for optimizing the most critical ventilator settings, such as inspiratory pressure and PEEP; all with the goal of achieving a better gas exchange due to a more homogeneous ventilation, to detect and reduce atelectasis, tidal recruitment, and overdistension. This may all contribute to a reduction of ventilator-induced lung injury.

## Perceived limitations of EIT in clinical routine

Even though the first EIT devices were developed more than 25 years ago, up to now the use of EIT has been limited to a fairly small number of experts and research groups. These groups continue to investigate the technology in the context of various scientific studies. However, it seems that the "path to the Holy Grail"[16] is longer than was expected initially.

This begs the question: What are the reasons why EIT has not yet found its place in the daily clinical routine that it obviously deserves?

The lack of EIT adoption as a viable, routine bedside clinical tool is likely due to the perception that EIT devices still are not sufficiently adapted to "real-world" requirements for the use in ICUs, and that is for various reasons:

For example, a patient's intrathoracic bioelectric properties are only slightly changed by mechanical ventilation, changes of end expiratory lung volume, and cardiac activity. So far, the electronics used for EIT have been developed to a point where they could reliably be used in animal trials, healthy humans, and even in

## Enhancing evaluation of EELV changes

It is common sense that an increase of end-expiratory lung volume (EELV) is not necessarily beneficial to the patient. EIT could help clinicians to assess whether an increase of EELV was mainly due to reopening of atelectatic lung regions or rather caused by overdistension (Fig. 7).

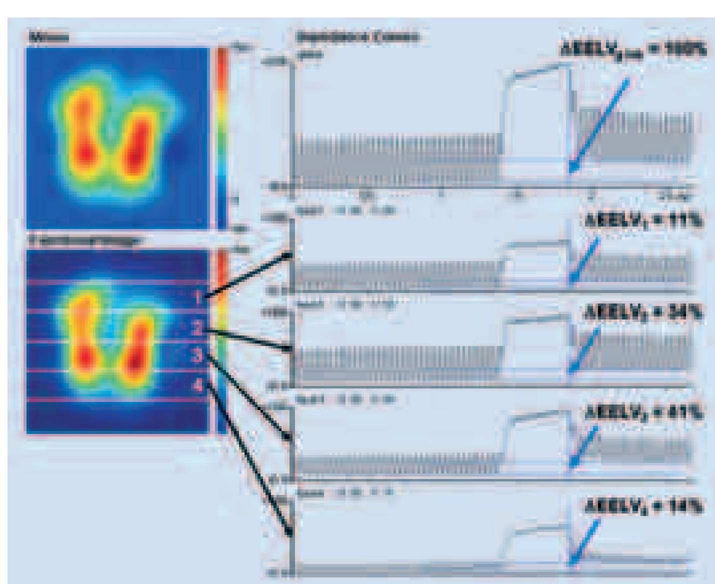


Fig. 7: Changes of EELV after a recruitment maneuver. While the upper curve displays global impedance changes (representing volume changes within the whole EIT slice) the four curves below reflect the regions defined in the functional image in ventral-dorsal orientation. In this patient, EELV increased mostly in region 3 (41%).

"My general idea of EIT is that it is a giant step forward in the handling of ventilator patients. I think EIT will bring a new clarity into handling patients with uneven lung disease, how to recruit, and how to optimize PEEP. Even if it provides less sharp pictures than CT, you have it continuously at the bedside. That is really fantastic."
**Prof. Dr. med. Ola Stenqvist, 2005**
**Dept. of Anesthesia and Intensive Care, Sahlgrenska University Hospital, Göteborg, Sweden**

many patients. However, in patients with massive lung or tissue edema, the tiny impedance changes caused by ventilation can be up to ten times smaller than that in healthy subjects. Many prototypes simply failed to detect pulmonary and cardiac activity in these patients. Yet in clinical practice, it is patients with acute lung injury and associated lung edema who would probably benefit the most from EIT monitoring.

Also, in the past 16 (or even 32) single electrodes had to be attached around the patient's thorax and each one connected to the proper cable. Even for a well-trained study nurse, this resulted in a typical preparation time of about 20 min in a clinical setup before the first EIT measurement could be performed. For clinical trials, this preparation time was deemed acceptable; however, for normal clinical routine it is certainly not.

Even after EIT data was acquired, clinical information could not be extracted from the EIT data rapidly enough to demonstrate the usability of EIT to support clinical decision-making. The various EIT software tools, which have been created for data evaluation, were mainly focused on providing a versatile means for offline analysis of EIT data to address scientific questions; these tools did not enable the clinician to perform data interpretation online, i.e. directly at the bedside.

Since EIT measurements were time-consuming, occasionally provided only distorted data, and, if the interpretation of these data was not possible directly at the bedside, clinicians could not gather enough experience on interpretation of EIT data, and the corresponding adjustment of ventilator settings based on EIT data.

However, Dräger Medical is convinced that EIT will achieve widespread use in critical care medicine once it is capable of quickly providing reliable, easy-to-interpret data. And based on our progress so far, we are confident that this time is not far away.

**Literature**


1. **Victorino JA et al** (2004) Imbalances in regional lung ventilation: a validation study on electrical impedance tomography. Am J Respir Crit Care Med 169:791-800
2. **Frerichs I et al** (2002) Detection of local air content by electrical impedance tomography compared with electron beam CT. J Appl Physiol 93:660-666
3. **Hinz J et al** (2003) Regional ventilation by electrical impedance tomography: a comparison with ventilation scintigraphy in pigs. Chest 124:314-322
4. **Hinz J et al** (2003) End-expiratory lung impedance change enables bedside monitoring of end-expiratory lung volume change. Intensive Care Med 29:37-43
5. **van Genderingen HR et al** (2004) Regional lung volume during high-frequency oscillatory ventilation by electrical impedance tomography. Crit Care Med 32:787-794
6. **Kunst PW et al** (1998) Ventilation and perfusion imaging by electrical impedance tomography: a comparison with radionuclide scanning. Physiol Meas 19:481-490
7. **Frerichs I et al** (2002) Regional lung perfusion as determined by electrical impedance tomography in comparison with electron beam CT imaging. IEEE Trans Med Imaging 21(6):646-52
8. **Hinz J et al** (2005) Effect of positive end-expiratory pressure on regional ventilation in patients with acute lung injury evaluated by electrical impedance tomography. Eur J Anaesth 22:817-825
9. **Frerichs I et al** (1998) Electrical impedance tomography in monitoring experimental lung injury. Intensive Care Med 24:829-836
10. **Frerichs I et al** (2003) Electrical impedance tomography: a method for monitoring regional lung aeration and tidal volume distribution? Intensive Care Med 29:2312-2316
11. **Frerichs I et al** (2001) Non-invasive radiation-free monitoring of regional lung ventilation in critically ill infants. Intensive Care Med 27:1385-1394
12. **Odenstedt H** (2005) Slow moderate pressure recruitment maneuver minimizes negative circulatory and lung mechanic side effects: evaluation of recruitment maneuvers using electric impedance tomography. Intensive Care Med 31:1706-1714
13. **Amato MB** et al (1998) Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome. N Engl J Med 338:347-54.
14. **Hinz J et al** (2006) Regional pulmonary pressure volume curves in mechanically ventilated patients with acute respiratory failure measured by electrical impedance tomography. Acta Anaesthesiol Scand 50:331-339
15. **Frerichs I et al** (2002) Regional lung perfusion as determined by electrical impedance tomography in comparison with electron beam CT imaging. IEEE Trans Med Imaging 21(6):646-52
16. **Arnold JH** (2004) Electrical impedance tomography: On the path to the Holy Grail. Crit Care Med 32:894-895
17. **Erlandson K et al** (2006) Positive end-expiratory pressure optimization using electric impedance tomography in morbidly obese patients during laparoscopic gastric bypass surgery. Acta Anaesthesiol Scand 50:833-839



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