Chest electrical impedance tomography examination, data analysis, terminology, clinical use and recommendations: consensus statement of the TRanslational EIT developmeNt stuDy group

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ONLINE SUPPLEMENT 6

EIT definitions and nomenclature

EIT definitions

Table E6.1 EIT terms and definitions

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Absolute EIT		aEIT (A-EIT)	An EIT imaging mode in which each image of the impedance distribution is calculated from a single frame of EIT data. It differs from a difference EIT image (tdEIT or fdEIT) which are calculated from two measurement frames. aEIT is significantly more sensitive than difference EIT to electrode contact quality, movement and EIT system changes, and based on current technology, is currently not yet ready for clinical use.
Adjacent current stimulation pattern	Sheffield stimulation pattern		A current stimulation pattern in which electrical current is sent sequentially through adjacent pairs of electrodes. For example, first, electrodes 1 and 2 are used, followed by 2 and 3, and so on. Historically, this is the most common current stimulation pattern.
Aeration change image	Aeration change map		The Aeration change map is an EIT image that represents the change in regional distribution of lung impedance between two points in time. When regional values at end-expiratory time points are compared the corresponding Aeration change image shows regional changes in end-expiratory lung volumes.
Anterior-to-posterior ventilation ratio	Upper-to-lower ventilation ratio	A/P ratio (U/L ratio)	A functional EIT measure used to quantify the distribution of ventilation in the antero-posterior direction. A/P ratio is calculated as the ratio of A (the sum of the ventilation measured in the image pixels in anterior (ventral) half of the image) to P (the sum of the ventilation measured in the image pixels in the posterior (dorsal) half of the image). (In supine posture, the anterior equals the upper, non-dependent and the posterior the lower, dependent regions.)
Applied potential tomography		APT	An obsolete name of electrical impedance tomography used until the early nineties of the last century.
Arbitrary units		A.U. (AU)	The measurement unit commonly used in EIT to quantify the amplitude of impedance changes within EIT image pixels. Current tdEIT image reconstruction algorithms do not produce images with well-defined units, and their sensitivity can depend on many factors such as subject posture and electrode placement details. It is thus common to express the image units as “arbitrary”. As an alternative to A.U., EIT images can be calibrated to the patient and measurement configuration in order to generate physiological image units.

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Baseline	Baseline measurement, (Reference, Reference measurement)	BL	Time difference EIT determines impedance changes against a reference (or baseline) measurement. Various choices of BL measurement can be used, depending on the nature of clinical information to be derived. Its definition has a big impact on the calculation of impedance changes and derived EIT based parameters. Some common definitions of baseline are: mean of EIT data, data at end-expiration or end-inspiration, a moving average of EIT data or a moving average of end-expiratory events.
Center of ventilation	Center of gravity	CoV	A functional EIT measure used to quantify the distribution of ventilation in relation to the anteroposterior or right-to-left chest diameter and expressed as percentage. The geometric center of fEIT pixels is calculated and expressed as a fraction of the vertical or horizontal image size. In the former case, values lower than 50% imply that ventilation is predominantly directed towards ventral (anterior) regions, in the latter one towards the right lung.
Change in end-expiratory lung impedance	End-expiratory lung impedance change (Change in end-expiratory impedance)	ΔEELZ (ΔEELI)	The difference in end-expiratory EIT values between two points in time.
Chest EIT examination	Chest EIT imaging (chest EIT scanning)		Use of EIT with electrode placement on the chest to obtain information on regional lung ventilation, aeration and function and/or heart action and/or lung perfusion.
Current stimulation frequency	Stimulation frequency		Frequency of the alternating drive current applied to the body through the electrodes. Common devices use frequencies of 10 kHz - 250 kHz. The measured tissue impedance properties vary with current stimulation frequency.
Current stimulation pattern	Current injection pattern		The configuration and order in which electrical current is input into electrodes by the EIT device. Most EIT systems use a "pair drive" current stimulation pattern, in which current flows through a pair of electrodes, while the other electrodes are passive. During each current stimulation a set of voltage measurements is acquired using the measurement pattern.
Differential image			Vendor-specific term for an image generated by subtraction of two functional images characterizing tidal ventilation distribution. The differential image can show positive or negative values indicating an increase or decrease in regional tidal ventilation over time.

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Dorsal ROI	Posterior ROI	D (ROI 4)	The region of interest within an EIT image that represents the back or spinal part of the body. When an EIT image is subdivided into 4 equal horizontal layers, the dorsal (posterior) part is the lowermost layer in the image.
Dynamic image			Real-time display of continuously updated relative impedance changes within the electrode plane shown as a series of tomograms in a movie-like style. The relative impedance changes are calculated using a baseline either at end of the last expiration, a moving average measurement, or a different user-selected value. (In the Sheffield Mark I device, this term was a synonym for time-difference image.)
EIT			Electrical impedance tomography. EIT refers to any method of generating tomographic images from electrical impedance measurements made with body surface electrodes.
EIT data file			File created by an EIT device, which contains all voltage measurements before data processing and image reconstruction. Many formats of EIT data files have been proposed. Some formats contain additional information, including reconstructed EIT images, details of the measurement configuration, patient details or other monitoring data.
EIT device			The electronic system which connects to the electrodes attached to the body surface, applies EIT stimulation currents and performs and records EIT measurements.
EIT electrode	EIT sensor		EIT electrodes provide electrical contact between the EIT device and the body. Many different types of electrodes are used, including individual ECG-type electrodes and electrodes integrated into belts or stripes. Some devices use active electrodes, in which electronic amplifiers and other hardware are physically placed on or near the electrode.
EIT examination			The process of performing EIT measurements on a subject.
EIT image			Collective term for any kind of image created from EIT measurements, including dynamic, frequency difference, functional, raw, or time-difference images.
EIT image pixel			A pixel (or picture element) is the smallest image element in a 2D EIT image. EIT images are calculated on a grid of image pixels. For 3D EIT images, the corresponding elements are image voxels.
EIT measurement			1) The process of EIT data acquisition. 2) The measured data resulting from an EIT data acquisition.
EIT sensitivity region			The roughly lens-shaped intra-thoracic volume the impedance changes of which contribute to the generated EIT images. The thickness of this plane depends on the placement and size of the electrodes used, the dimension, the bioelectric properties, and the shape of the thorax, and particularly on the morphological structures within the chest. The sensitivity region is relatively small close to the periphery, but increases in size towards the center.

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
EIT raw data	EIT data set (EIT data file)		Voltages obtained during EIT measurement together with the measurement settings. The set of raw data acquired during one cycle of current applications and voltage measurements is typically called frame.
Electrode belt	Sensor belt, electrode stripe, patient interface		The patient interface onto which EIT electrodes are mounted to facilitate placement on a patient´s body. The form is specific to the EIT device, and can take the form of a belt or a more complex arrangement. It contains all components needed to attach EIT electrodes to the patient, including the electrodes themselves.
Electrode numbering			The numerical order in which body surface electrodes are addressed by the EIT device. In most applications, EIT electrodes are enumerated sequentially from the sternum to the left and subsequently the right hemi-thorax.
Electrode skin contact impedance			The impedance to electrical current flowing across the contact between the electrode and the body. It is affected by the skin properties, skin preparation (including contact agents), and electrode contact area. Low electrode skin contact impedance is necessary to obtain high quality EIT recordings. Many EIT devices provide continuous information on this value, in order to ensure data quality.
Electrode plane			The plane intersecting the centers of the body surface EIT electrodes. The most common ones are the transverse or the oblique thoracic planes.
Frame	Scan		A complete set of voltage measurements collected by application of one complete cycle of current stimulations in a specified pattern. A frame of EIT data is used to reconstruct one raw EIT image.
Frequency-difference EIT		fdEIT (FD-EIT)	An EIT imaging mode in which two data frames are acquired at different current stimulation frequencies. The reconstructed image represents the difference in tissue properties between the two stimulation frequencies. fdEIT requires an EIT system capable of multi-frequency operation.
Functional EIT image		fEIT image	An EIT image calculated from a time-series of EIT images, designed to characterize a particular physiological feature. Each fEIT image pixel is calculated from that pixel's time-series values. Many types of fEIT images have been defined. Two broad categories can be identified: 1) fEIT images based on the EIT data alone, such as tidal images, and 2) fEIT images based on EIT and additional monitoring data, such as images of regional opening pressures.
Global	Global information		A value calculated from an EIT image, which represents the entire EIT plane. The global value can be calculated either as the sum or the average of the pixel values in the EIT image.

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Global change in end-expiratory lung impedance		$\Delta EELI_{global}$	The global value of an aeration change image generated from differences in end-expiratory EIT values between two points in time. (Some vendors normalize the value and calculate it as the fraction of tidal impedance variation at the first of the two time points.)
Global impedance signal	Global impedance waveform, (Global impedance curve, Global impedance time course)		The global impedance signal is the global impedance change as a function of time.
Global minute tidal variation		MTV_{global}	The average of the global tidal variation over the previous minute.
Global tidal variation	Global tidal impedance variation, Global ventilation-related impedance change	TV_{global} (TIV_{global})	The global value of a tidal variation image.
Image orientation			EIT images are shown in the conventional medical orientation, i.e. looking at them from the patient´s feet towards the head. This means that anterior sections of the thorax are imaged at the top and its right side on the left side of the image.
Impedance		Z	A measure of the opposition that an electrical circuit (for EIT, the body tissue) presents to the stimulation current. Gases (e.g. air in the lungs) have high impedance, while fluids with high ion concentrations (e.g. blood and saline) have low impedance. Electrical impedance is measured as a magnitude and a phase offset with respect to the stimulation current. Most current tdEIT image reconstruction algorithms currently do not use the phase offset value.
Impedance change	Impedance difference	ΔZ	Changes in the value of impedance.
Measurement pattern			The spatial configuration and order by which voltage measurements are performed by the EIT device during current stimulation with a particular stimulation pattern. Most EIT systems make measurements only on passive electrodes (i.e. those which are not used for current stimulation).

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Mid-dorsal ROI	Mid-posterior ROI	MD (ROI 3)	The region of interest within an EIT image that represents the body part above the most dorsal (posterior) section of the body. When an EIT image is subdivided into 4 equal horizontal layers, the mid-dorsal layer is represented by ROI 3 (i.e. above ROI 4).
Mid-ventral ROI	Mid-anterior ROI	MV (ROI 2)	The region of interest within an EIT image that represents the body part below the most ventral (anterior) section of the body. When an EIT image is subdivided into 4 equal horizontal layers, the mid-ventral part is represented by ROI 2 (i.e. below ROI 1).
Minute image			Vendor-specific term which characterizes tidal volume distribution. It displays pixel tidal impedance variation values averaged over one minute.
Normalized tidal variation	Relative tidal stretch		Tidal variation normalized to maximum tidal variation in the image. Image regions with very low values of normalized tidal variation imply low ventilation. (In a vendor-specific taxonomy, pixels with values <10% are called 'silent spaces'.)
Pixel			The smallest element in a digital image. EIT images are reconstructed and displayed with an image size that depends on the algorithm and EIT system. The image size is represented by the number of horizontal pixel rows and vertical pixel columns (e.g. 32x32).
Pixel impedance signal			The signal obtained by representing the calculated value in a single image pixel over the time for which it was measured.
Pixel impedance tidal variation			The magnitude of the variations in a pixel impedance signal due to tidal ventilation.
Stimulation current	Excitation current (Drive current, Injection current)		The electrical current applied to the body during EIT scanning. Currents are applied at the current stimulation frequency across pairs of stimulation electrodes in order to measure the resulting voltage on the body surface from which the impedance is then calculated. Stimulation currents are designed to be below the human threshold of perception, and safe against macroshock.
Stimulation pattern	Drive pattern		The spatial pattern or order by which electrodes are used for current stimulation. Pair drive EIT systems apply current across one pair of electrodes at a time. The adjacent current stimulation pattern (the most common) applies current sequentially through adjacent pairs of electrodes.

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Region of interest		ROI	An area within an image on which further analysis is performed. Based on the definition of the ROIs, regional information expressed as waveforms or parameters can be displayed. ROIs can be defined by user definition, such as horizontal layers or quadrants, or automatically, such as the ventilated region of an image. The smallest possible ROI is a single image pixel. Anatomy-related ROIs (i.e. lung contours) can be derived from other medical imaging techniques. For layer- and quadrant-based ROI definitions, the following conventions are used: when arranged as horizontal layers, ROI 1 represents the ventral (anterior) part; when arranged as quadrants, ROI 1 represents the upper left, ROI 2 the upper right, ROI 3 the lower left, ROI 4 the lower right quadrant.
Regional	Regional information		Information derived from a predefined ROI within an EIT image.
Regional change in end-expiratory lung impedance		$\Delta EELI_{ROI}$	The regional value of an aeration change image generated from differences in end-expiratory EIT values between two points in time. (Some vendors normalize the value and calculate it as the fraction of tidal impedance variation at the first of the two time points.)
Regional impedance signal	Regional impedance waveform, (Regional impedance curve, Regional impedance time course)		The regional impedance signal is the impedance change in a ROI as a function of time.
Regional minute tidal variation		MTV_{ROI}	The average of the regional tidal variation over the previous minute.
Regional tidal variation		TV_{ROI}	The regional value of a tidal variation image.
Relative impedance change	Normalized impedance difference	rel. ΔZ	A measurement unit commonly used to quantify the amplitude of impedance changes within EIT image pixels. A synonym to arbitrary units (A.U.). The term “relative” signifies that images are reconstructed with respect to a baseline and are not presented in any well-defined physiological units.

Term	Alternative terms	Abbreviation (Alternative abbreviation)	Explanation
Right-to-left ventilation ratio		R/L ratio	A functional EIT measure used to quantify the distribution of ventilation in the right-to-left direction. R/L ratio is calculated as the ratio of R (the sum of ventilation image pixels in the left half of the image) to L (the sum of ventilation image pixels in the right half of the image). (EIT uses the conventional radiological image orientation with the right side of the body shown on the left side of the image and vice versa.)
Scan	Frame		A complete set of EIT measured data from which a single image can be reconstructed. A scan requires measurement at all electrodes in the measurement patterns for each stimulation pattern.
Scan rate	Frame rate		The scan rate is the frequency at which EIT scan data are measured and expressed as frames (or scans) per second. Typical scan rates used to monitor ventilation are between 20 and 50 images per second; however, there can sometimes be a trade-off between EIT data quality and high scan rates.
Signal quality		SQ	Indicator of the accuracy and reliability of displayed EIT data. Low quality EIT data can result in poor or erroneous images. There are several common causes of impaired signal, such as poor electrode-skin contact, patient movement, interference from other medical devices, and other electromagnetic noise. There is currently no standard for the calculation of signal quality.
Status image			Vendor-specific term which characterizes tidal volume distribution. It can reflect the instantaneous values of tidal impedance variation, or their averaged values over one minute.
Tidal variation			Difference between the EIT data at end-inspiration and end-expiration for an individual breath.
Tidal variation image	Tidal image (tidal ventilation map)		An image representing the regional distribution of tidal volume, calculated as difference of the EIT images at end-inspiration and end-expiration for an individual breath.
Time-difference EIT		tdEIT (TD-EIT)	An EIT imaging mode based on data acquired in sequence over time. The reconstructed image represents the difference in tissue properties between a measurement at a particular time and a baseline measurement. tdEIT is the most common EIT imaging mode.
Ventral ROI	Anterior ROI	V (ROI 1)	The region of interest within an EIT image that represents the anterior or sternal part of the body. When an EIT image is subdivided into 4 equal horizontal layers, the ventral part is the uppermost layer in the image represented by ROI 1.

Table E6.2 Medical terms relevant for chest EIT

Term	Alternative terms	Abbreviation (Alternative Abbreviation)	Explanation
Aeration			Volume of gas contained within the lung at a given moment of time. (EIT allows the assessment of regional aeration changes induced e.g. by variation in positive end-expiratory pressure (PEEP).)
Atelectasis	Lung collapse		A condition where alveoli are deflated and collapsed which may be caused by a blockage of airways and subsequent gas resorption and / or excessive external pressure on the alveoli. (Regional EIT signals in atelectatic lung regions do not exhibit ventilation-related impedance changes or these are very low.)
Alveolar recruitment			Alveolar recruitment describes the sustainable re-expansion of previously collapsed alveoli which results in aeration and ventilation of the recruited parts of the lung. Re-expansion of collapsed lung tissue is one of the primary goals of respiratory care and is aimed at improving pulmonary gas exchange and lung mechanics, but also at protecting the lungs from ventilator-associated lung injury. (In EIT, regional alveolar recruitment can be identified by an increase in regional end-expiratory impedance and by the re-occurrence of previously absent ventilation-related impedance changes in regional waveforms e.g. after a PEEP increment.)
Derecruitment	Atelectasis, lung collapse		Loss of end-expiratory lung volume leading to a lack of gas and respective ventilation within a lung area. Strictly speaking, atelectasis or lung collapse is the result of derecruitment but in clinical practice all terms are used interchangeably. (In EIT data, the effects of derecruitment can be observed during a decremental PEEP trial that includes sufficiently high initial inspiratory pressures and PEEP levels, where the recruitable parts of the lung are opened. At a certain PEEP level further PEEP reduction may cause a decrease of regional respiratory system compliance which is then interpreted as derecruitment.)
Dependent lung			Area of the lungs most exposed to gravity induced pressure, where the lung itself (and other intrathoracic organs like the heart) above this area apply a superimposed pressure. In supine position, the dependent lung regions are located in the dorsal part of the lung.

Term	Alternative terms	Abbreviation (Alternative Abbreviation)	Explanation
Dorsal	Posterior	D	Related to the position of the subject's spine. In EIT imaging of a subject in the supine position, the lower aspect of the image represents the part closest to the subject's spine.
End-expiratory lung volume		EELV	Sometimes synonymously used with the term functional residual capacity (FRC). FRC equals the volume of gas in the lungs by the end of passive tidal expiration in spontaneously breathing subjects. At this volume, the elastic recoil forces of the lungs and chest wall are in equilibrium. However, mechanically ventilated patients exhale against PEEP rather than ambient pressure, which is why the term end-expiratory lung volume (EELV) should be used instead of FRC; the latter term to be used for subjects breathing at ambient pressure, only. EELV (resp. FRC) describes the gas volume which can contribute to gas exchange between two breaths. Adequate PEEP settings during mechanical ventilation help in maintaining a sufficient EELV and thus in keeping alveoli and airways open. (EIT can trace regional changes in EELV elicited for instance by PEEP variation.)
Functional residual capacity		FRC	The gas volume present within the lungs at the end of a passive expiration against ambient pressure.
Non-dependent lung			Area of the lungs without superimposed pressure caused by gravity. In supine position, the non-dependent lung regions are located in the ventral (anterior) part of the lung.
Overdistension	Overinflation, Hyperinflation, Hyper-distension		Excessive expansion of the lungs at the end of inspiration, commonly caused by either high tidal volumes or high end-expiratory lung volumes resulting from high PEEP levels. (In EIT, the presence of overdistension must be anticipated whenever a lack of ventilation is observed in the non-dependent lung areas. However, overdistension is usually systematically diagnosed by a decremental PEEP trial, causing regional compliance to increase after PEEP reduction which is then interpreted as the presence of overdistension at the previous higher PEEP levels.)
Peak inspiratory pressure		PIP	Maximum pressure applied during positive pressure ventilation to deliver air into the lungs.

Term	Alternative terms	Abbreviation (Alternative Abbreviation)	Explanation
Positive end-expiratory pressure		PEEP	Pressure at end expiration used in ventilated patients to oppose passive emptying of the lung and to keep the airway pressure above the atmospheric pressure. PEEP is used to maintain a sufficiently large end-expiratory lung volume and to keep airways open. (PEEP-induced changes in regional aeration can be mapped by EIT.)
PEEP titration	PEEP trial		Intervention aimed at identifying the most appropriate level of PEEP for an individual mechanically ventilated patient. PEEP is usually titrated systematically downward starting at high levels. Often, a recruitment maneuver is performed prior to this intervention to assure, that recruitable lung regions are open before the titration is started. PEEP can also be titrated upward to find the best PEEP to keep airways open.
Plateau pressure		Pplat	Pressure that is present during the inspiratory plateau phase.
Recruitment maneuver		RM	Intervention, usually performed with a mechanical ventilator, aimed at re-expanding collapsed lung tissue. In order to recruit collapsed lung tissue, sufficiently high peak pressures and PEEP levels must be temporarily imposed to exceed the critical opening pressure of the affected lung region. After the recruitment maneuver PEEP levels must be kept high enough to prevent subsequent derecruitment. Recruitment maneuvers also have a time related component as the time required to open (heterogeneous) lung regions varies. (The effects of a recruitment maneuvers on regional lung aeration and ventilation can be assessed by EIT during both conventional and high-frequency oscillatory ventilation.)
Tidal recruitment	Cyclic opening and closing (repeated alveolar opening and collapse)		Describes a condition where alveoli and small airways collapse during each expiration and are re-opened with each inspiration. This condition can cause ventilator associated lung injury (VALI). (EIT can estimate the amount of tidal recruitment by analysing regional ventilation delay inhomogeneity and regional respiratory system compliance.)
Ventilation			Movement of gas into and out of the lung during breathing. (EIT can trace ventilation-induced variation in regional EIT waveforms.)

Term	Alternative terms	Abbreviation (Alternative Abbreviation)	Explanation
Ventilator-associated lung injury		VALI	Lung injury that resembles acute respiratory distress syndrome (ARDS) and that occurs in patients receiving mechanical ventilation. VALI may be associated with pre-existing lung pathology such as ARDS. However, due to the pre-existing lung pathology it cannot be determined whether VALI was caused by mechanical ventilation. Therefore it is considered associated with rather than caused by mechanical ventilation. (VALI modifies regional respiratory system mechanics and leads to regional changes in aeration and ventilation that can be mapped by EIT. The impact of therapy and/or changed ventilator settings can be assessed by EIT.)
Ventilator-induced lung injury		VILI	Acute lung injury directly induced by mechanical ventilation in animal models. Since VILI is usually indistinguishable from the diffuse alveolar damage of other causes, it can only be discerned definitely in animal models. (VILI has been used as a model of acute lung injury in multiple EIT studies. Because VILI results in typical changes in regional aeration and ventilation these can be tracked by EIT.)

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