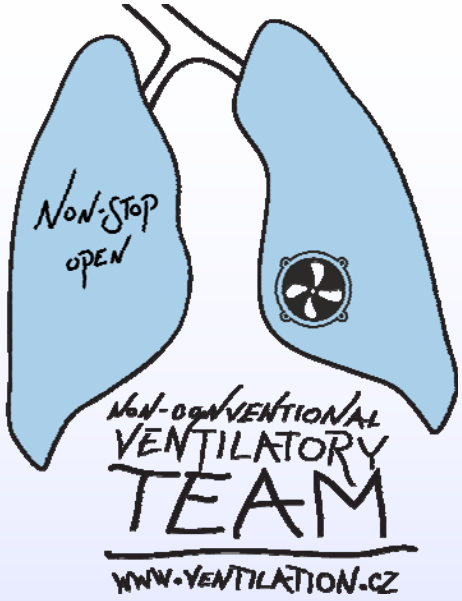
Electrical Impedance Tomography for lung recruitment monitoring

— Technical aspects of clinical usage and interpretation



Karel Roubík, Vladimír Sobota

Faculty of Biomedical Engineering
Czech Technical University in Prague, Czech Republic

roubik@fbmi.cvut.cz, www.ventilation.cz

Electrical impedance tomography

Monitoring of ventilation:

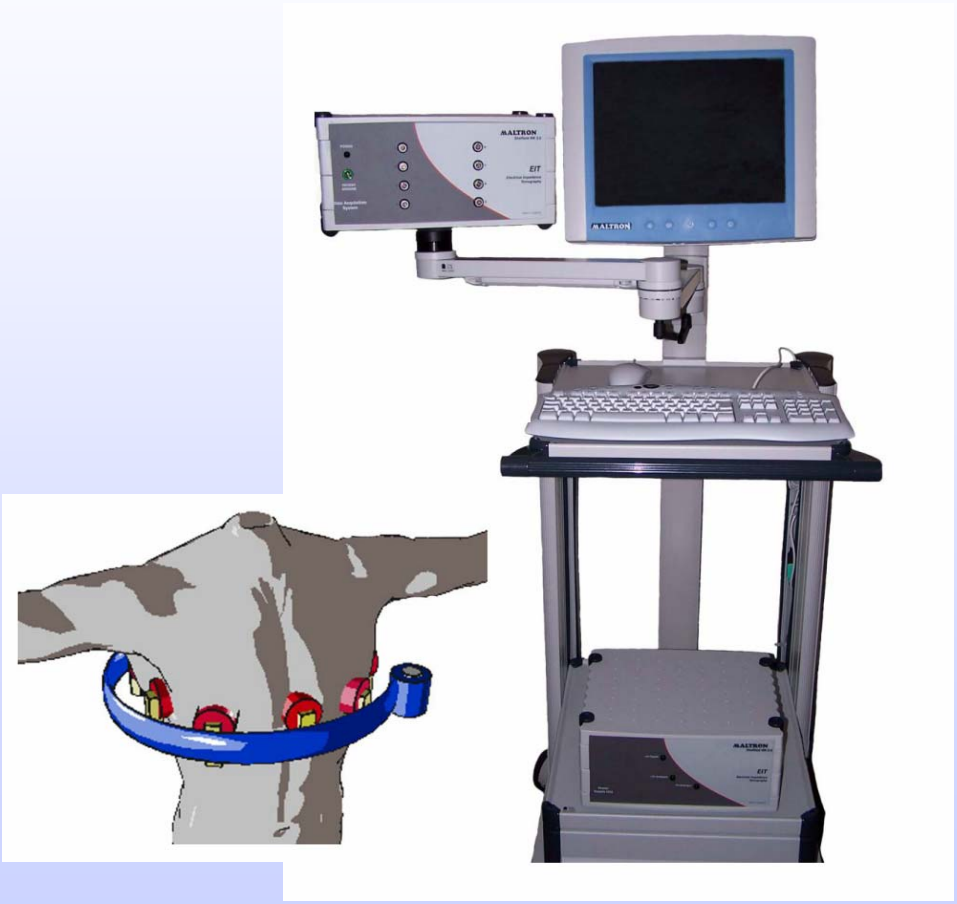
+ noninvasive,
+ bedside,
+ continuous,
+ no using ionizing radiation,
+ relatively inexpensive,
+ ...

+ “modern”

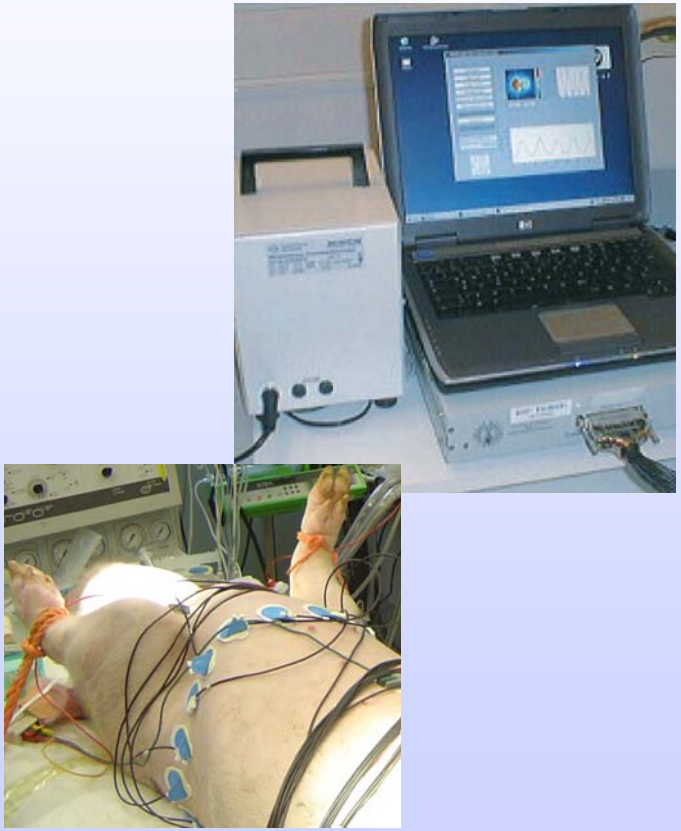
EIT systems currently used in lung ventilation monitoring

EIT System	Number of Electrodes	Electrode Belt
Maltron Sheffield Mk 3.5	8	NO
Goe MF II	16	NO
Dräger PulmoVista 500	16	YES, rubber
Timpel Enlight	32	YES, rubber
Swisstom-based devices	32	YES, textile

EIT systems currently used in lung ventilation monitoring



Maltron Sheffield Mk 3.5



Goe MF II

EIT systems currently used in lung ventilation monitoring

Dräger PulmoVista 500

Timpel Enlight (Brasil)

EIT systems currently used in lung ventilation monitoring

Swisstom BB^2

Salvia Elisa 800 VIT

Electrical impedance tomography

Monitoring of ventilation:

+ noninvasive,
+ bedside,
+ continuous,
+ no using ionizing radiation,
+ relatively inexpensive,
+ ...

- limitations, problems with evaluation and problems with EIT interpretation

Electrical impedance tomography

Monitoring of ventilation:

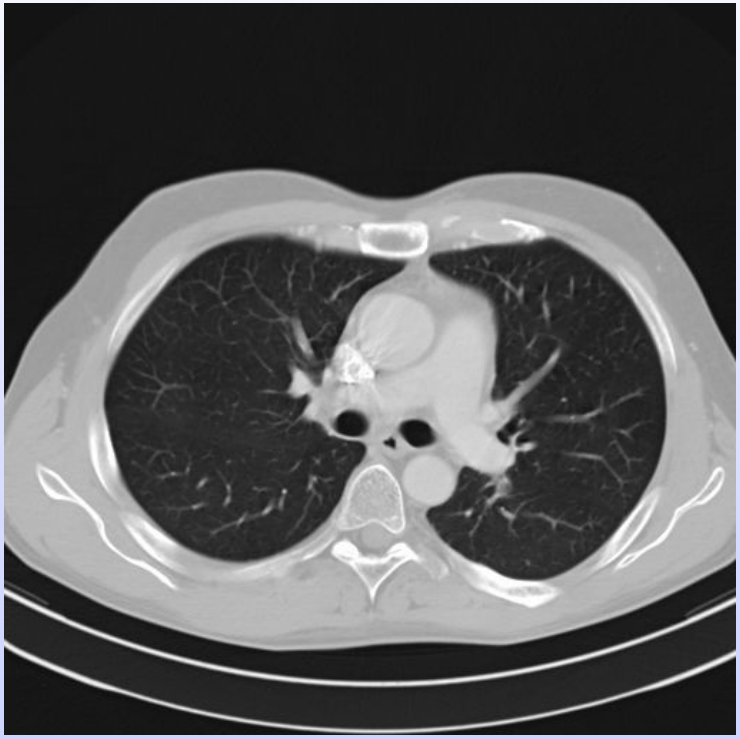
+ noninvasive,
+ bedside,
+ continuous,
+ no using ionizing radiation,
+ relatively inexpensive,
+ ...

The aim of the presentation is to show how EIT can be used for lung recruitment evaluation and to show possible sources of error during EIT data processing.

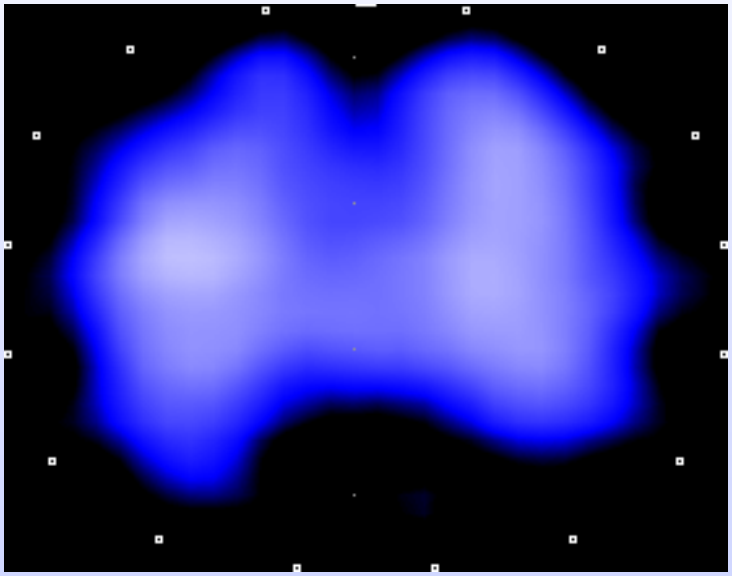
Comparison of CT and EIT

Low spatial resolution of EIT—does it matter?

CT scan



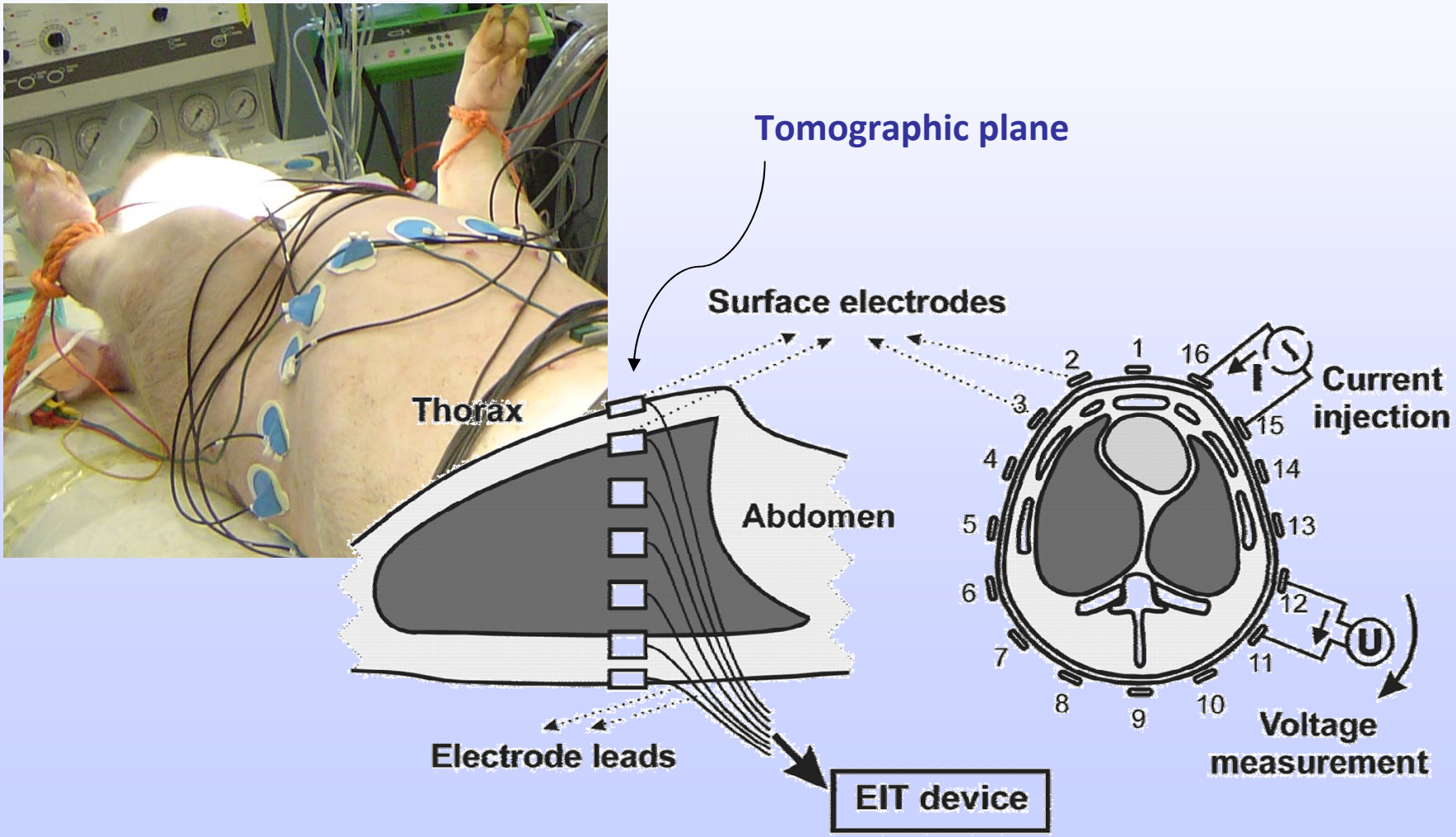
EIT image



Contrast in the lung EIT image is directly proportional to the changes of the lung volume. These changes in EIT image can be directly recalculated to changes in the lung volume.

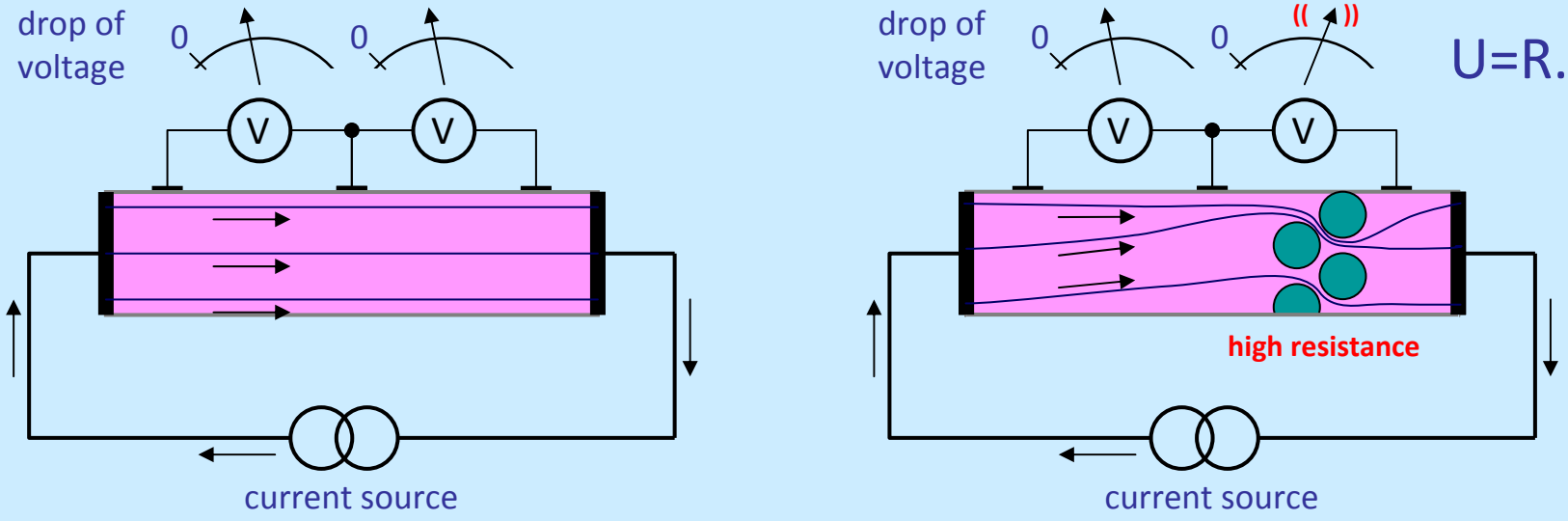
COULOMBE, N. et al. Physiol. Meas. 2005, 26, pp. 401-411

Electrical Impedance Tomography principles



Electrical Impedance Tomography principles

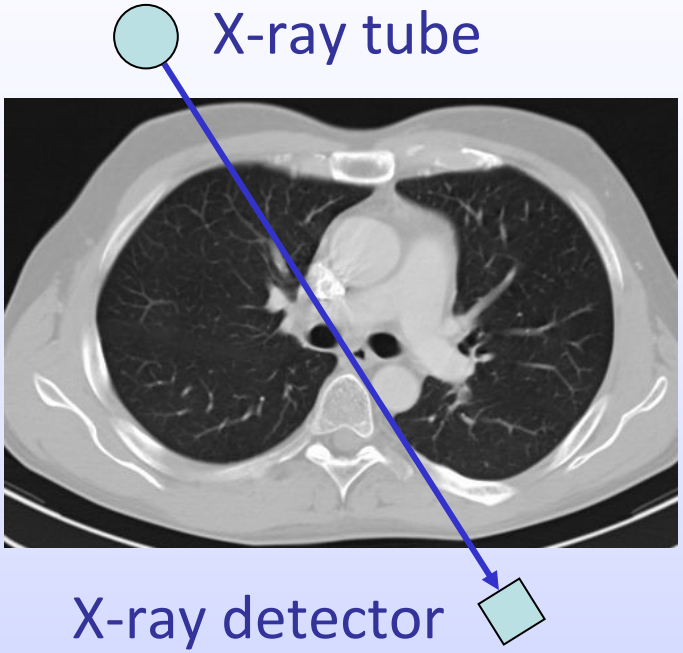
Principle: Conductivity of lungs is strongly affected by presence of gas. The more gas in the lungs, the higher the lung resistance.

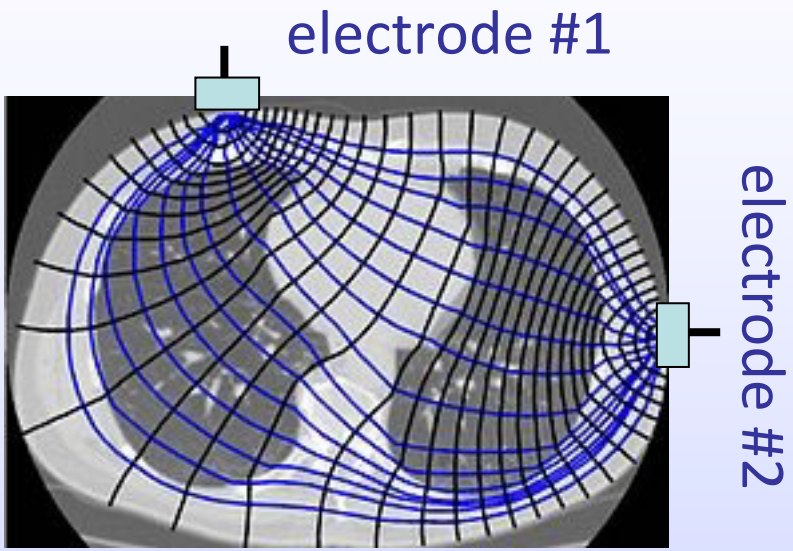


Principle: Measurement of impedances (resistances) of the lungs at different angles with a consequent image reconstruction similar to CT.

Principles of EIT

Low spatial resolution





- El. current preferably flows through regions with lowest resistance
- Resolution towards the center of the image decreases

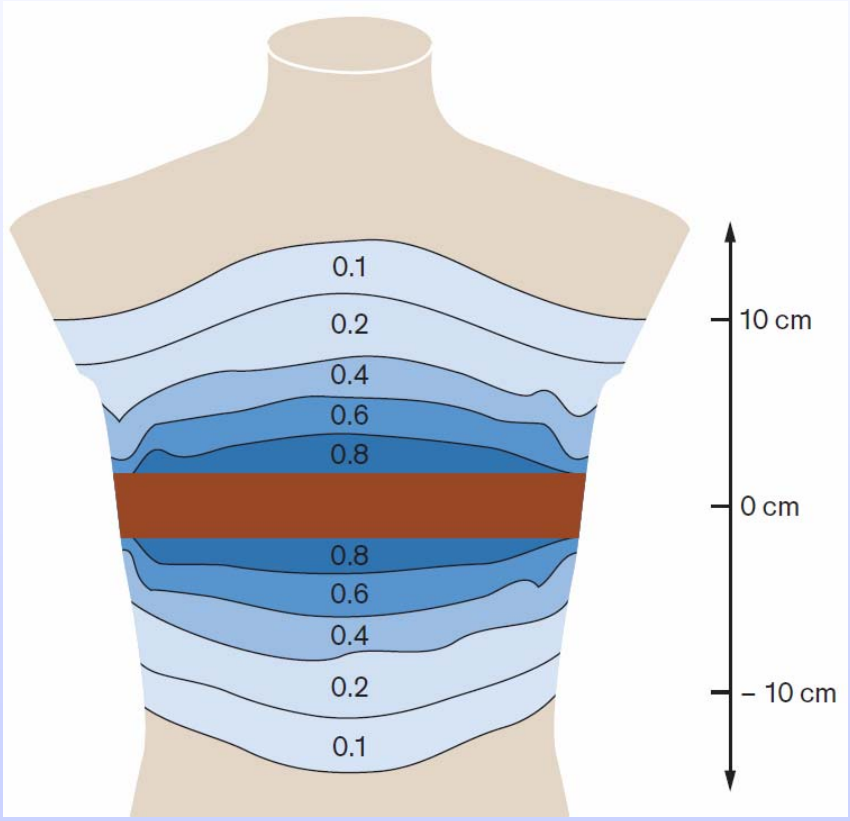
Further increase in number of electrodes does not improve the image resolution significantly

Principles of EIT

Wide “U.F.O.-disc-like” tomographic plane

- The tomographic plane is more than 10 cm wide, the width increases with depth
- Contribution of impedance changes from neighboring organs (heart, stomach)

Courtesy of 365PSD.com

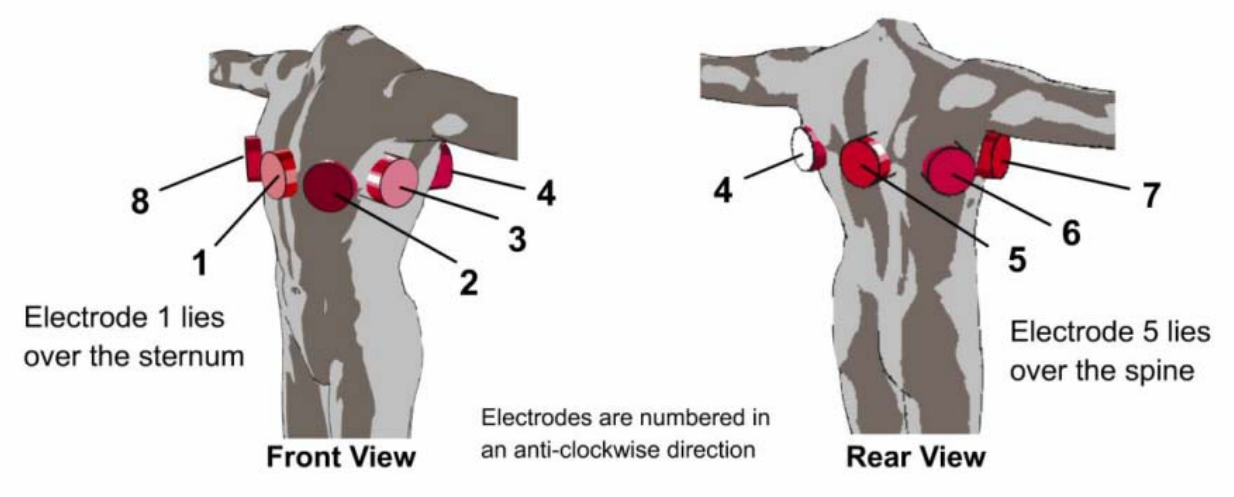


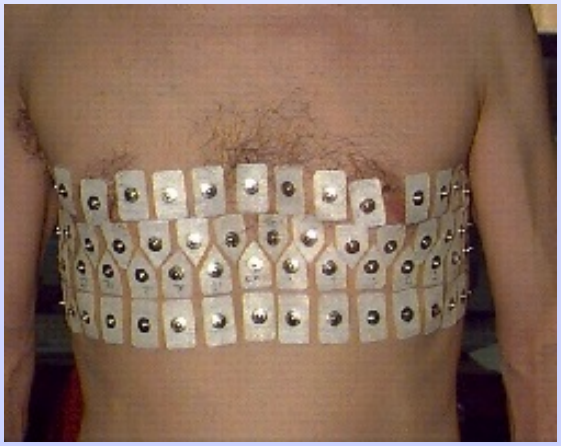
Stolen from Drëger

Data Acquisition

Placement of electrodes (when not integrated in a belt)

- Time consuming procedure
- The reconstruction algorithm assumes a certain (equidistant) position of electrodes—when electrodes are placed improperly, reconstruction errors occur



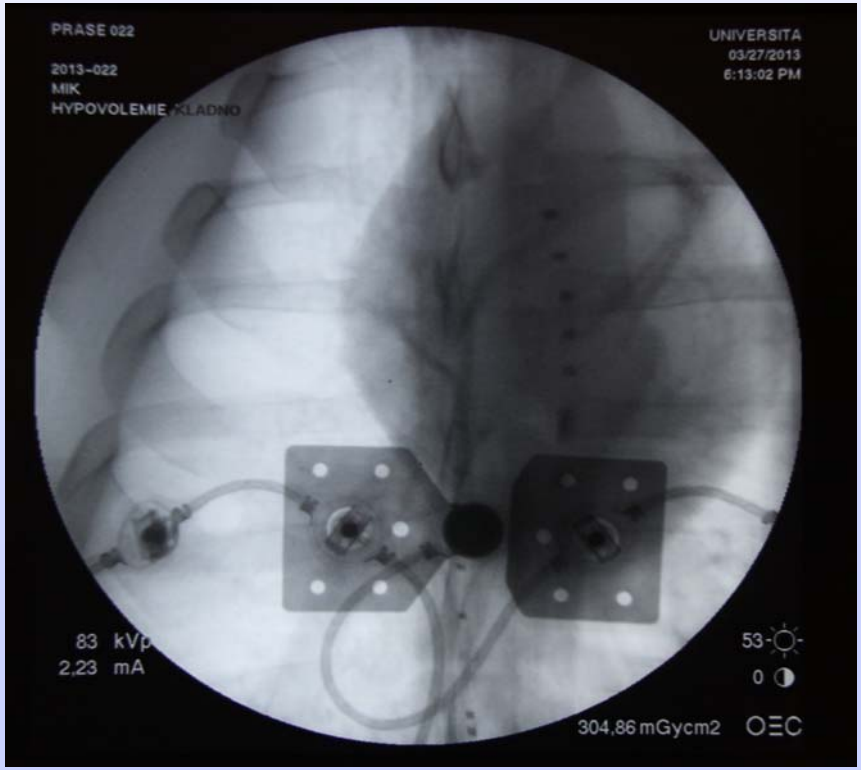


http://en.wikipedia.org/wiki/Electrical_impedance_tomography

Data Acquisition

Radial Rotation of the electrode belt

The image of electrode belt may be disturbing during X-ray imaging—temporary repositioning of the electrode belt may cause its rotation

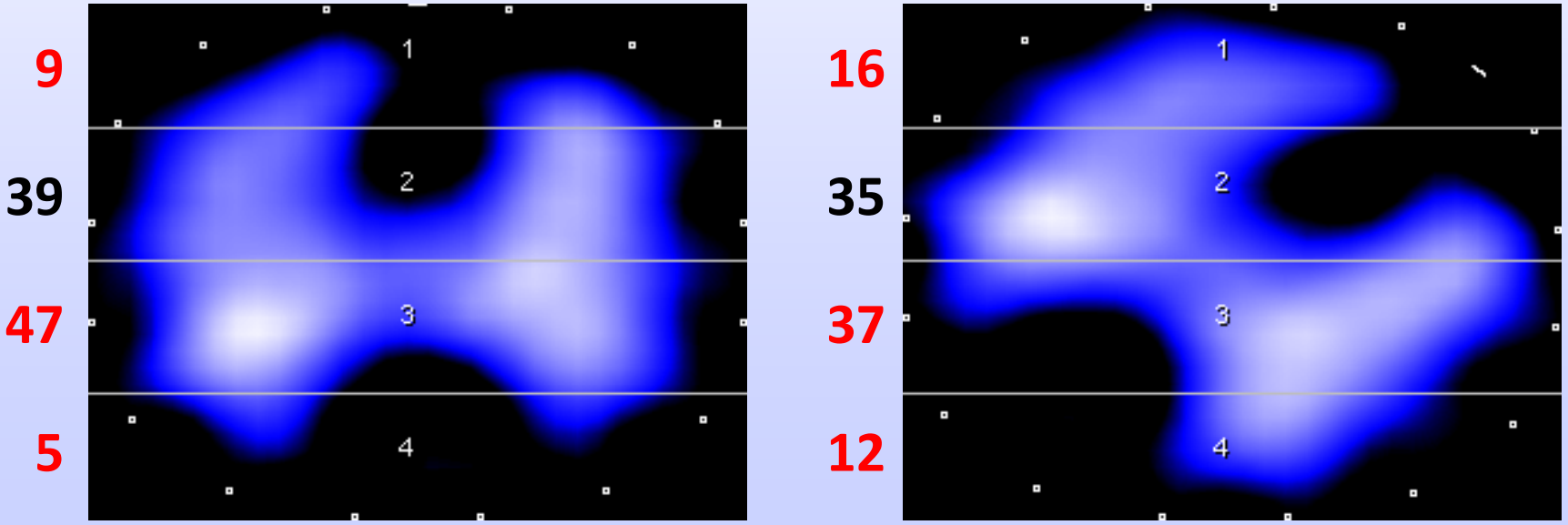


Animal experiment (pigs) with PulmoVista 500.

Data Acquisition

Radial Rotation of the electrode belt

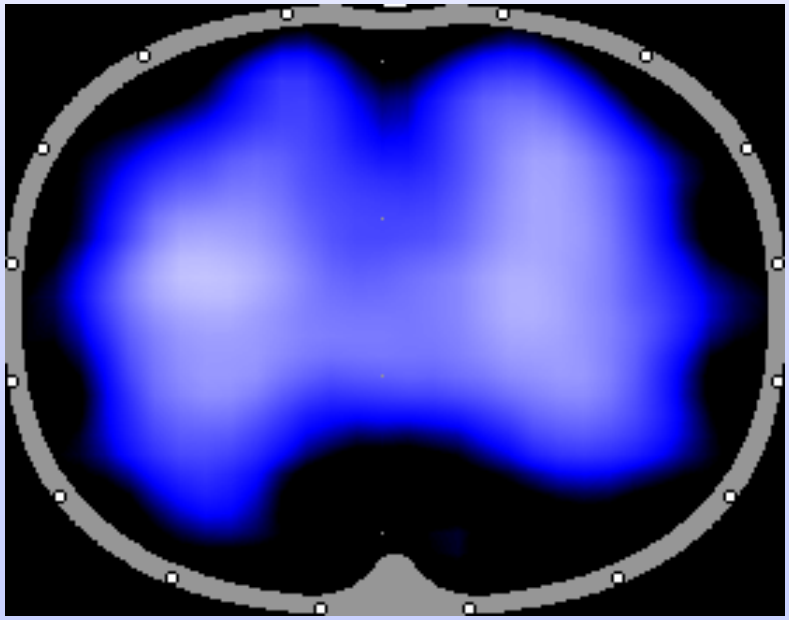
Comparison of regional ventilation (in %) at layer-defined regions of interest (ROIs) at a standard image and the same image rotated by 45°

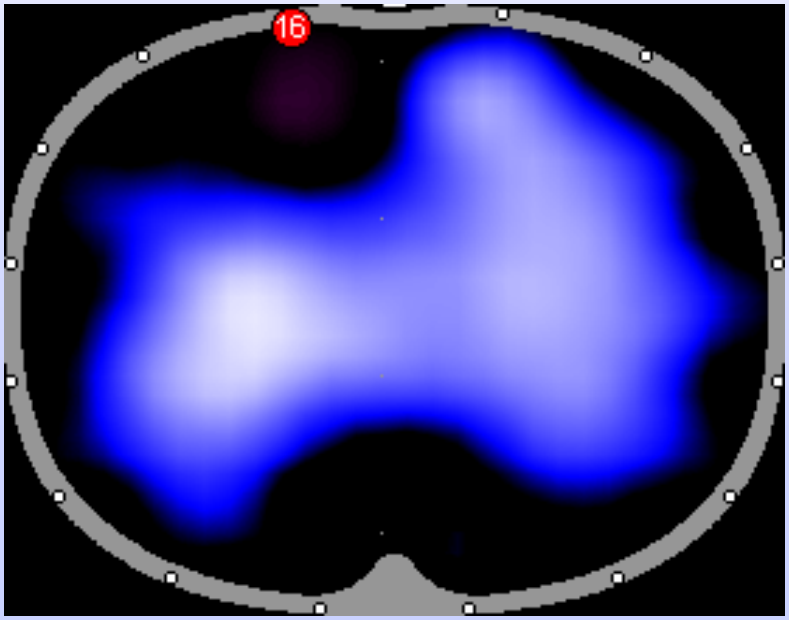


Data Acquisition

Insufficient contact of one or more electrodes

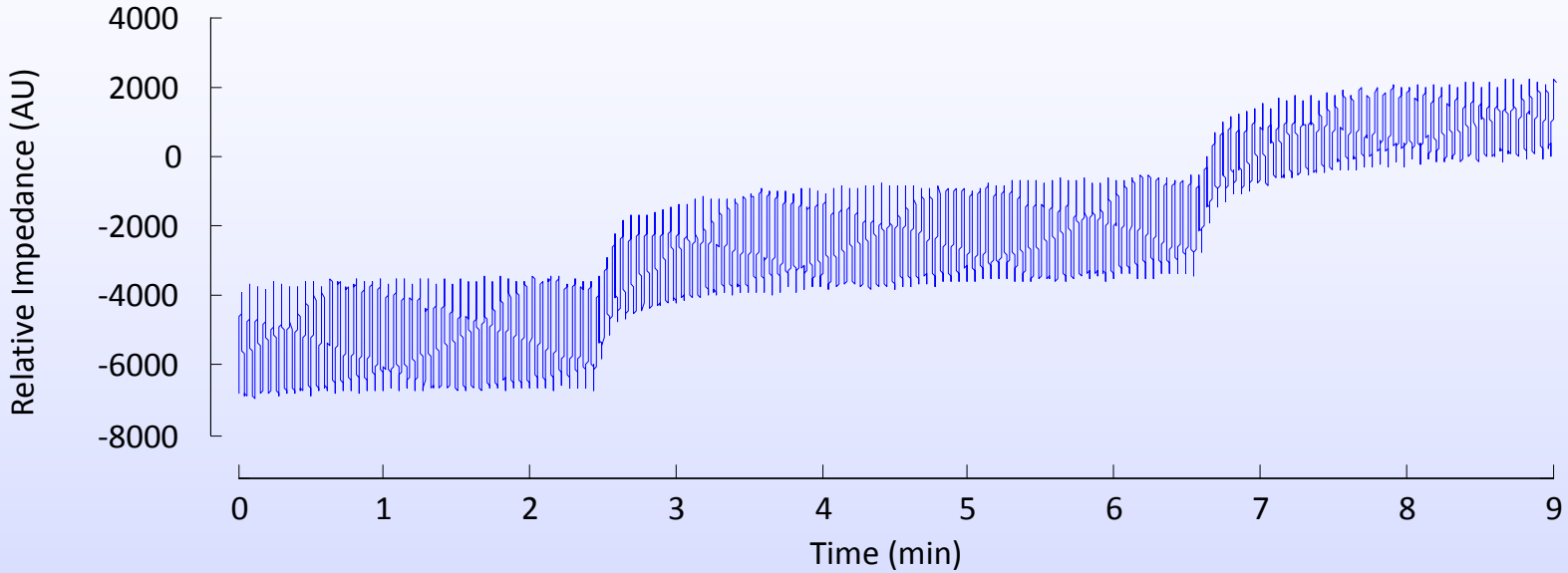
Comparison of two images within the same breath cycle when the electrode placed at sternum lost its contact at maximum inspirium



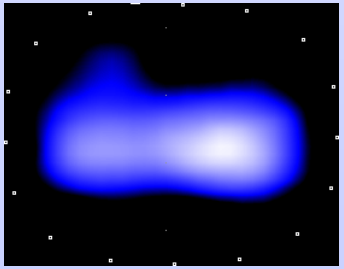


Data Processing

In time domain



In spatial domain



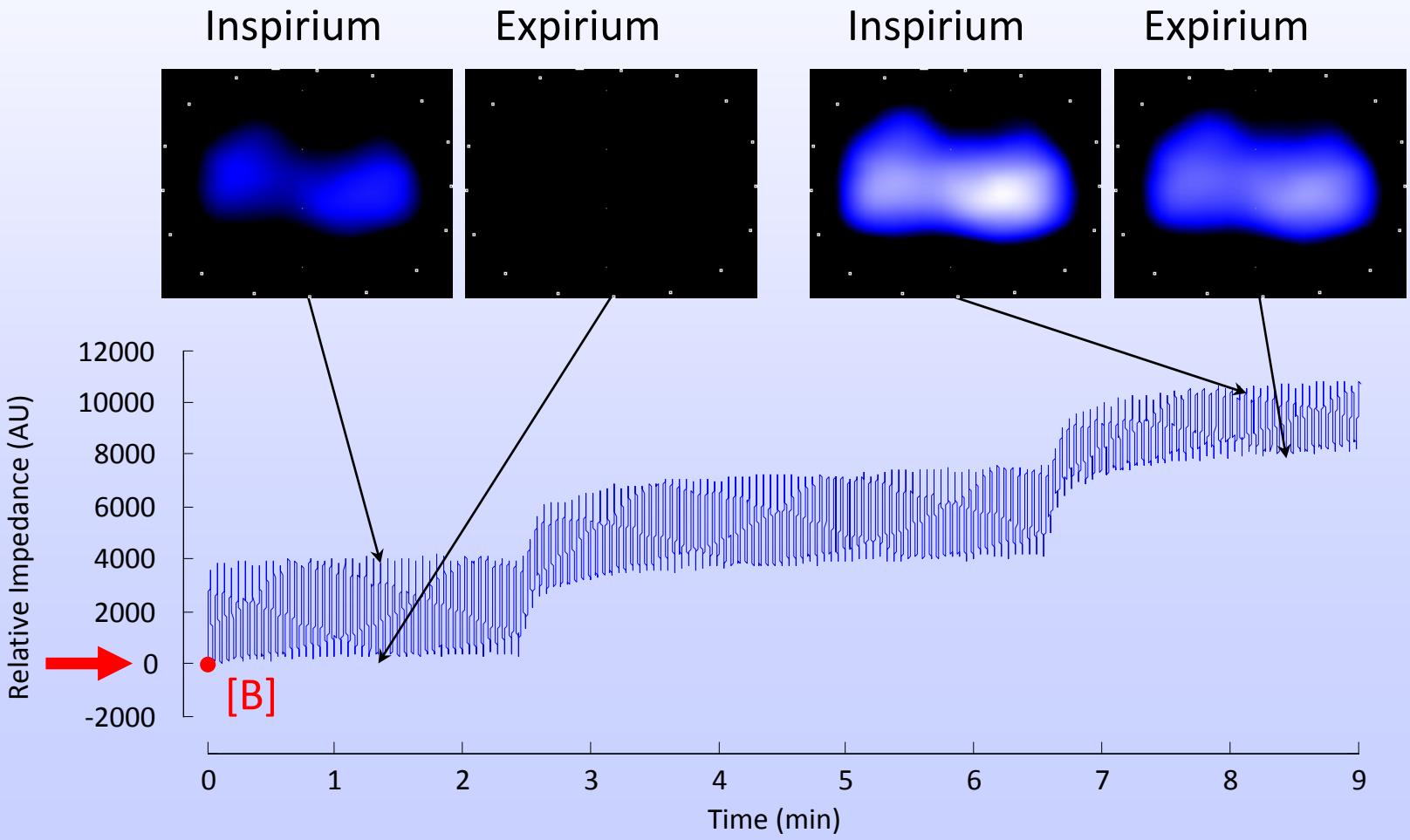
Contrary to CT, evaluation of EIT image by looking at it does not work!

Image analysis is required.

Data Processing

Selection of baseline

Change of color scale during PEEP steps—baseline in the beginning



Data Processing

Selection of baseline

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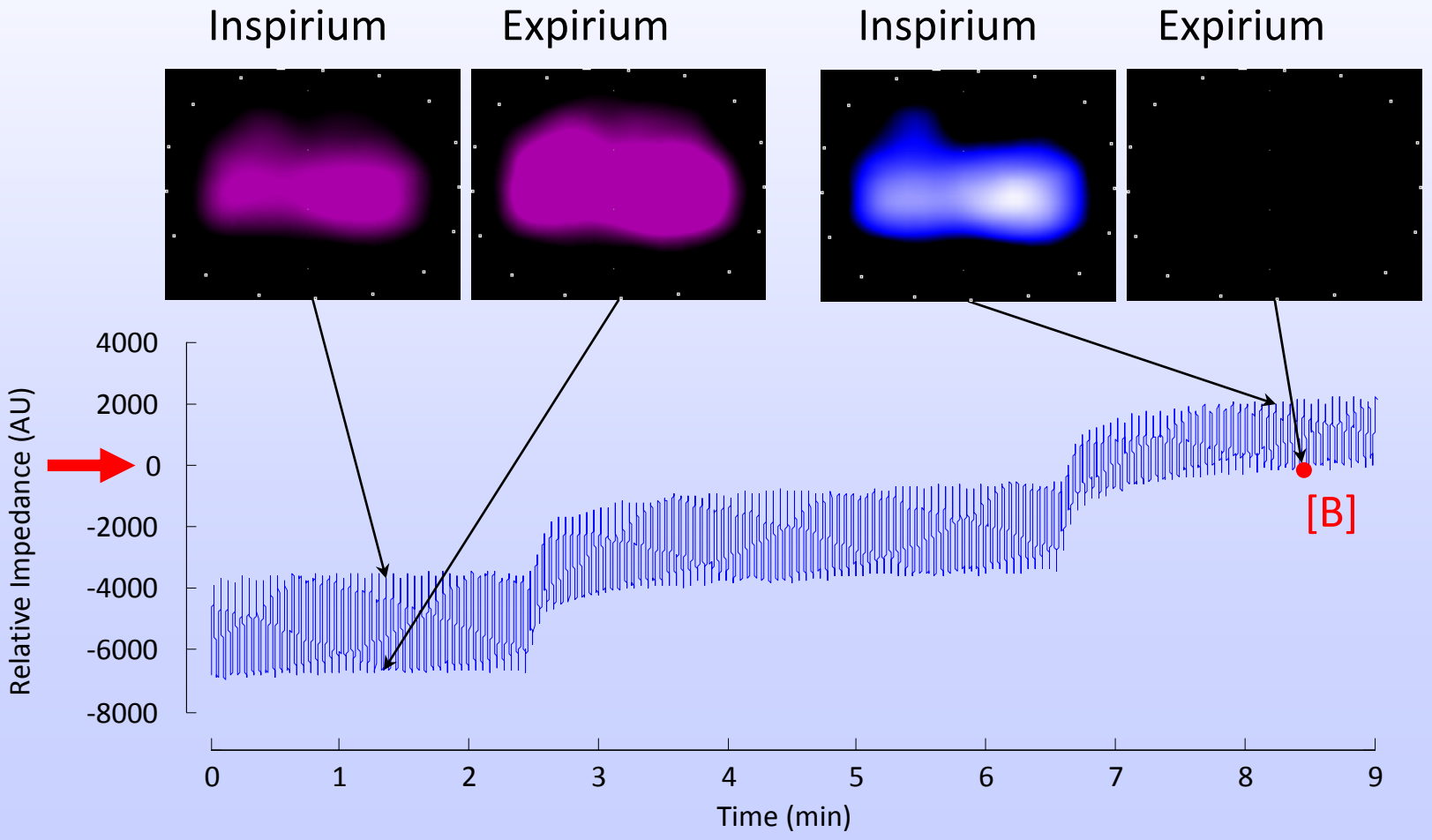
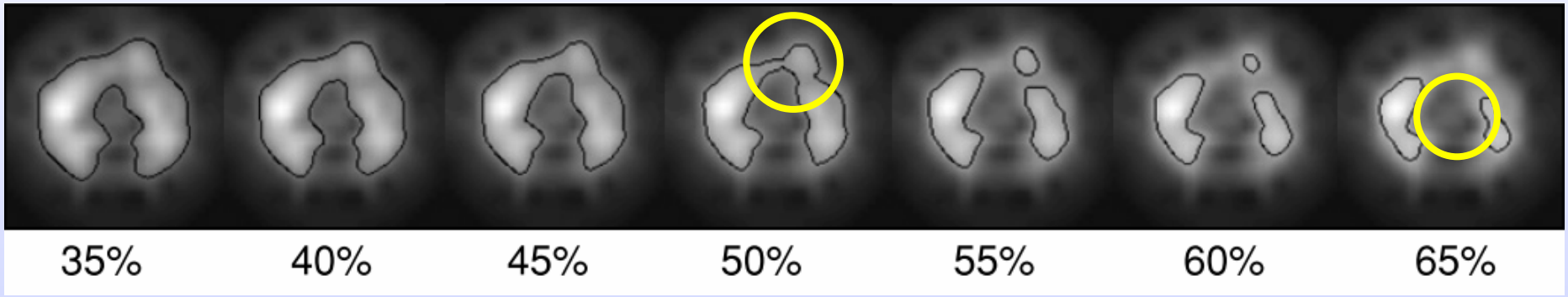


EIT in spatial domain

Regions Of Interest (ROIs)

Functional ROIs

- The edge criteria depend on the regional ventilatory function of the lungs



Standard deviation of relative impedance change of each pixel.

The higher the SD, the brighter the grey color.

PULLETZ, S. et al. Physiol Meas 2006, 27, S115-127

EIT in spatial domain

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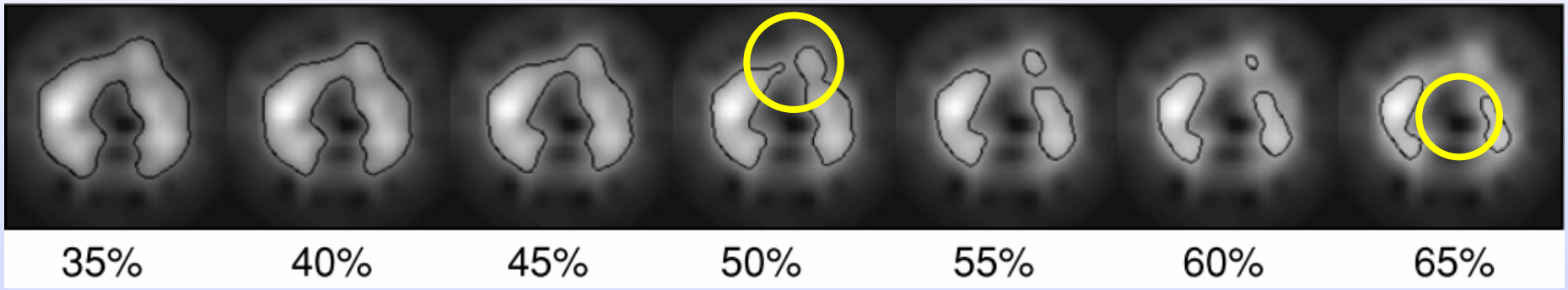


Values of linear regression coefficient calculated in each image pixel with pixel data as dependent variable and global (average) data as independent variable.

The higher the value of the regression coefficient, the brighter the grey color.

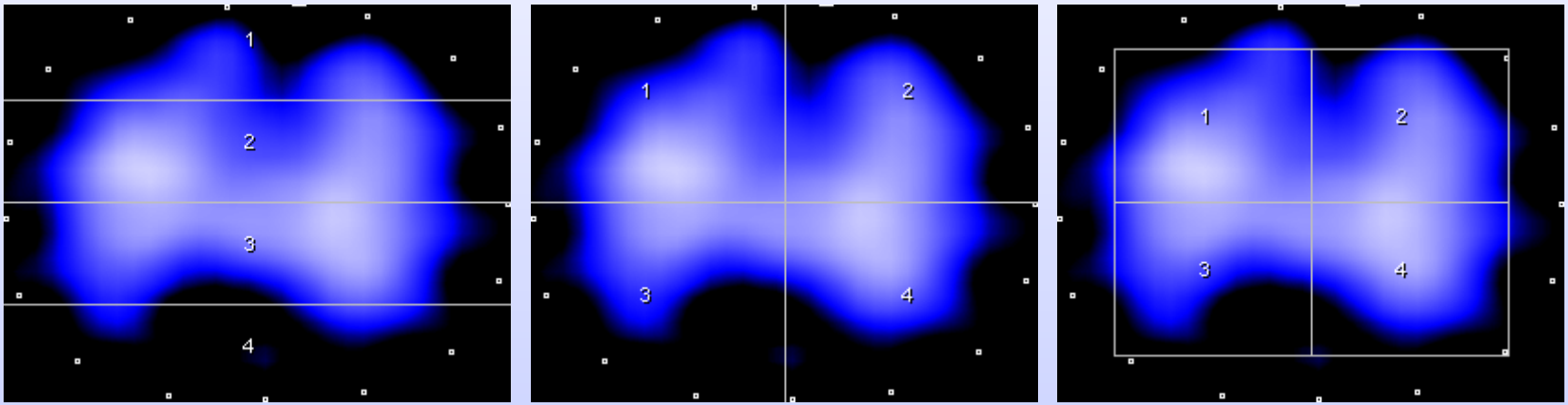
PULLETZ, S. et al. Physiol Meas 2006, 27, S115-127

EIT in spatial domain

Regions Of Interest (ROIs)

Arbitrary ROIs

- Defined as simple geometric objects
- Serve for calculation of regional ventilation (% of total V_T)



Layers | Quadrants 1 | Quadrants 2

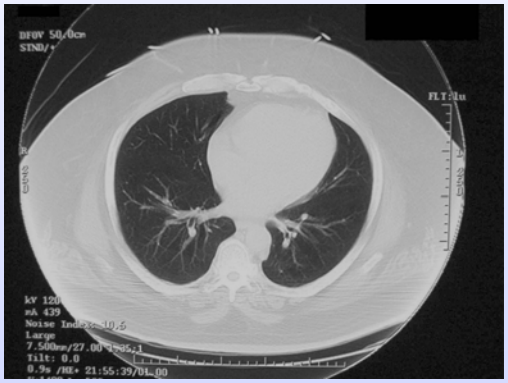
Images by authors

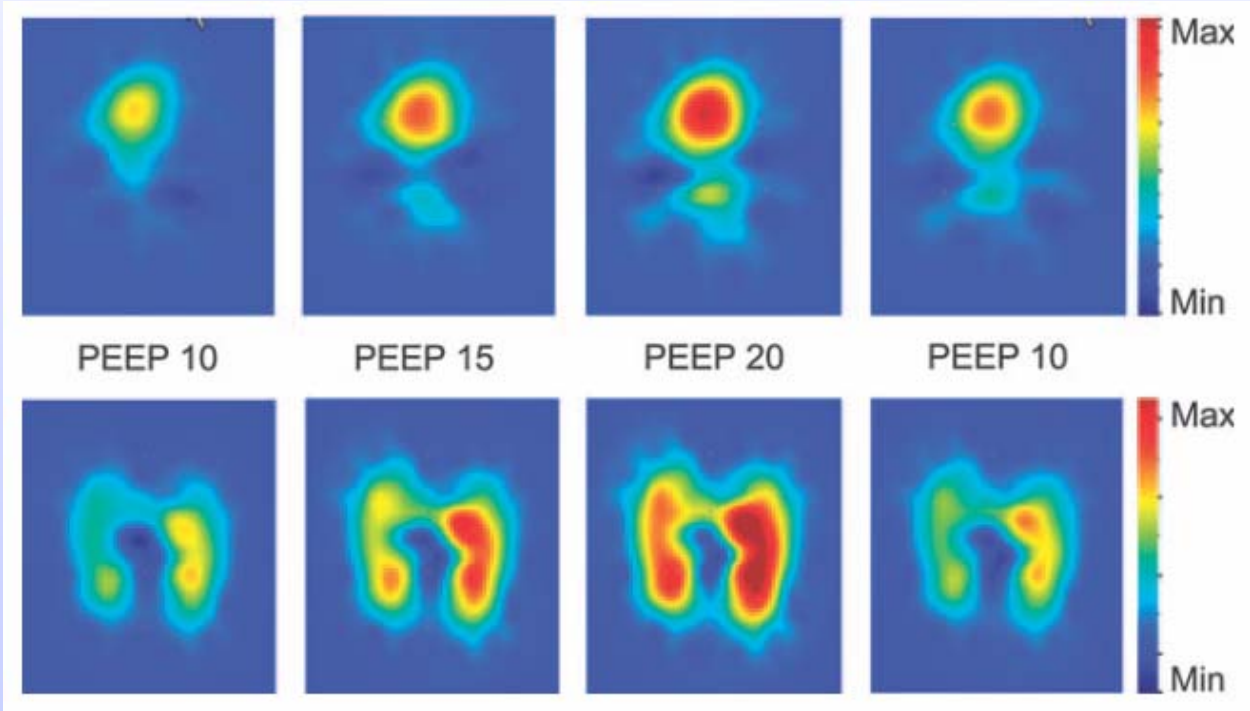
PULLETZ, S. et al. Physiol Meas 2006, 27, S115-127

EIT in spatial domain

EIT in morbidly obese patients

Distorted EIT images from a morbidly obese patient (top) at different PEEP levels and corresponding images from a normal weight patient (bottom).





ERLANDSSON, K. et al. Acta Anaesthesiol. Scand. 2006, 50, pp. 833-839

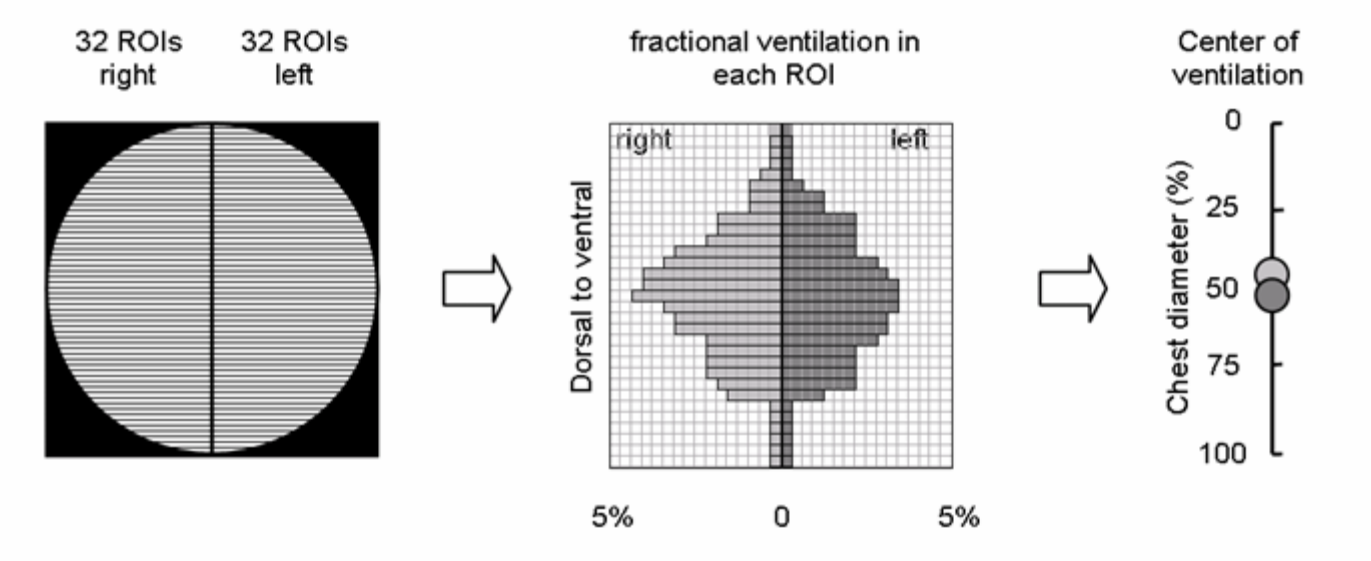
EIT in spatial domain

Center of Ventilation (CoV)

„The Center of Ventilation (CoV) reflects the distribution of ventilation in ventral-to-dorsal direction“

$$COV = \frac{TIV_{dorsal}}{TIV_{total}}$$

TIV = Tidal Impedance Variation



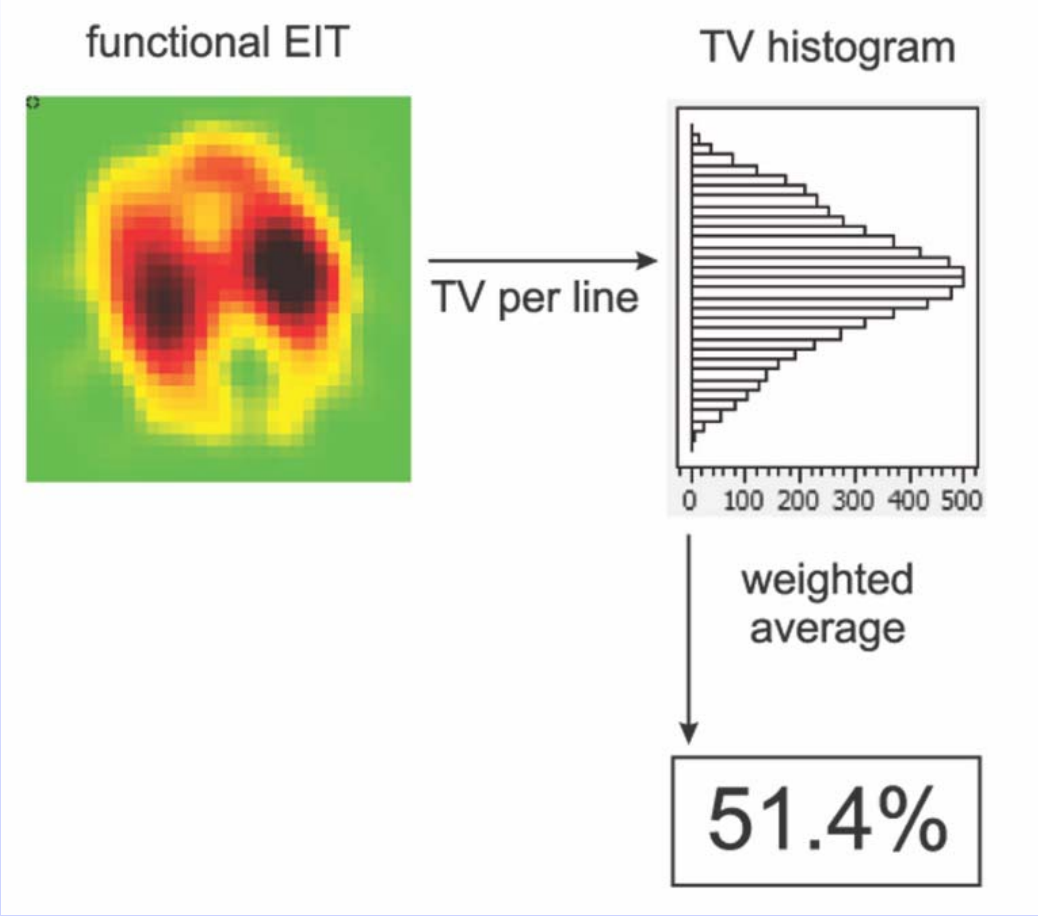
BLANKMAN, P. et al. Critical Care 2014, 18:R95
VAN HEERDE, M. Acta Anaesthesiol Scand 2010; 54: 1248-1256

EIT in spatial domain

Center of Gravity (CoG)

The Center of Gravity (CoG) is calculated as a **weighted average** of row / column sums.

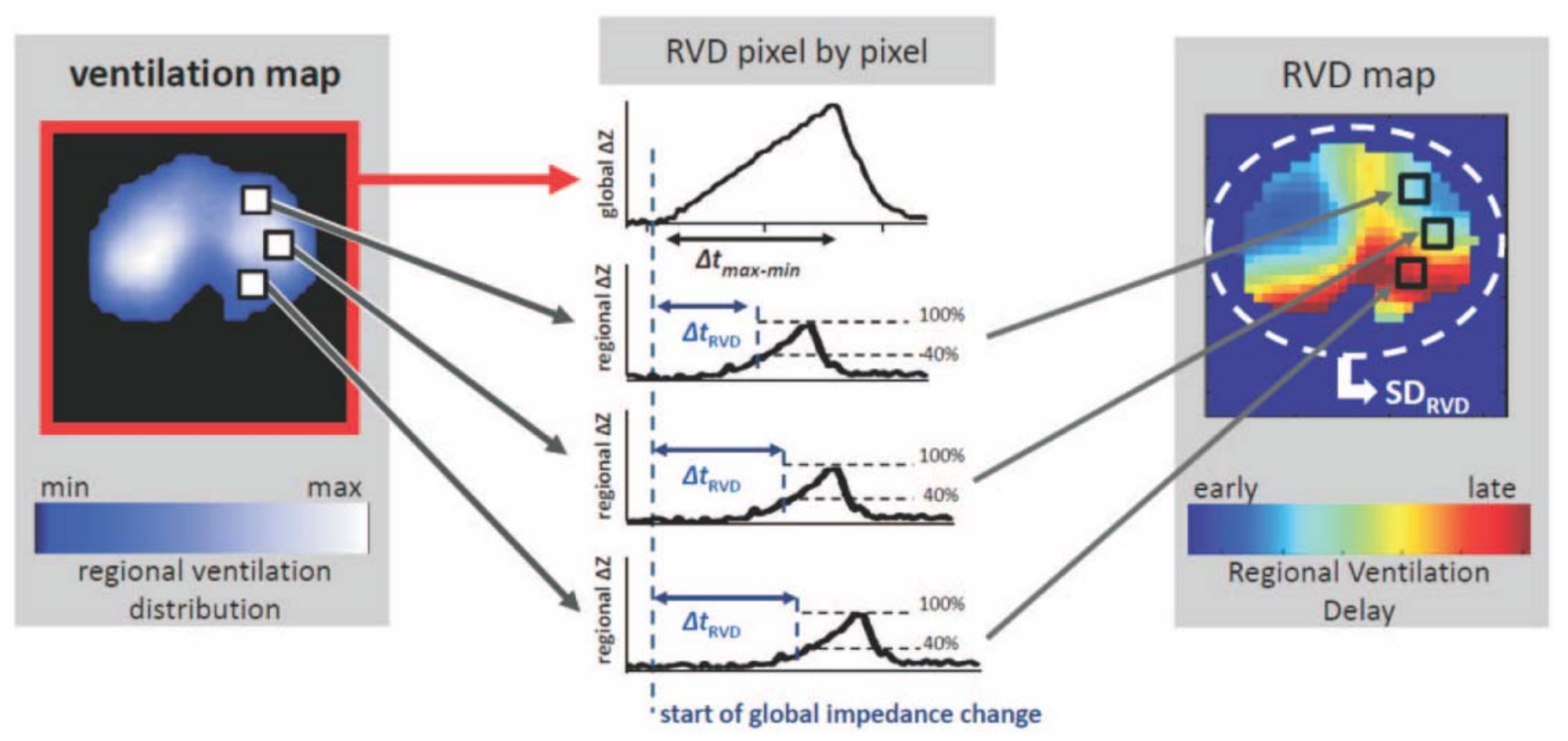
Note: **Authors frequently interchange the terms CoV and CoG. Thus, in some articles CoV refers to CoG.**



RADKE, O.C. et al. Anesthesiology 2012 Jun; 116(6): 1227-1234

EIT in spatial domain

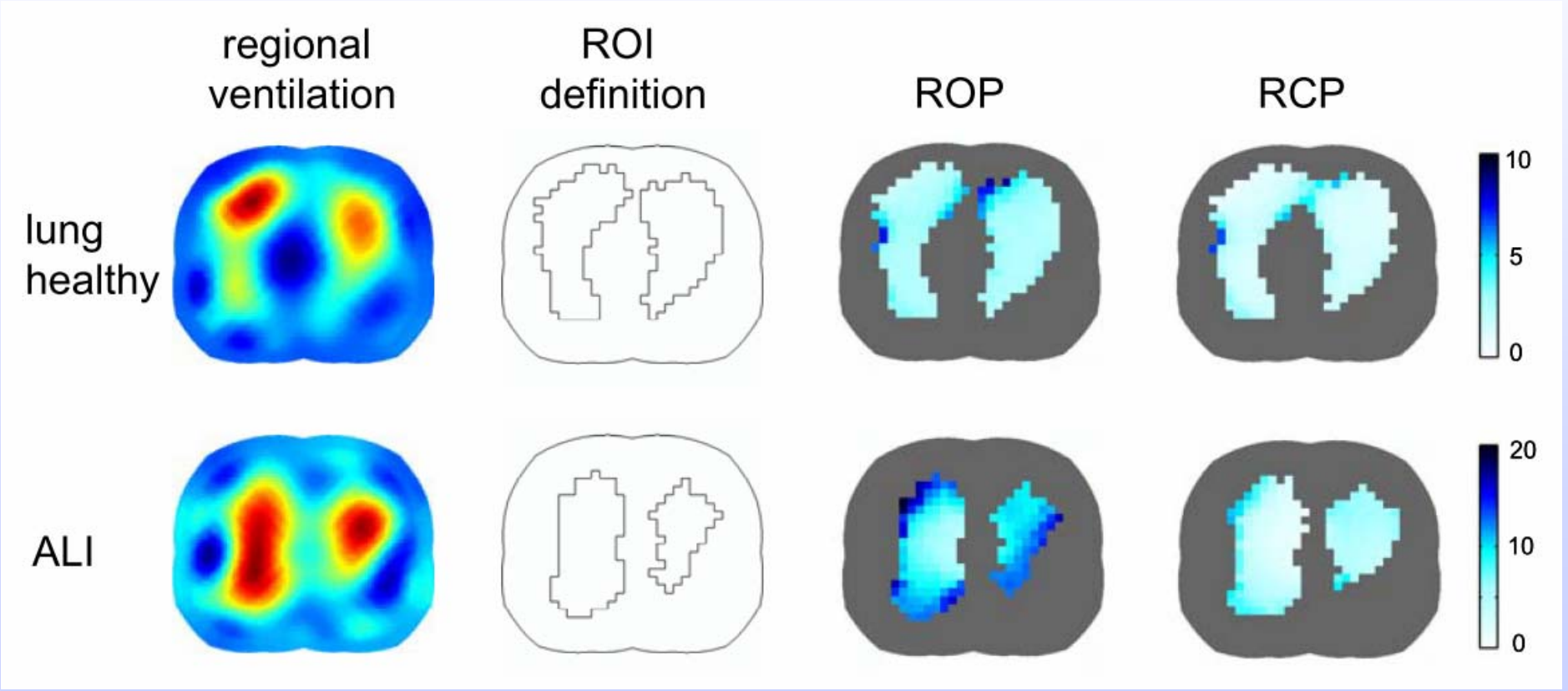
Regional Ventilation Delay



MUDERS, T. et al. Crit Care Med 2012, Vol. 40, No. 3

EIT in spatial domain

Regional Opening / Closing Pressure

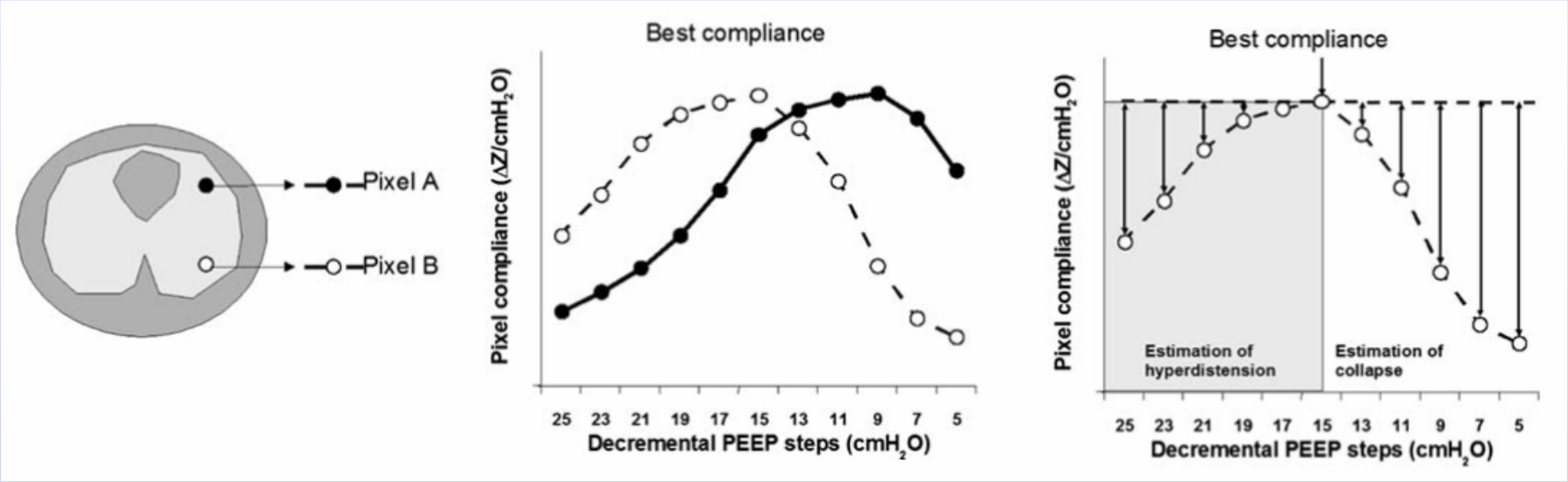


PULLETZ, S. et al. J Crit Care. 2012 Jun, 27(3):323.e11-8

EIT in spatial domain

Regional Compliance

Estimation of regional compliance helps to determine regional hyperdistension or collapse of lungs.

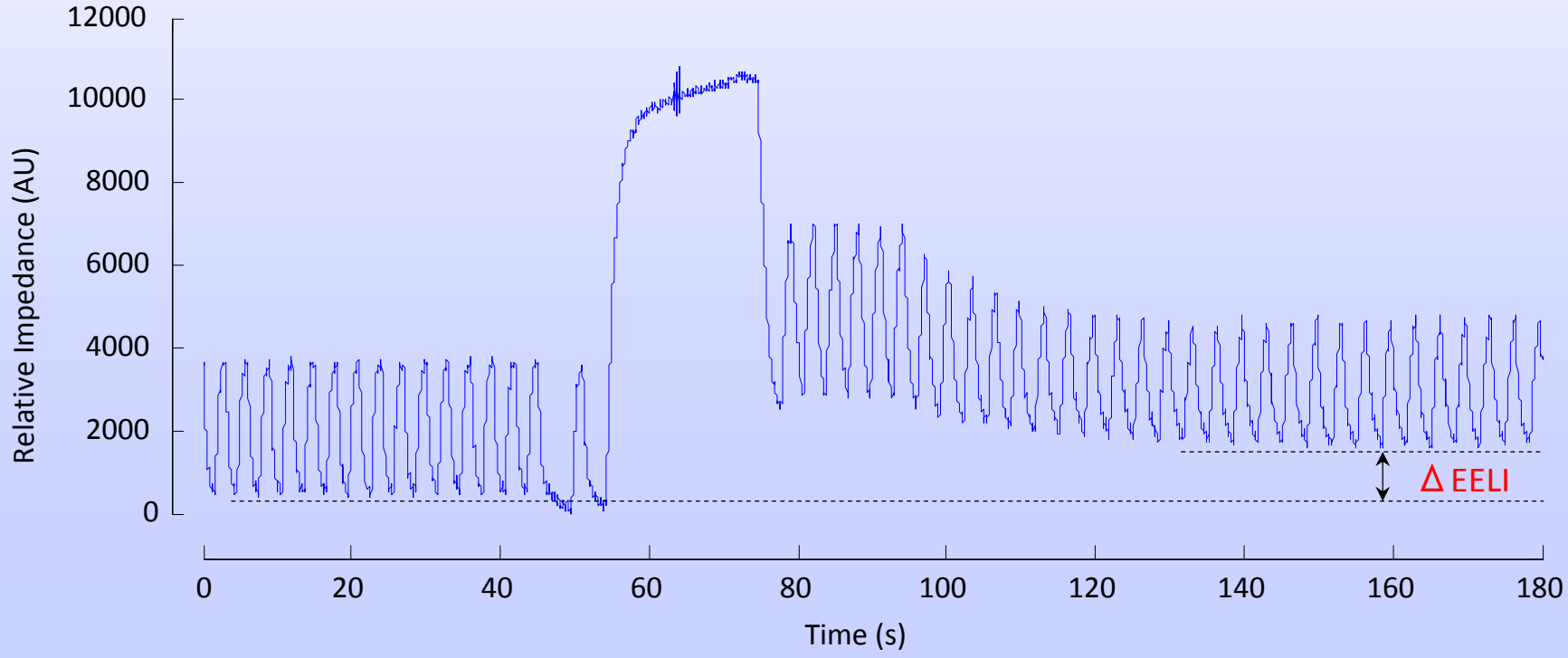


COSTA, E. L. V. et al. Intensive Care Med. 2009, 35, pp. 1132-1137

EIT in time domain

Evaluation of lung recruitment

Example of recruitment maneuver. The difference in End-Expiratory Lung Impedance (EELI) corresponds to the recruited parts of the lungs.

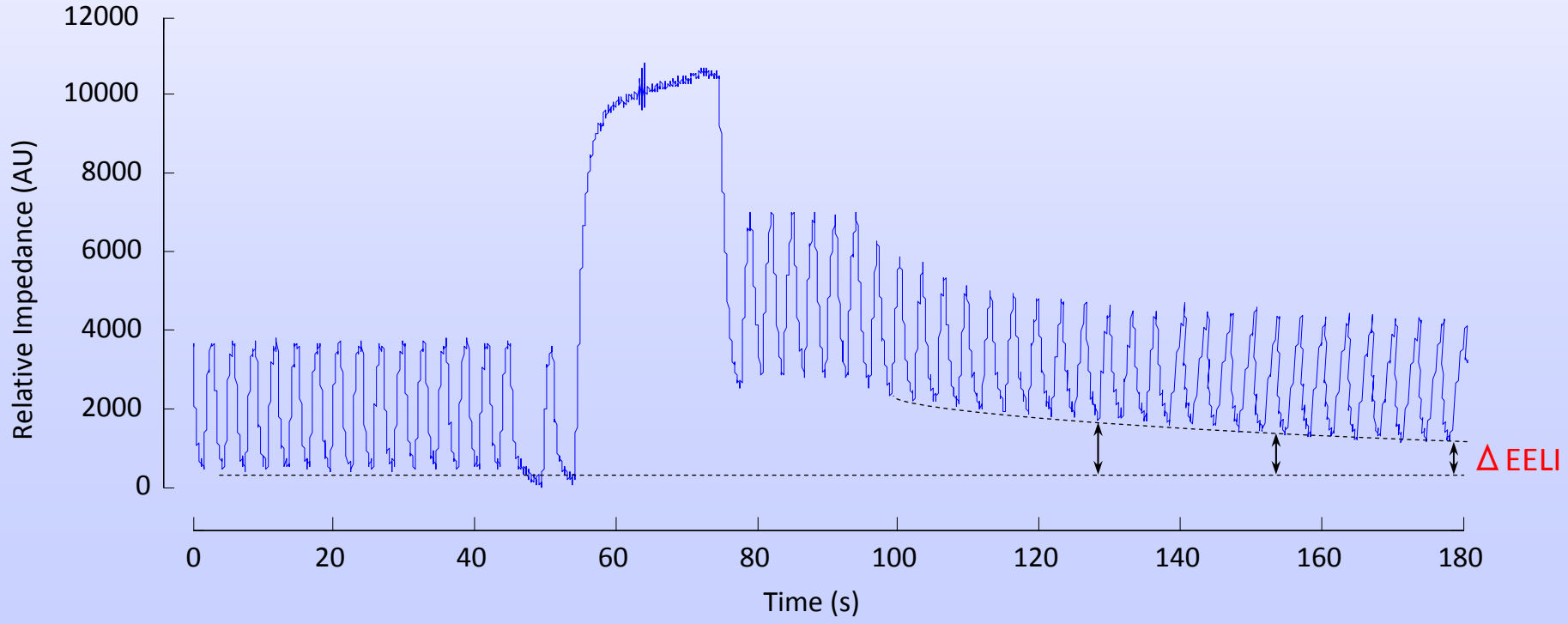


EIT in time domain

Evaluation of lung recruitment

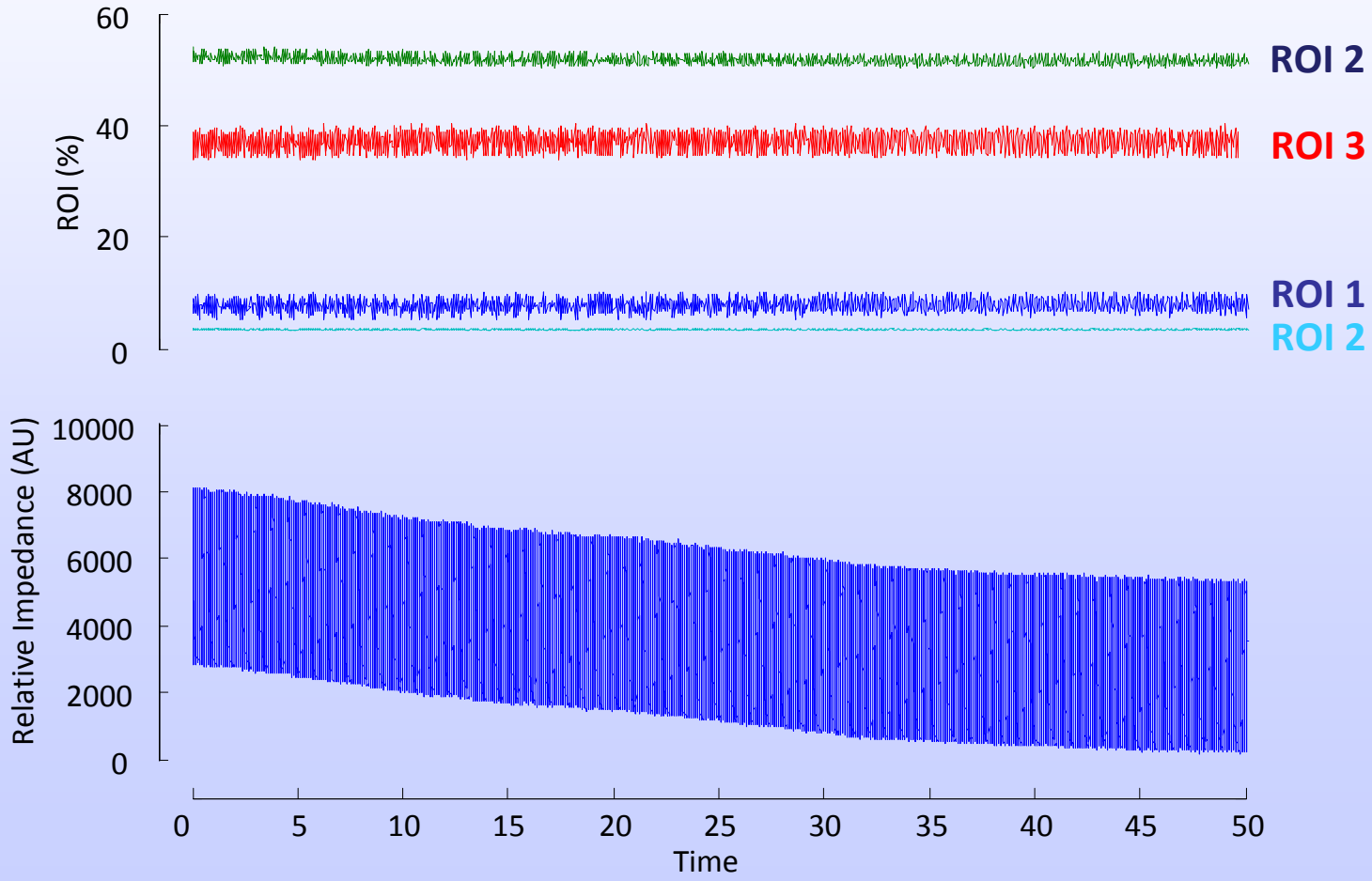
Example of recruitment maneuver **failure**.

Probably insufficient PEEP unable to keep the lungs open.



EIT ambiguities

Continuous drift not caused by atelectasis



Conclusion

- EIT is an interesting ~~imaging~~ monitoring[1] modality offering real time information about lung ventilation. Data processing is necessary.
- EIT data always have to be interpreted depending on the actual situation and procedure (since EIT is a functional imaging).
- Due to the complex processing and recent fast development, a ‘Gold Standard’ of data processing and visualization is still missing.

[1] based on imaging

Conclusion

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- EIT data always have to be interpreted depending on the actual situation and procedure (since EIT is a functional imaging).
- Due to the complex processing and recent fast development, a ‘Gold Standard’ of data processing and visualization is still missing.

Thank you for your attention!