Electricity in the Body

Carleton University Biomedical Engineering Society
Professor Presentation Night
11 February 2015

Andy Adler

Professor & Canada Research Chair in Biomedical Engineering
Systems and Computer Engineering, Carleton University, Ottawa

From Andy Adler: Can you please tell me more about what you want to hear? . . .

From: Vicky Madge via sce.carleton.ca

> *If you could talk about how you are involved at Carleton; what classes you teach currently (and maybe talk about your classes from uOttawa), your research projects currently underway (include objective, methods, and tools if possible) and anything else you can think of that will give the students a good indication of what to expect in the next couple years in undergrad and what to expect in a future in biomedical engineering. How does that sound?*

. . . what you want to hear?

. . . Six hours later . . .

. . . what you want to hear?

Classes

- Electronics & Bio-electronics
- Digital signal processing
- Biomedical instrumentation
- Medical imaging
- Introduction to Biomedical Engineering (grad)

Research . . .

Electricity in the body

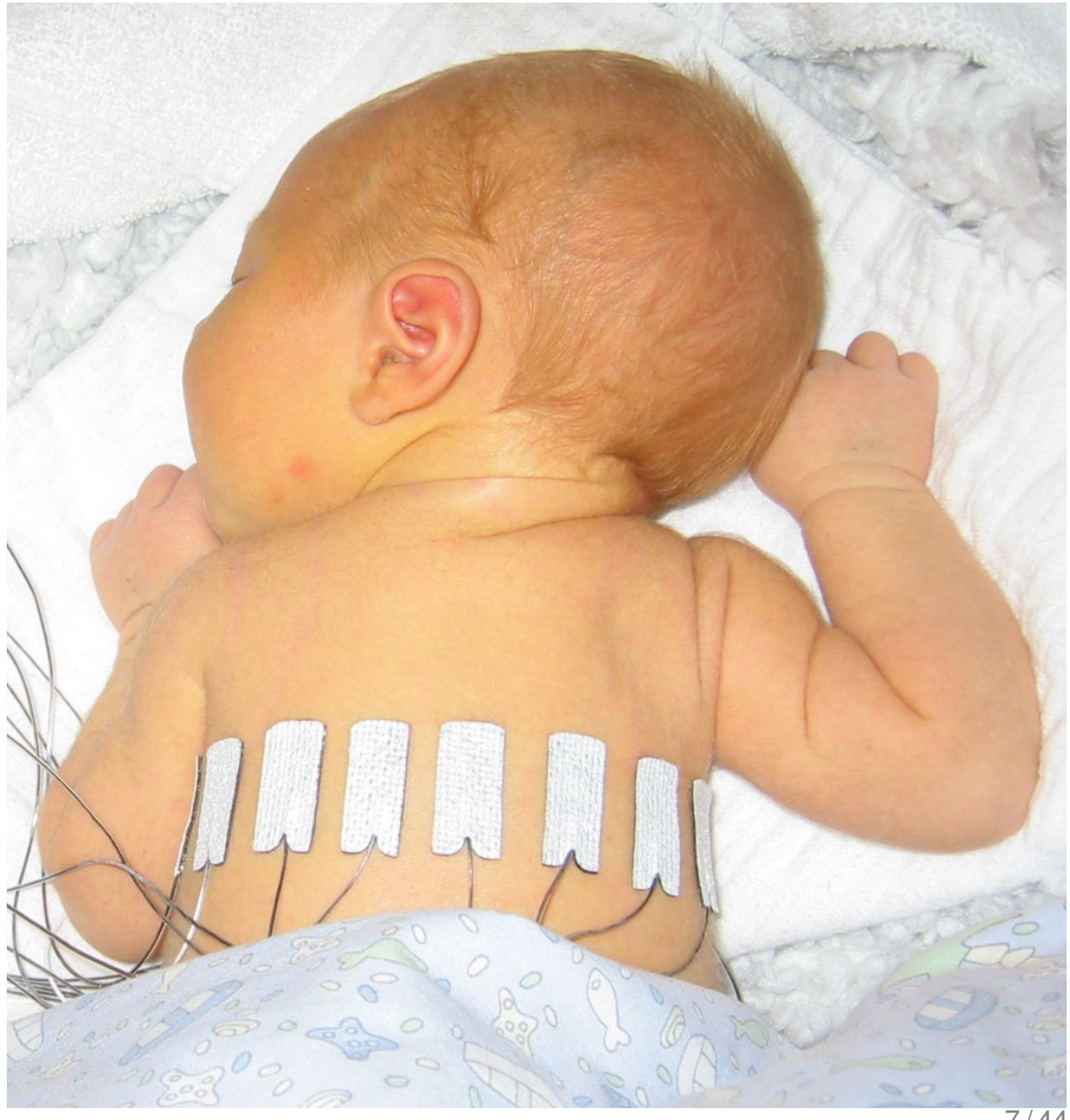
- Electrical imaging
- Cardiac mapping
- Tasers

. . . the future

Prediction is difficult, especially about the future.

— Niels Bohr

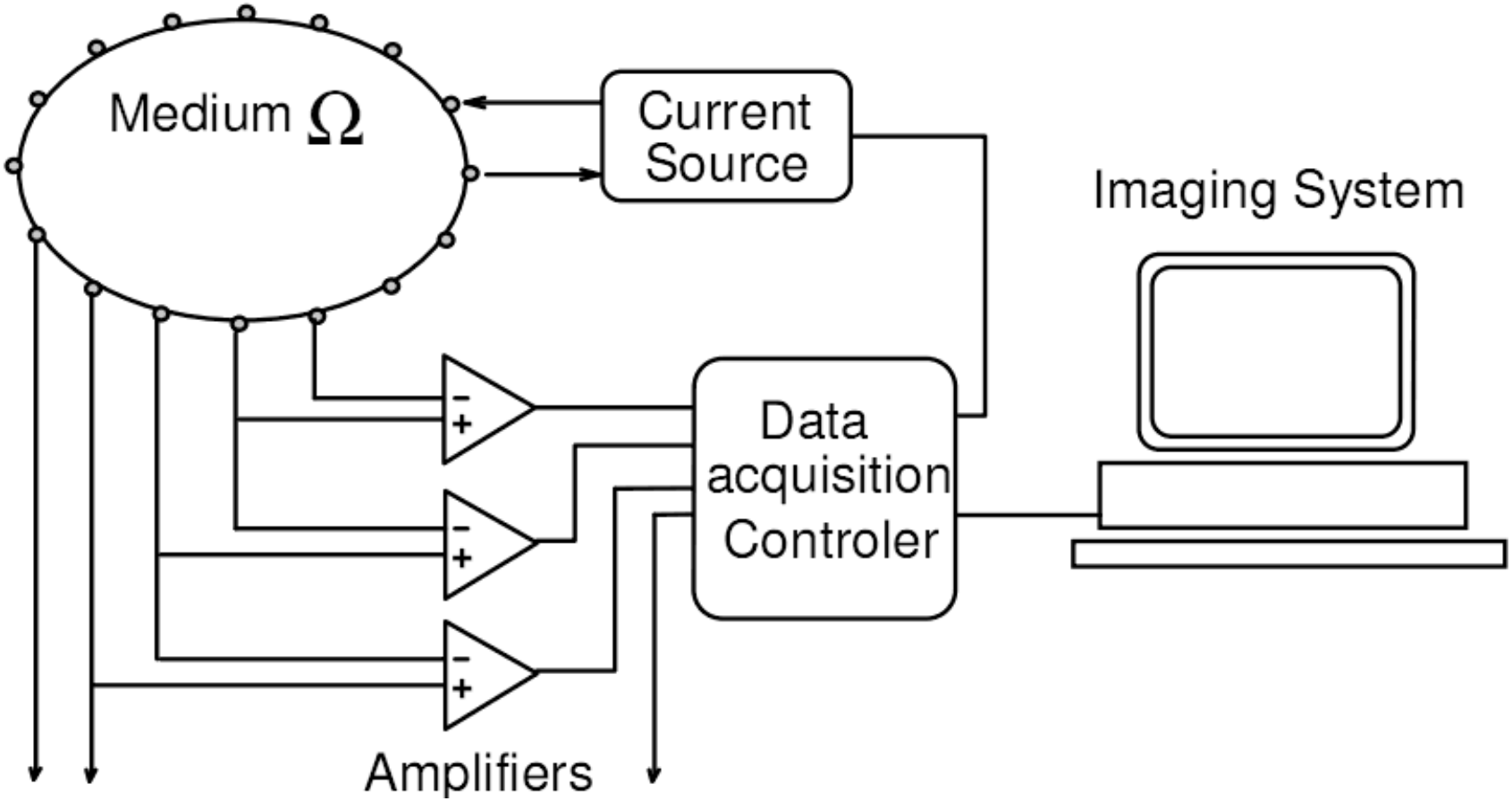
Electrical Impedance Tomography



10-day old healthy baby with EIT electrodes

Source: eidors3d.sf.net/data_contrib/if-neonate-spontaneous

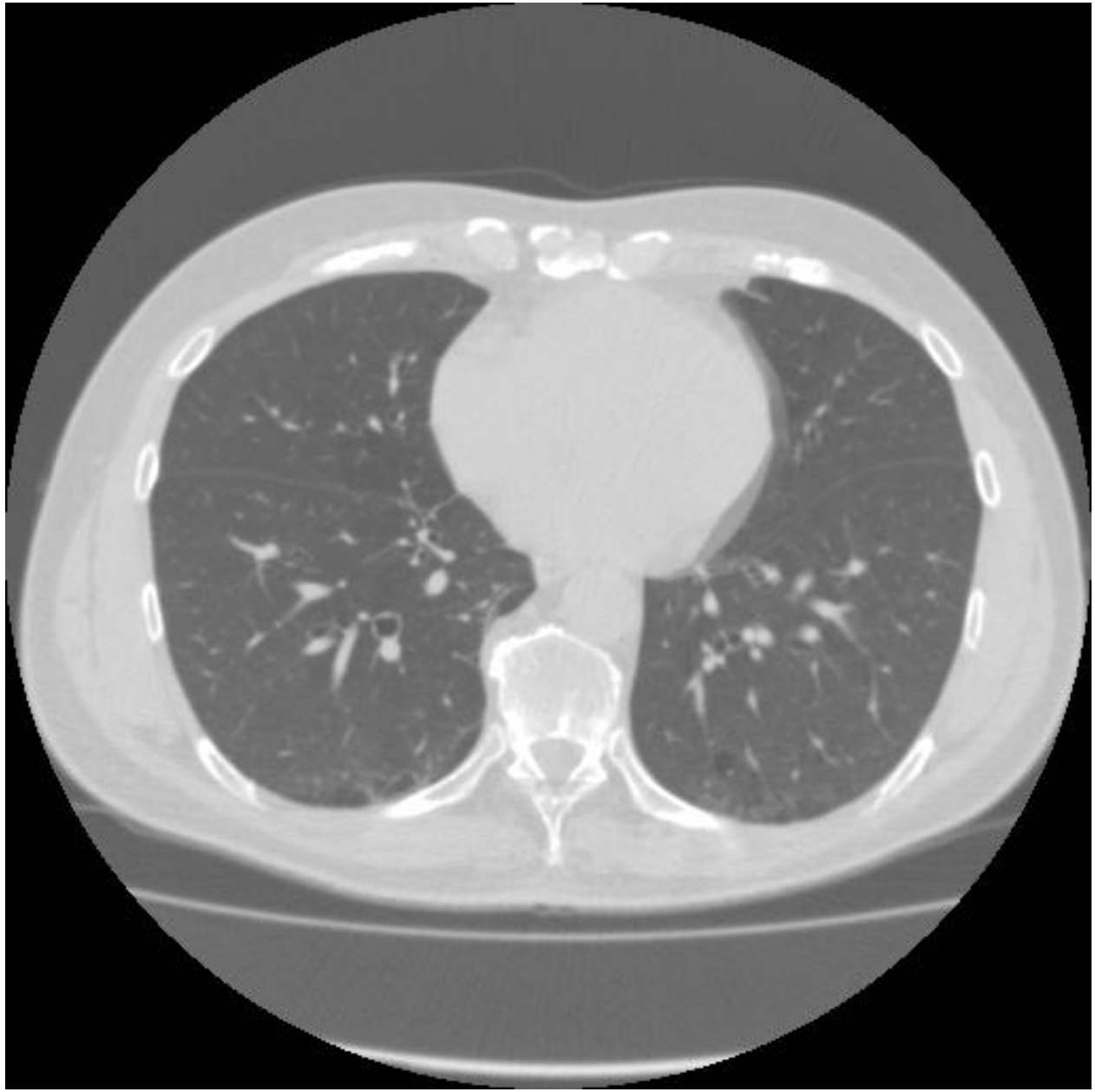
Electronics – Block Diagram



Current Propagation

Healthy Adult Male
CT slide at heart

Source: eidors3d.sf.net/tutorial/netgen/extrusion



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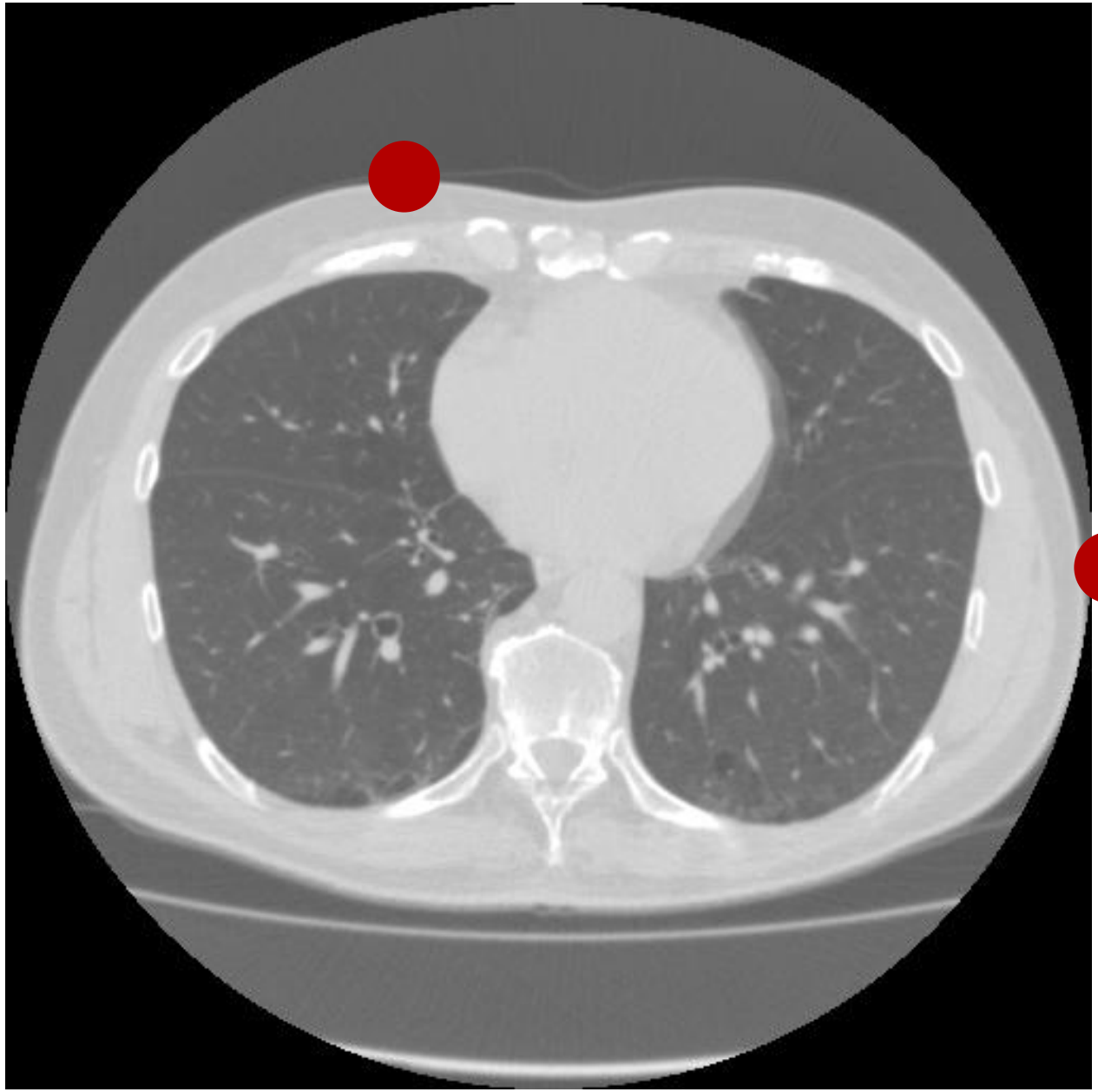

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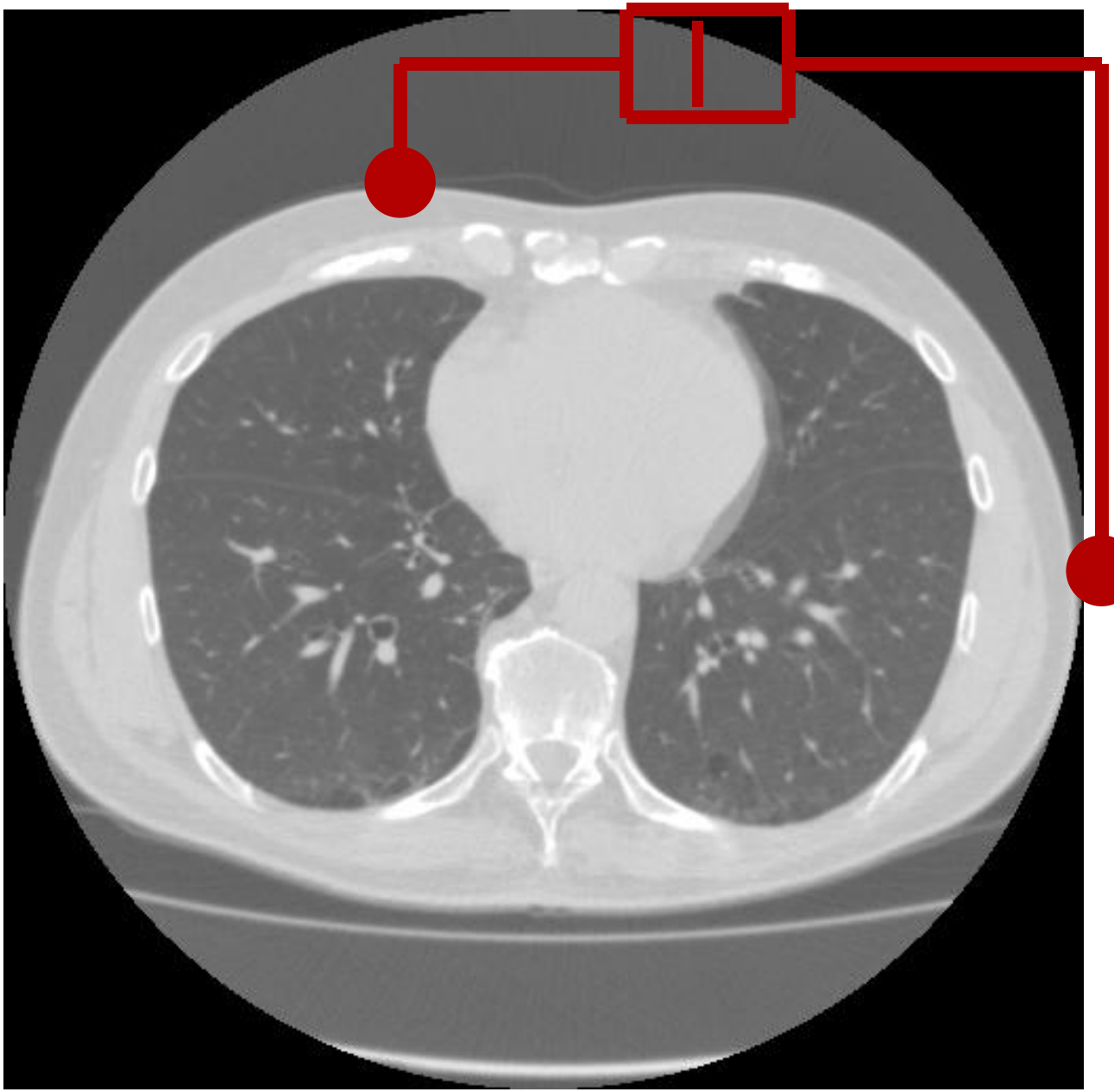

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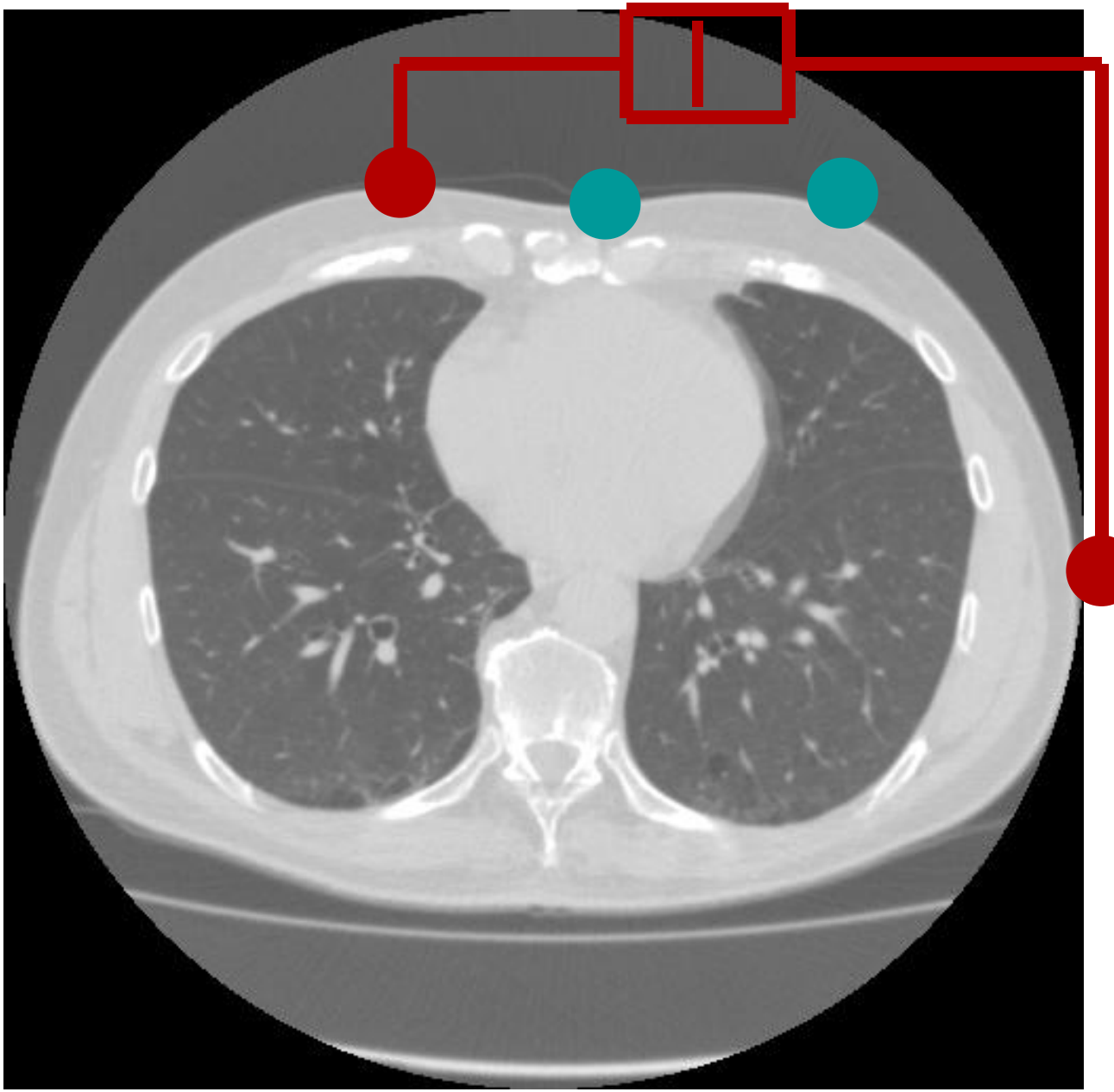

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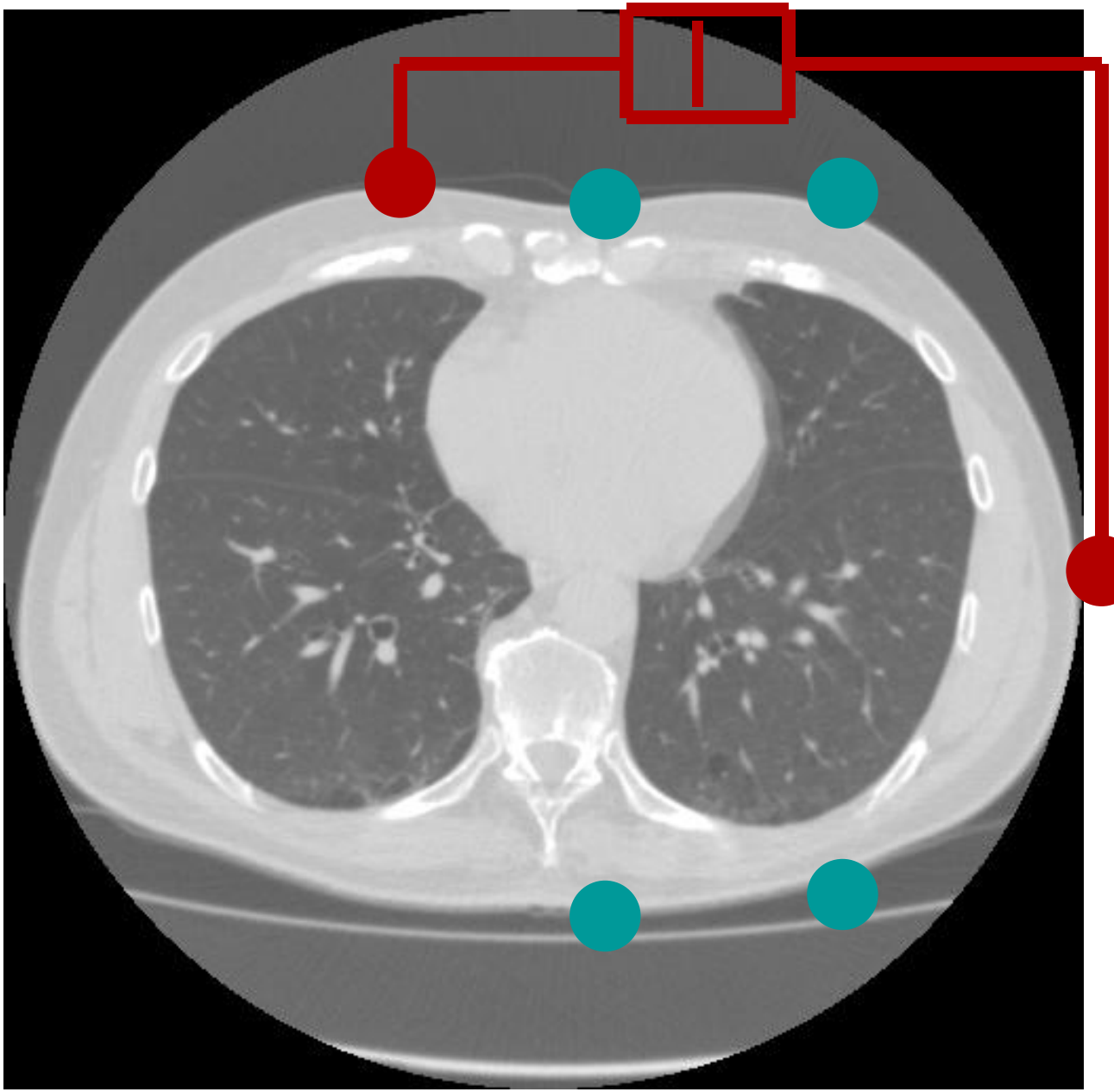
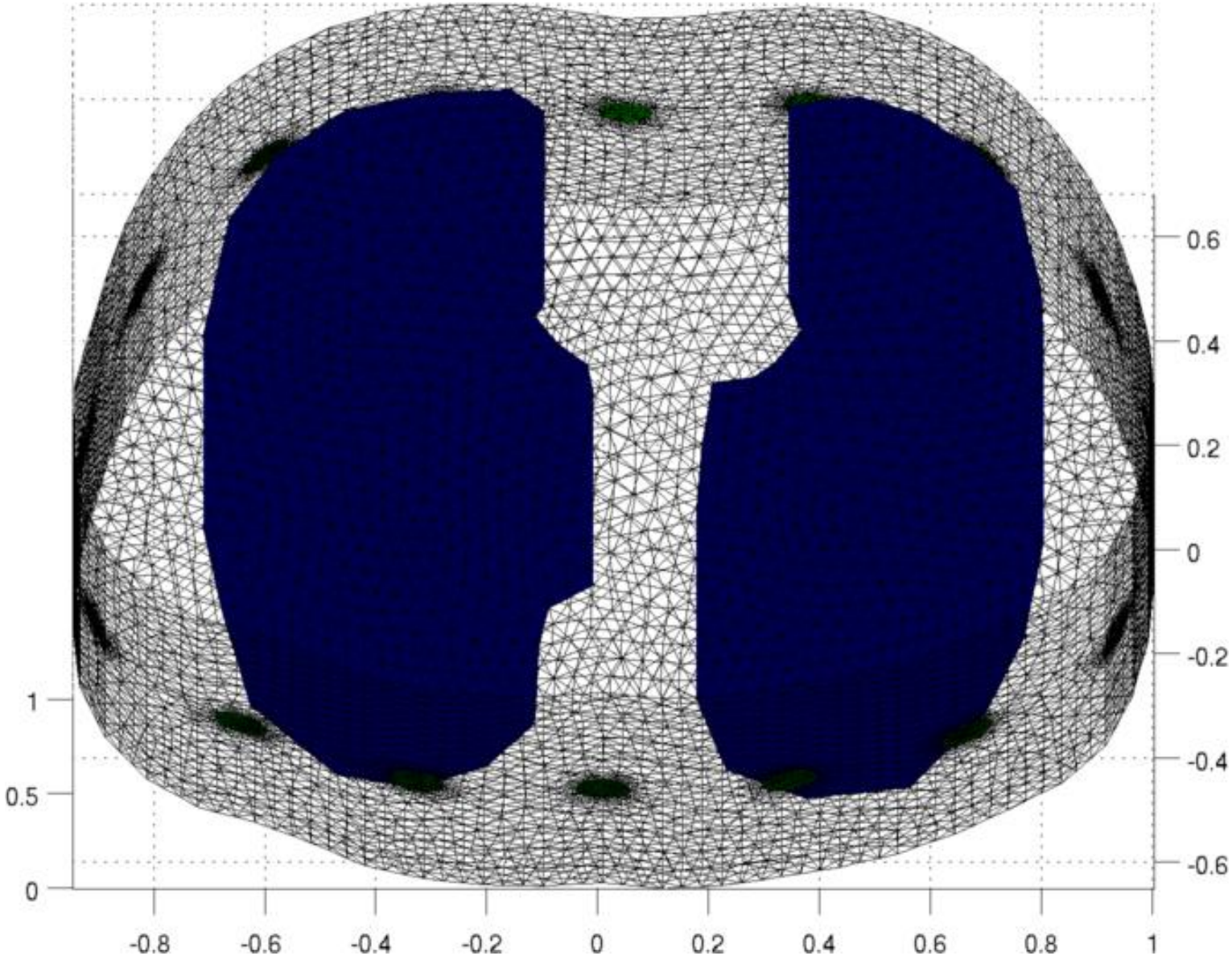


Finite Element Modelling



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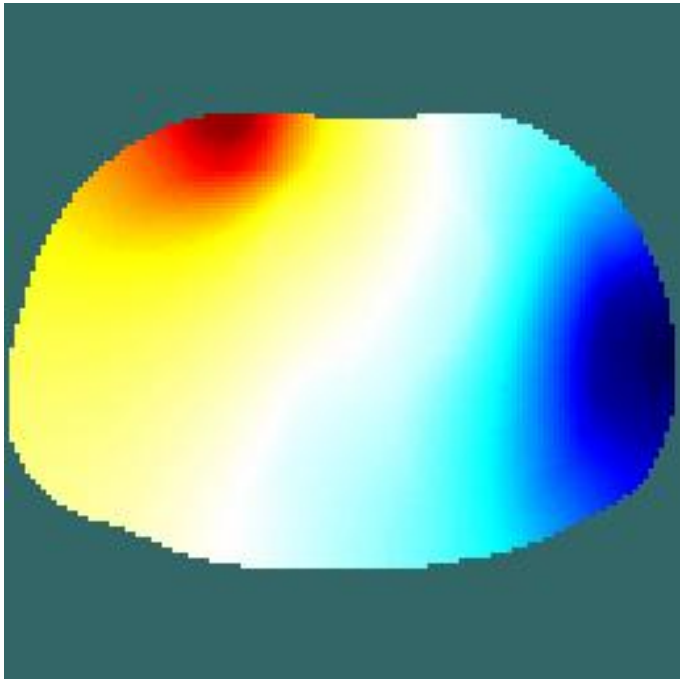
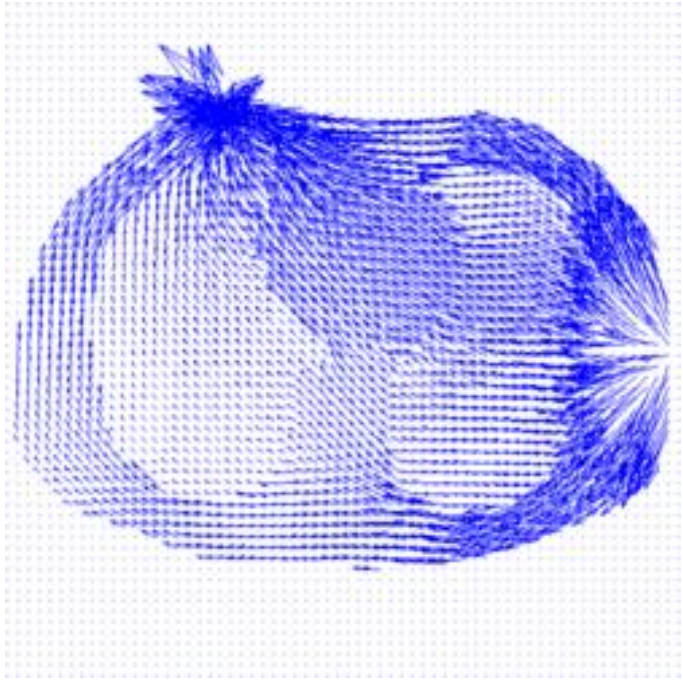


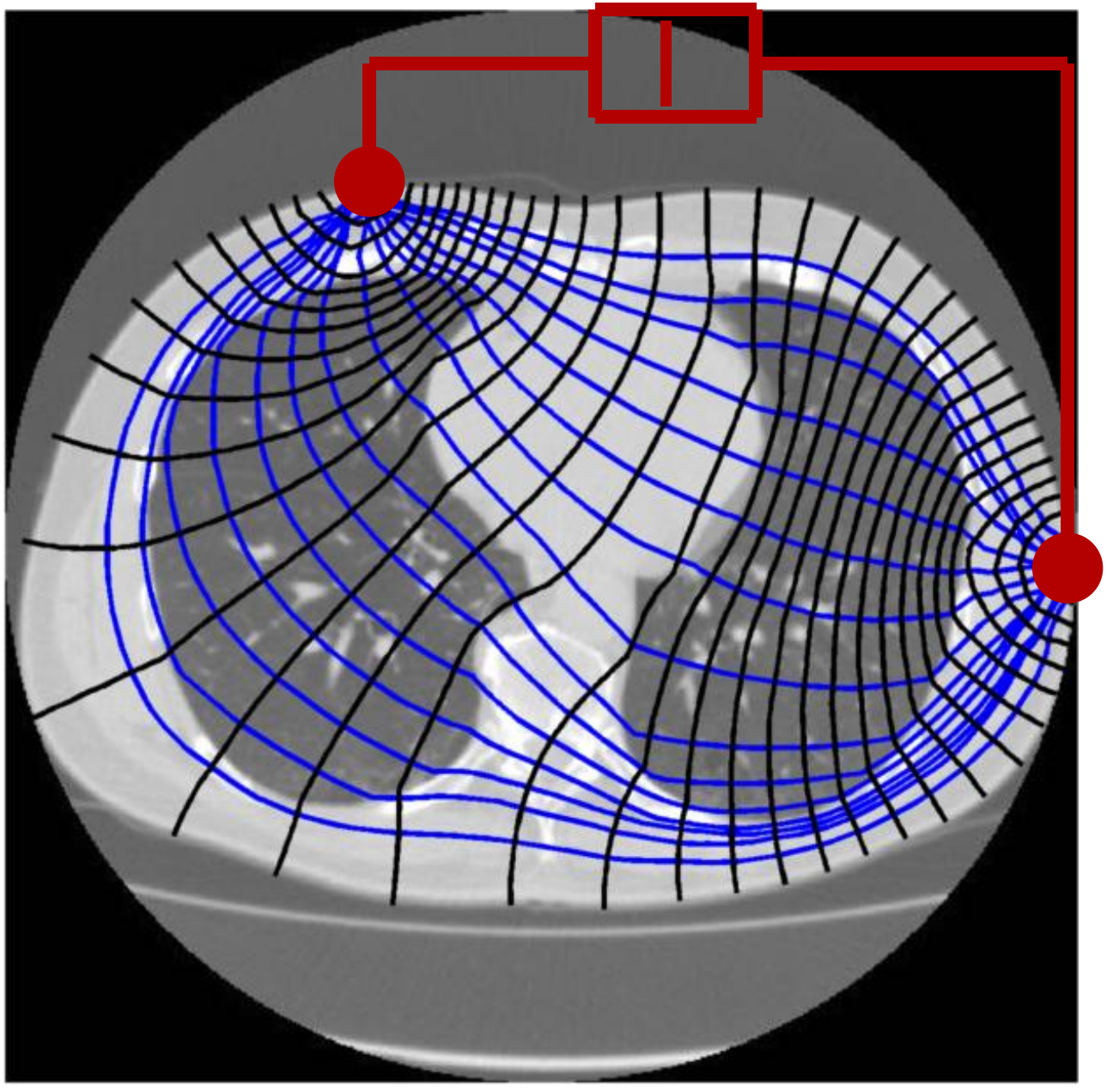
Simulated Voltages



Voxel Currents

Thorax Propagation

CT Slice with simulated current streamlines and voltage equipotentials



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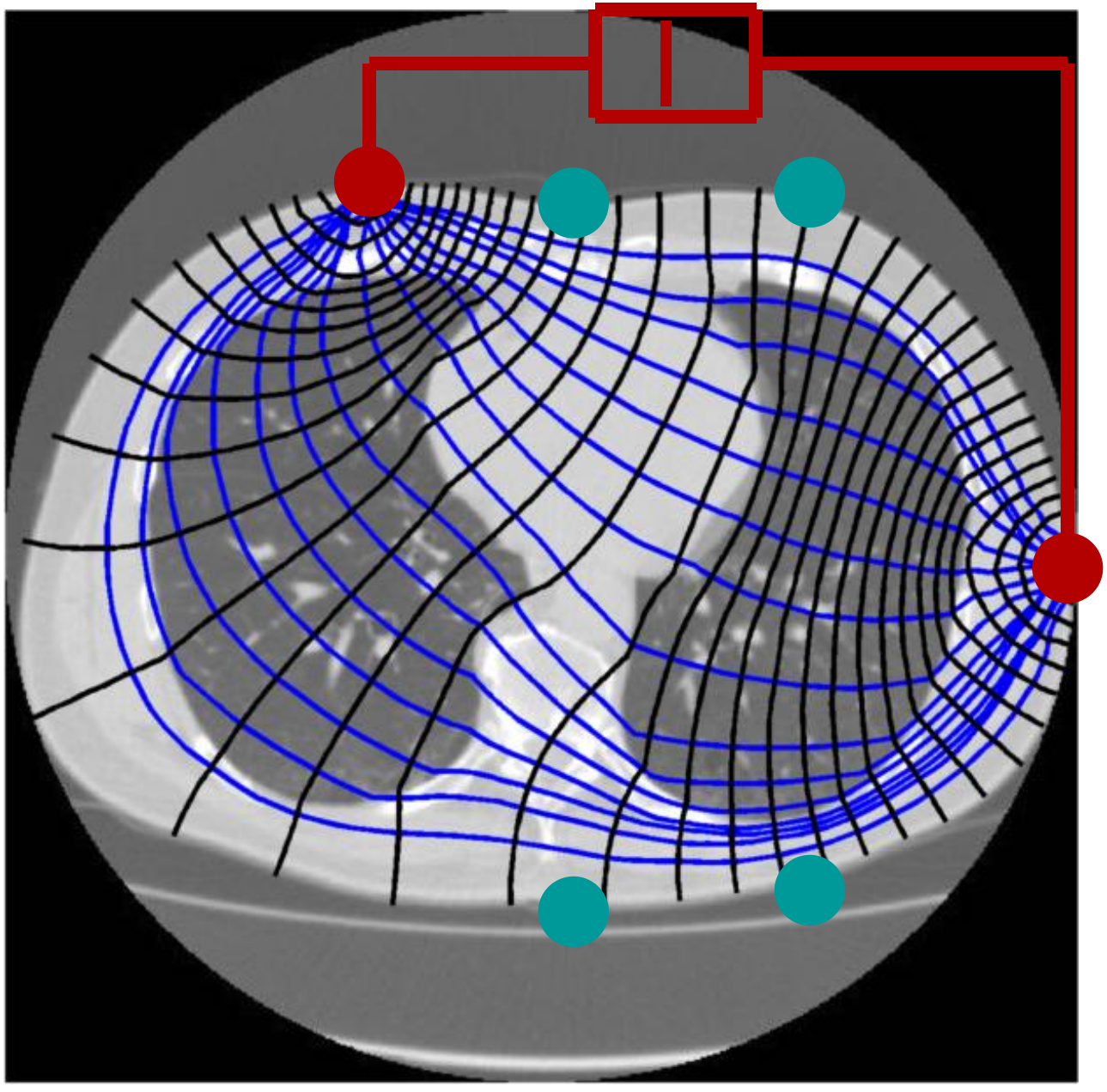
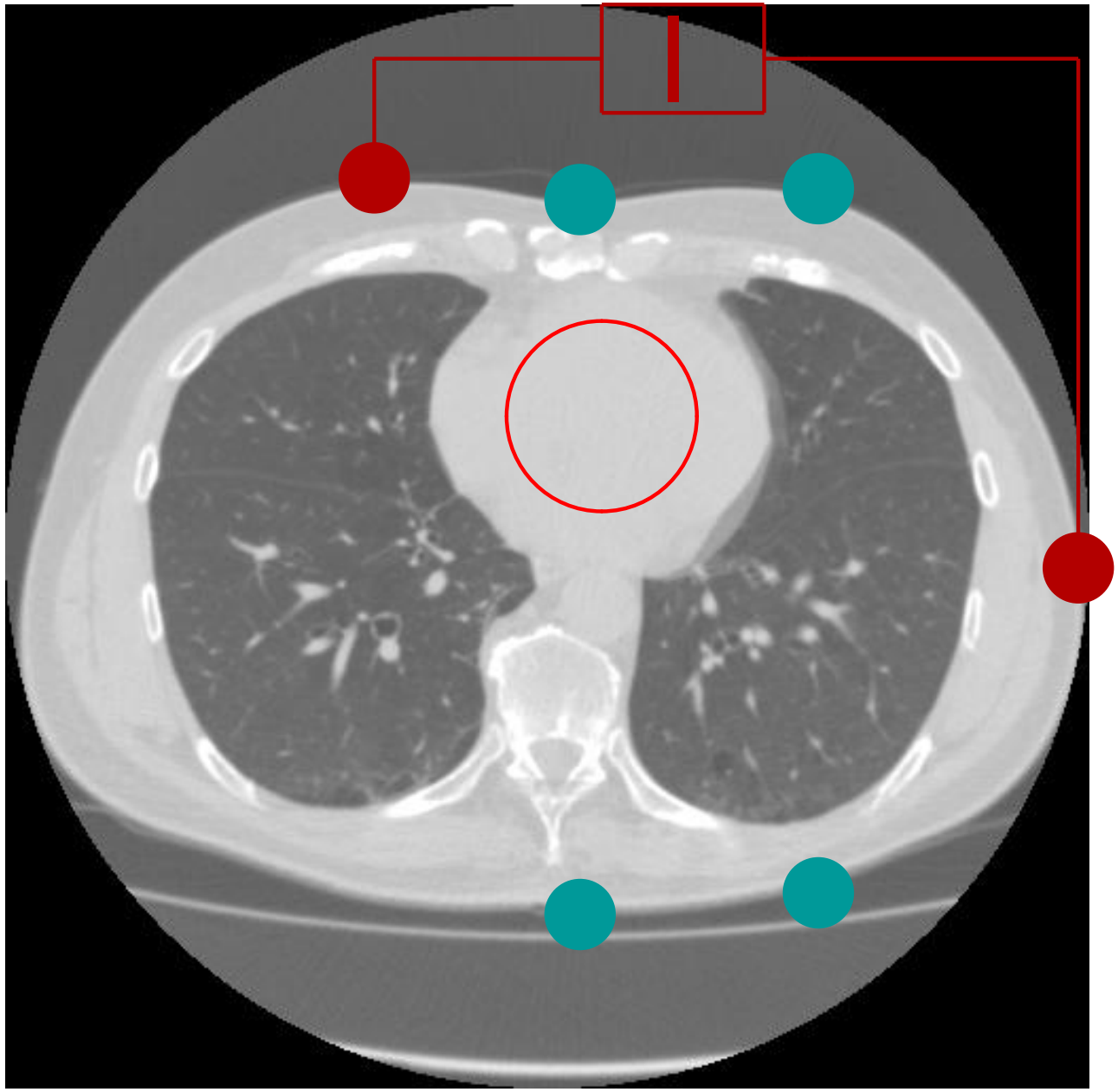


Changing Conductivity

Heart receives blood (diastole) and is more conductive



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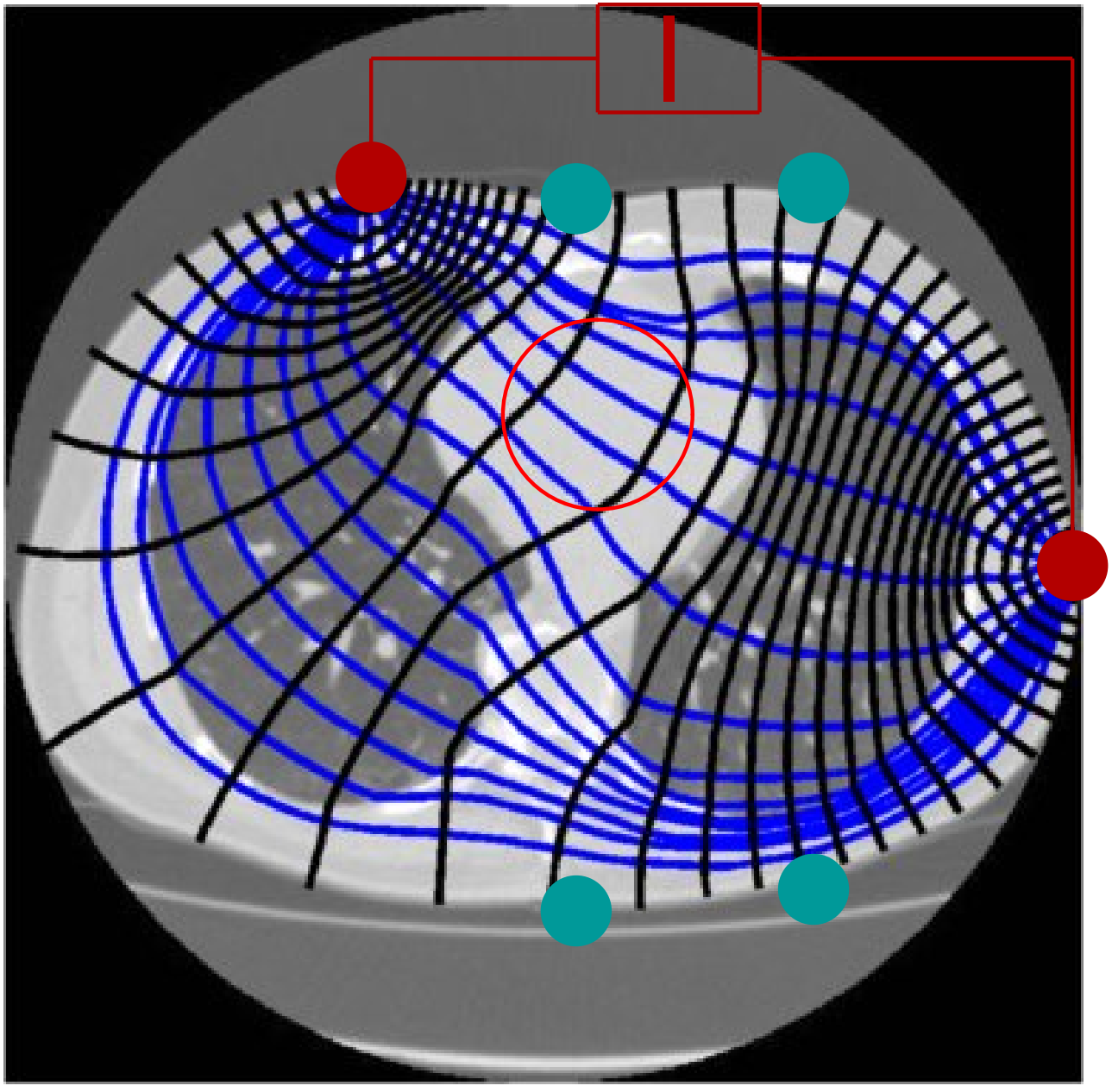

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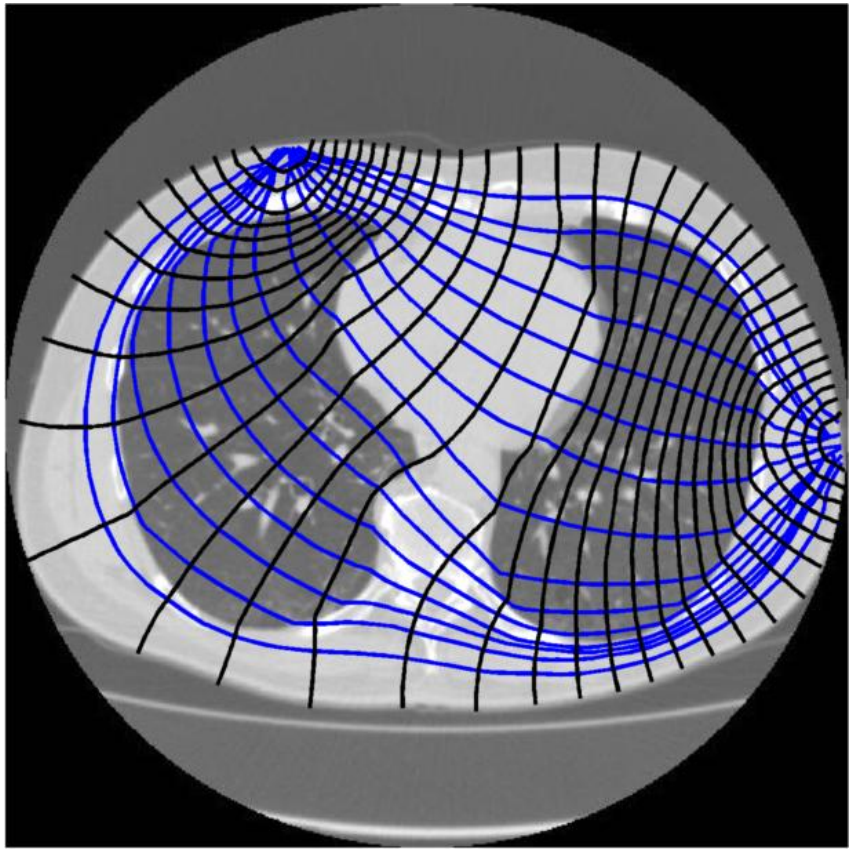
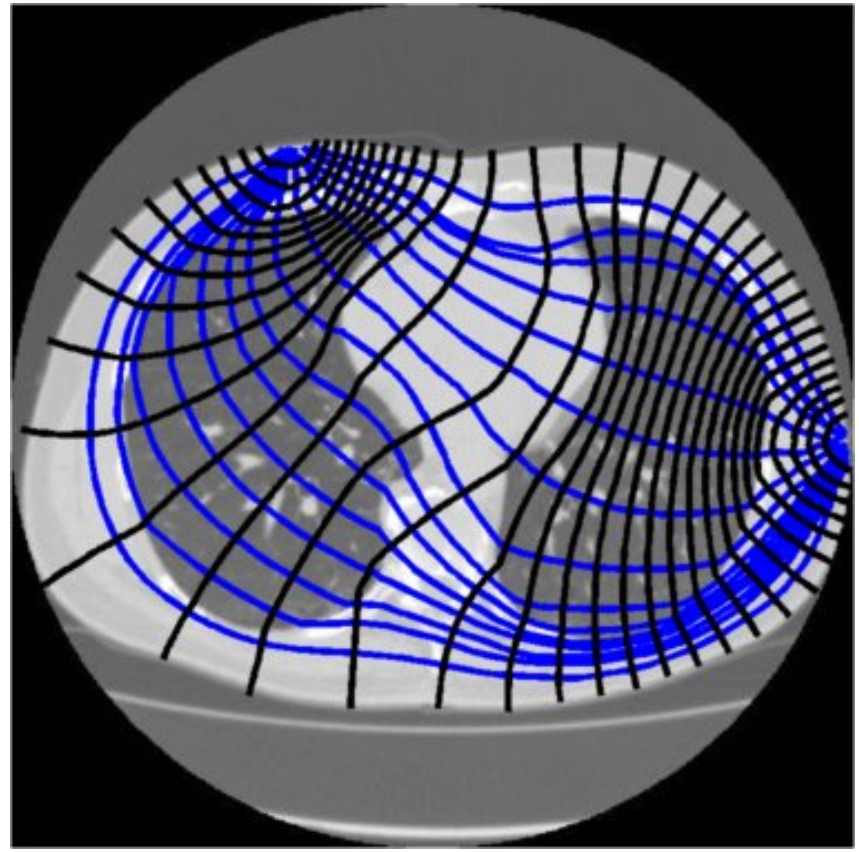
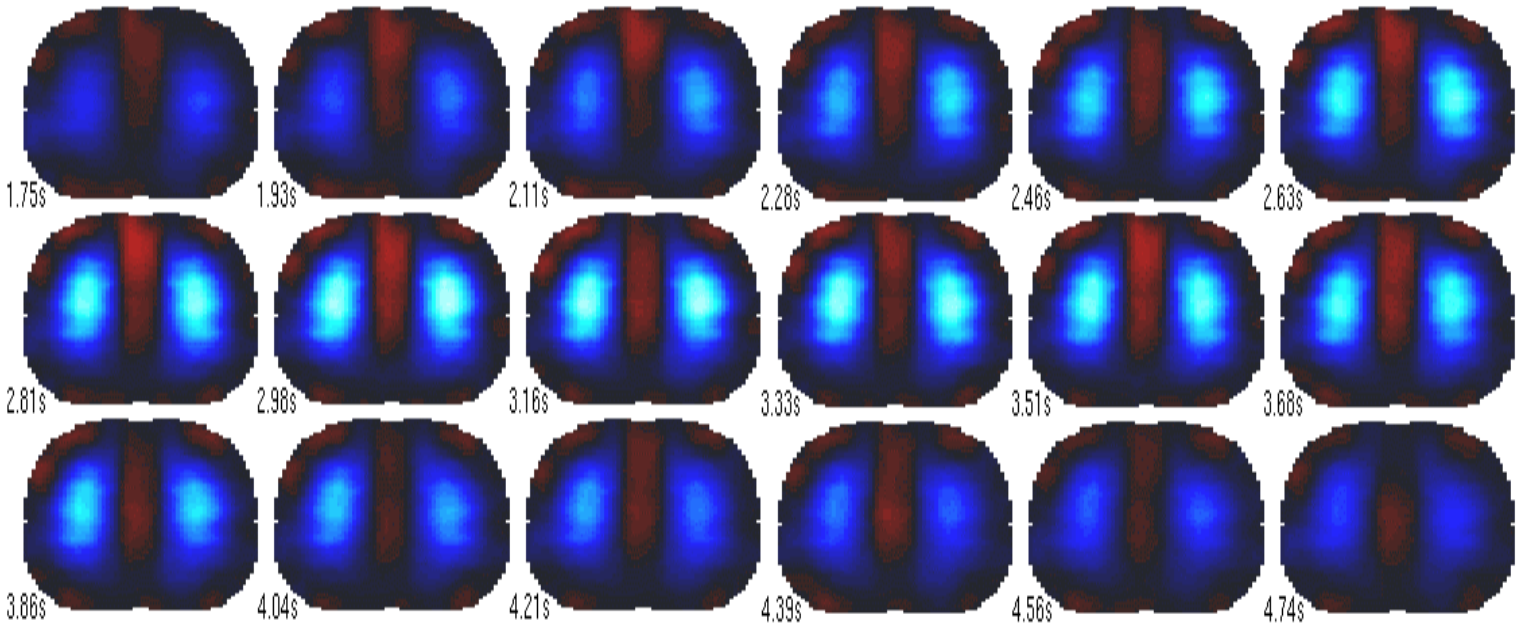


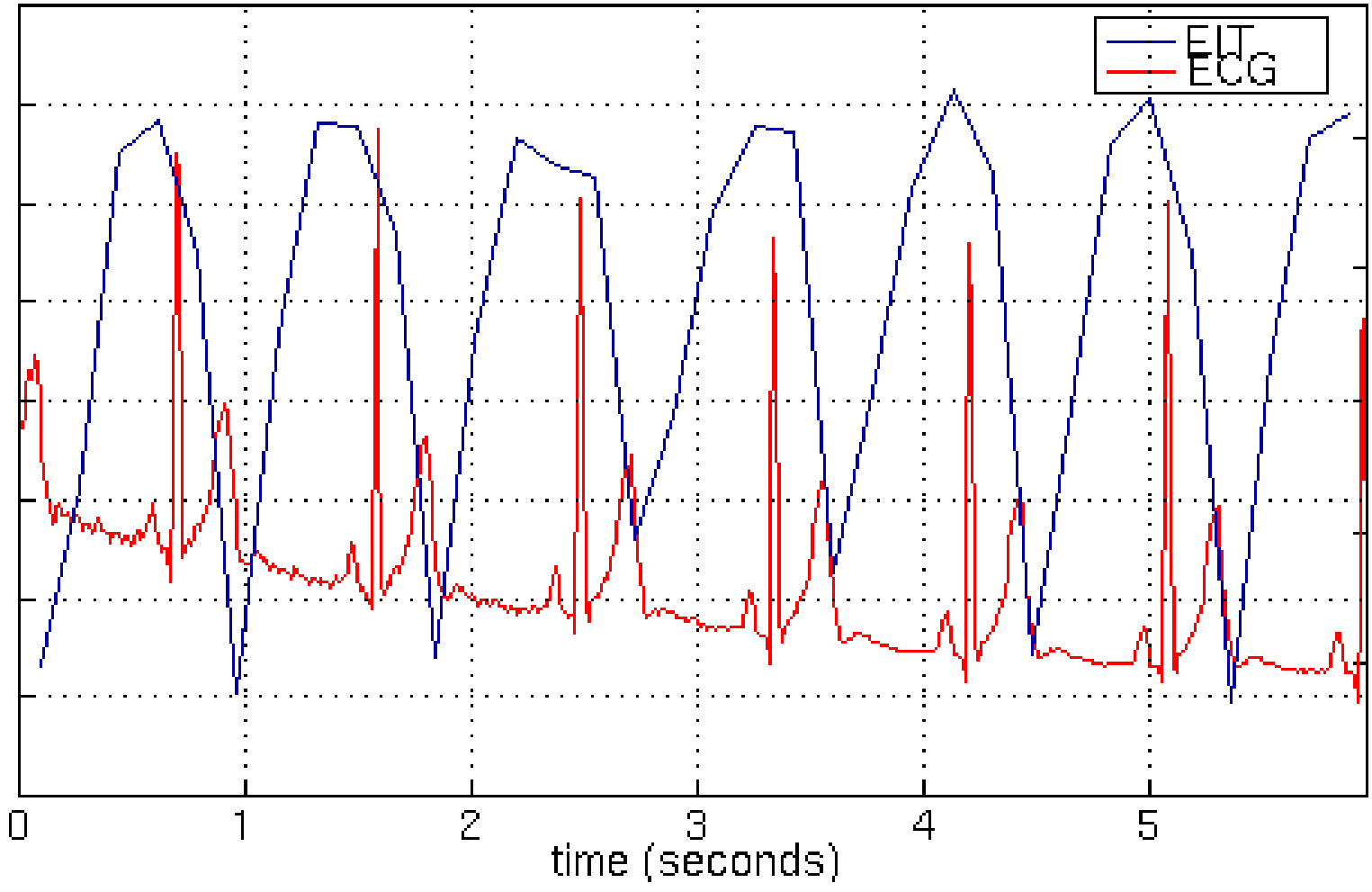


Application: Breathing



Chest images of tidal breathing in healthy adult

Application: Heart



EIT Signal in ROI around heart (and ECG)

Why Image Lungs? $\Rightarrow$ Respiratory Failure

Inadequate gas exchange by respiratory system
Hypoxemia ($O_2 \Downarrow$) or Hypercapnia ($CO_2 \Uparrow$)

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Causes

- Pulmonary dysfunction
  - Asthma, Emphysema, COPD, Pneumonia, Pneumothorax, Hemothorax, ARDS, Cystic Fibrosis
- Cardiac dysfunction
  - Pulmonary Edema, Arrhythmia, Congestive heart failure, Valve pathology

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Treatment

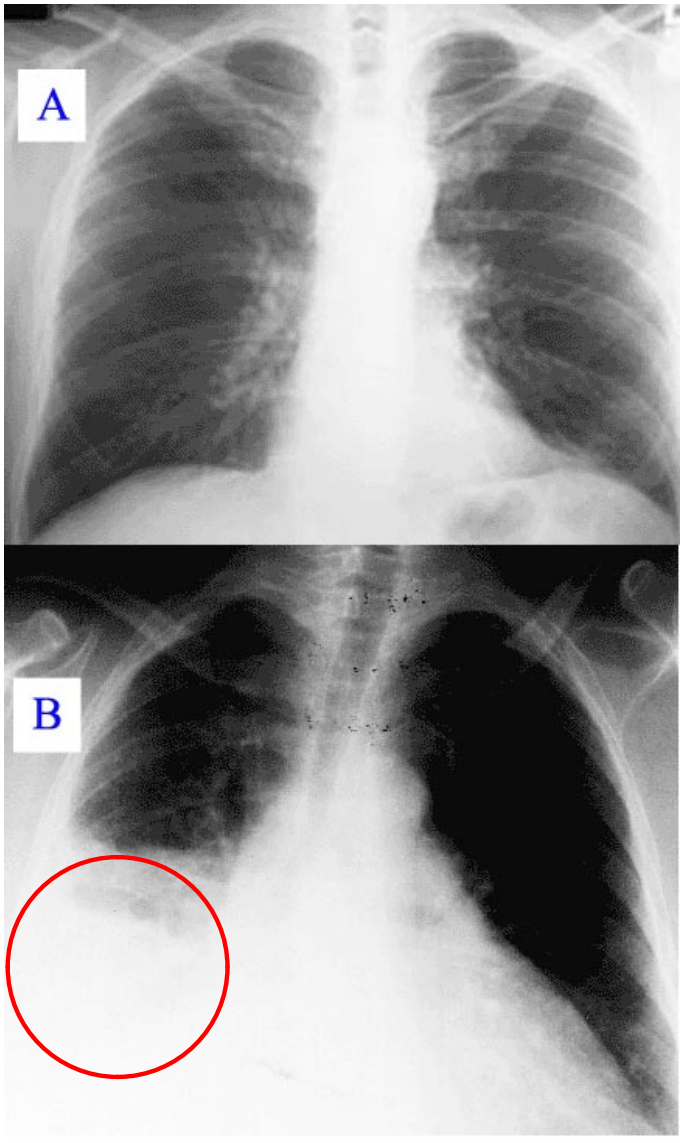
- Emergency treatment
- Treatment of underlying cause
- **Mechanical Ventilation**

Mechanical Ventilation

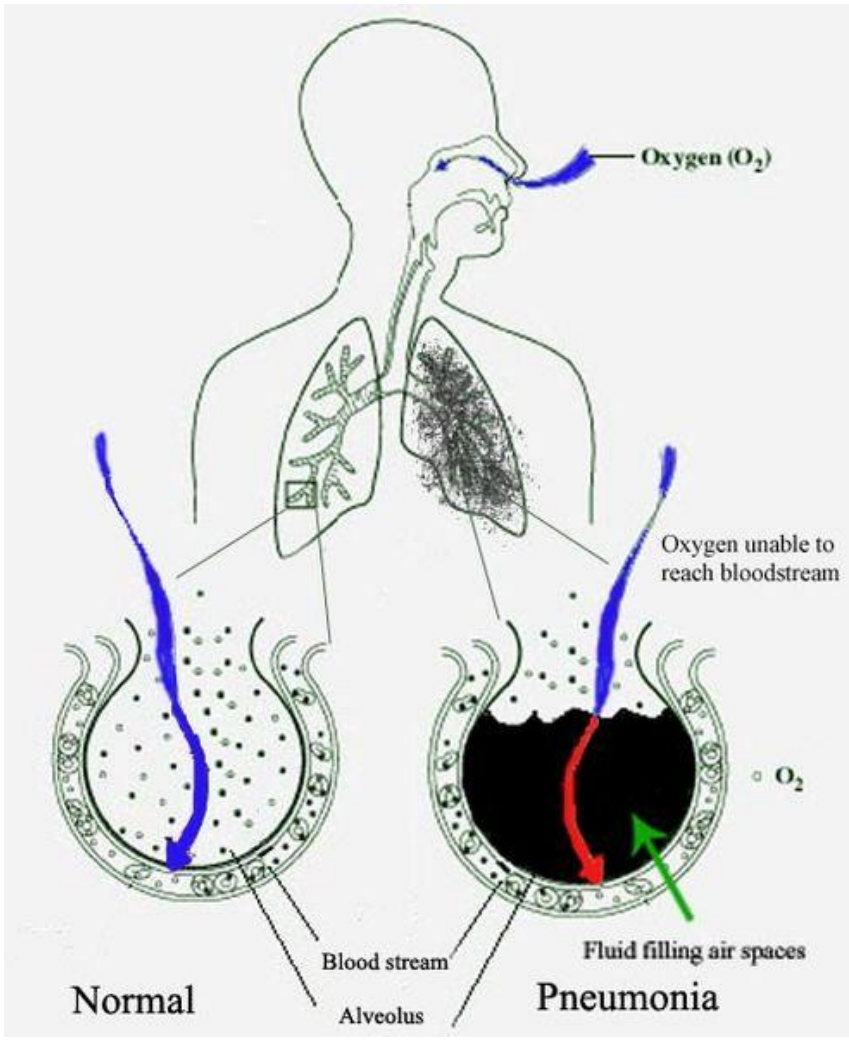
Mechanical Ventilator with EIT monitor

Source: Swisstom.com

Why image lungs? Example: Pneumonia

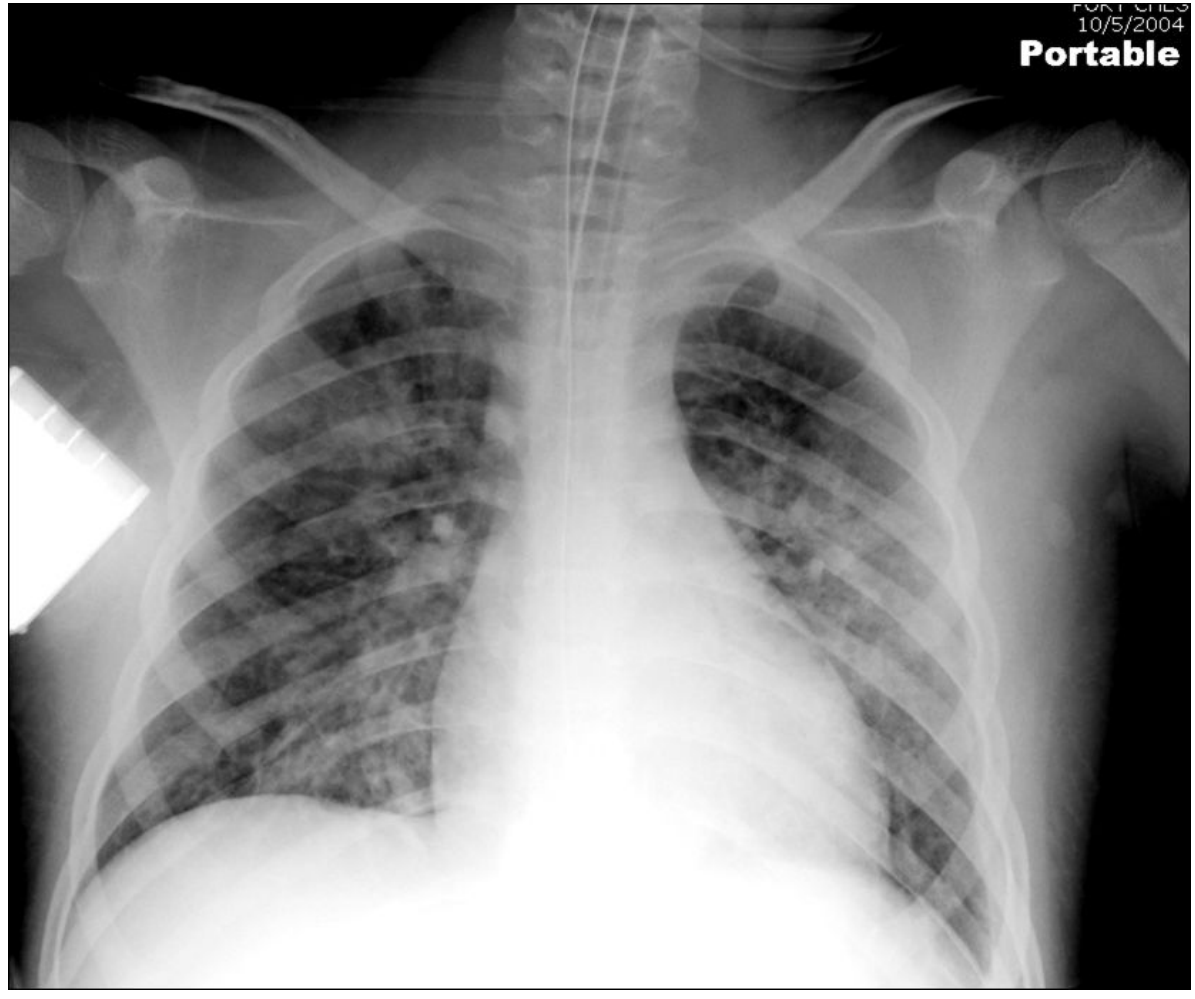


Source: en.wikipedia.org/wiki/Pneumonia



B: fluid in right lung

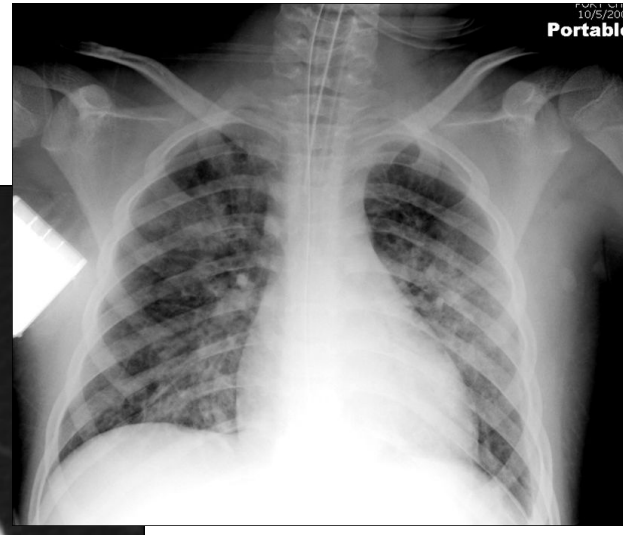
Acute Respiratory Distress Syndrome (ARDS)

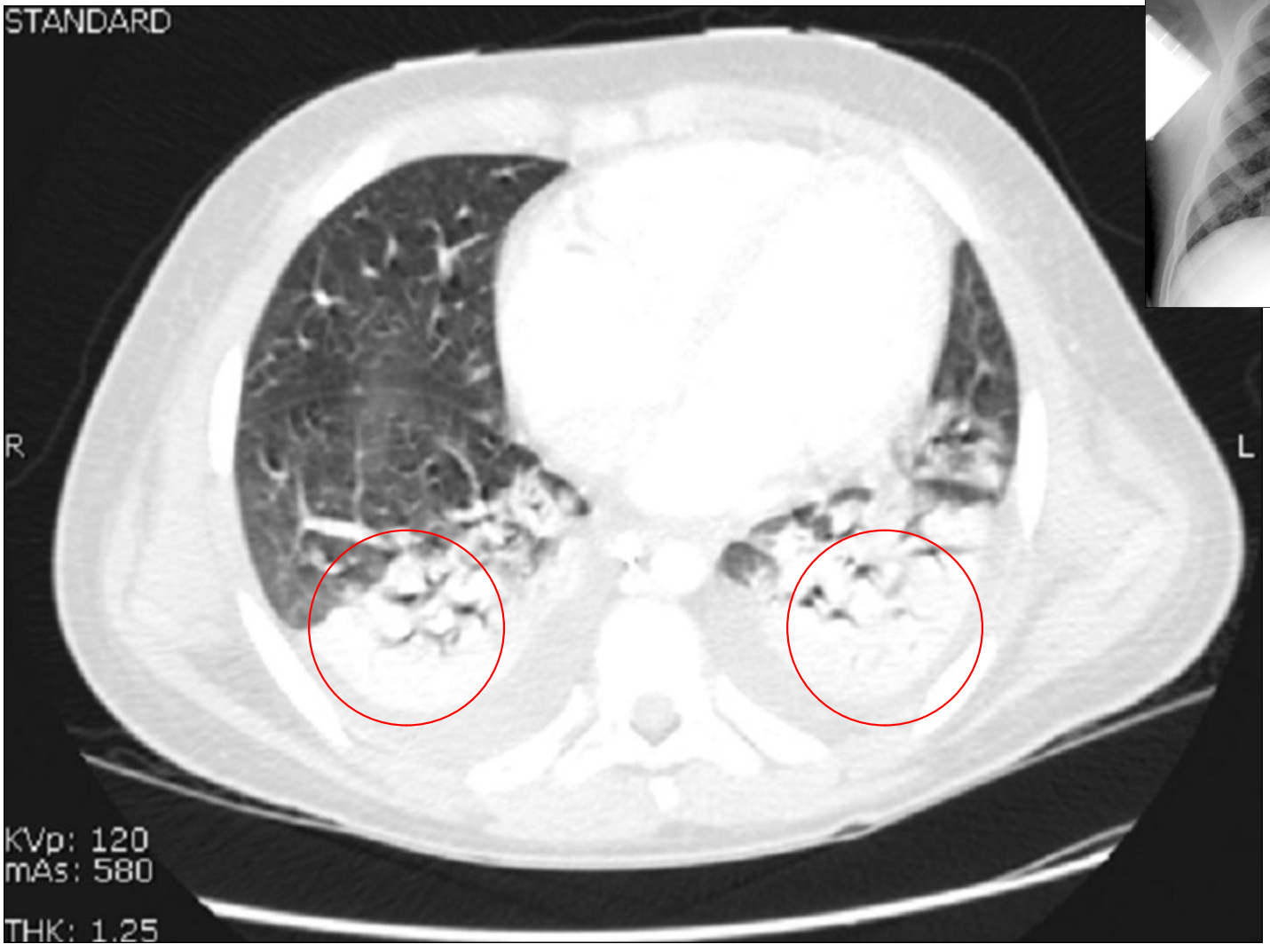


Chest X-ray of paediatric patient
Source: Wolf GK, Arnold JH, in

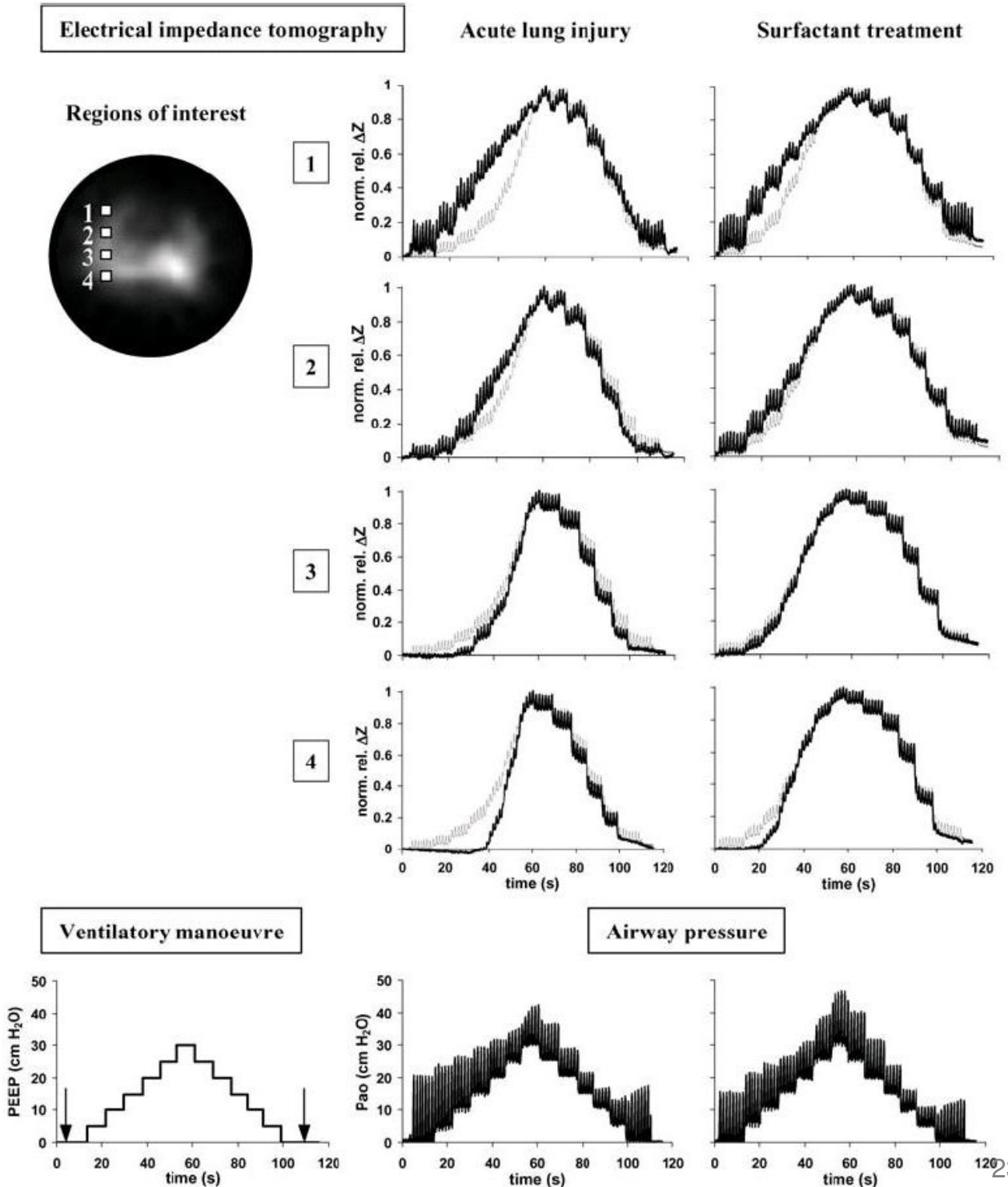
Yearbook of Intensive Care and Emergency Medicine, 2005

Acute Respiratory Distress Syndrome (ARDS)



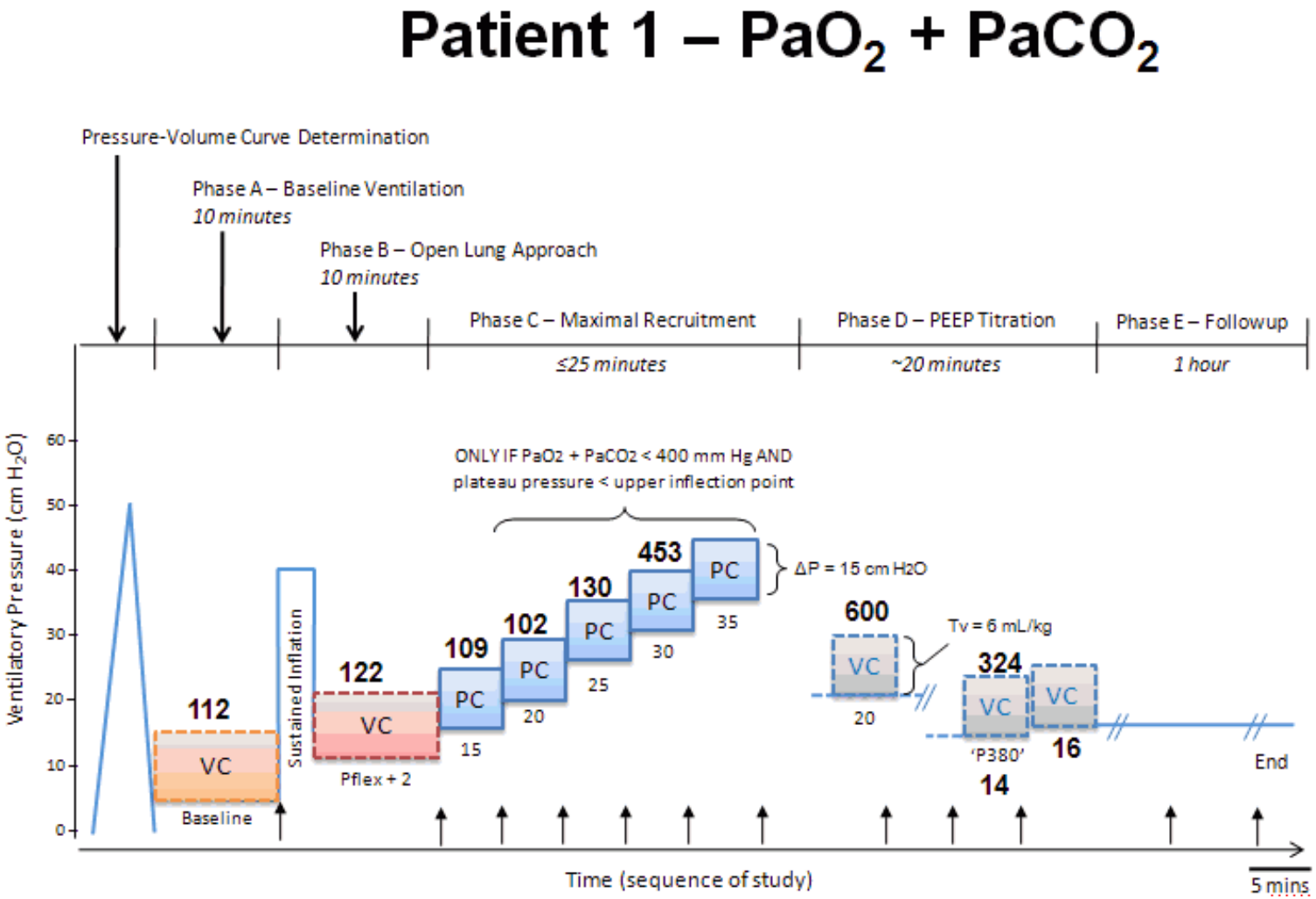


Regional Ventilation



Source: Frerichs *et al*, *Intensive Care Med*, 2003
eidors3d.sf.net/tutorial/lung_EIT/if_p

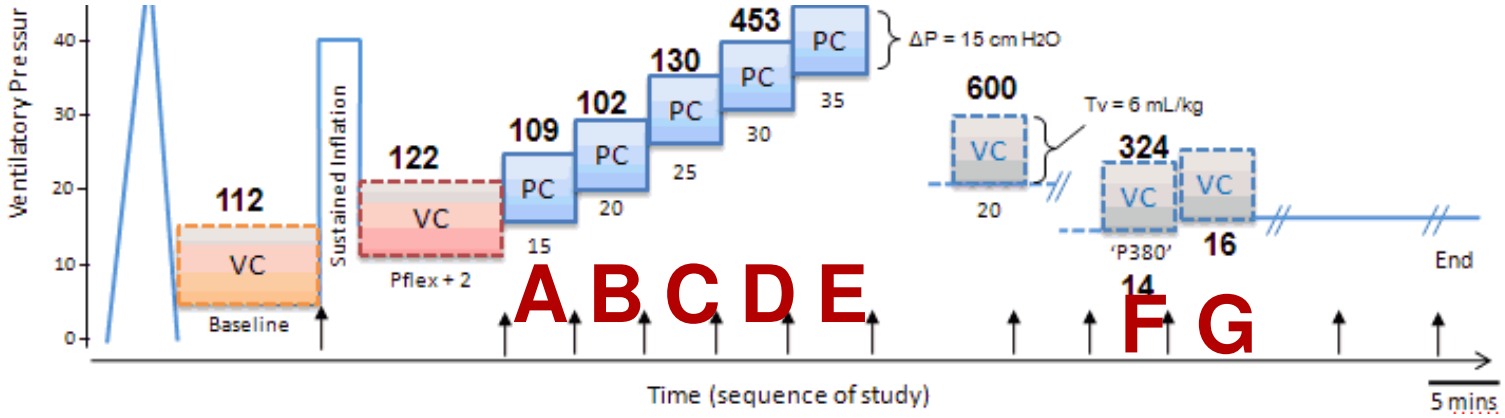
EIT in ARDS



Lung recruitment protocol (Patient: F, 5.9 years, 20 kg, ARDS triggered by parainfluenza pneumonia).

Source: GK Wolf *et al, Pediat. Crit. Care Med.*, 2012 eidors3d.sf.net/data_contrib/cg-2012-ards-recruitment/

EIT + Lung State



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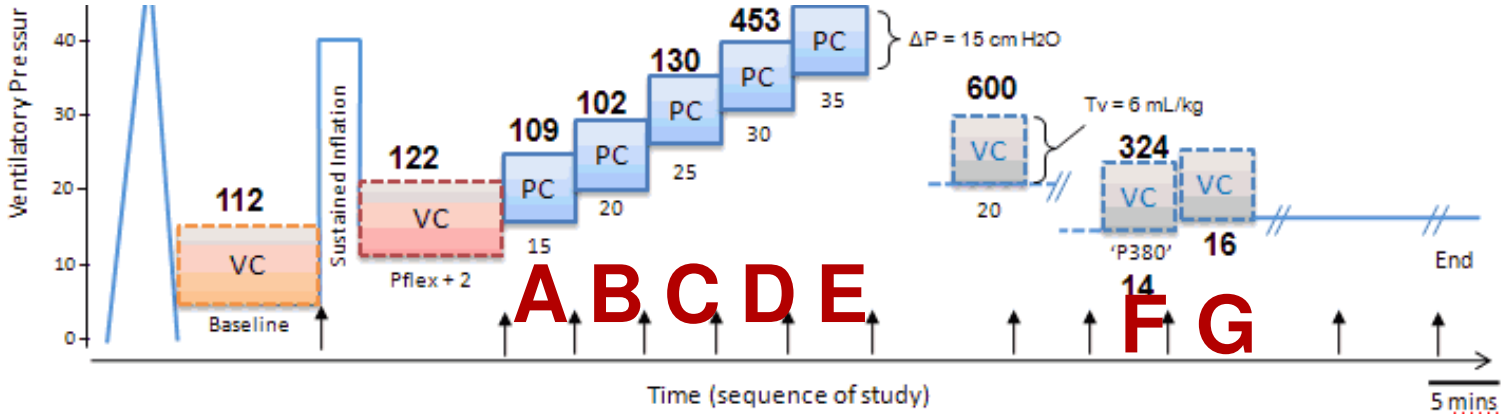
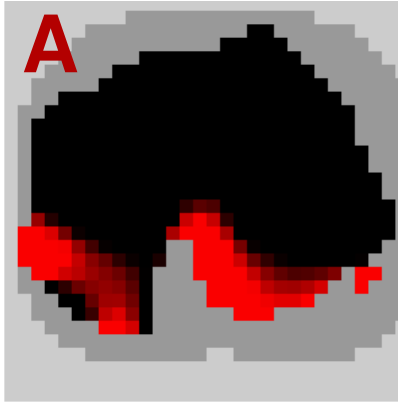
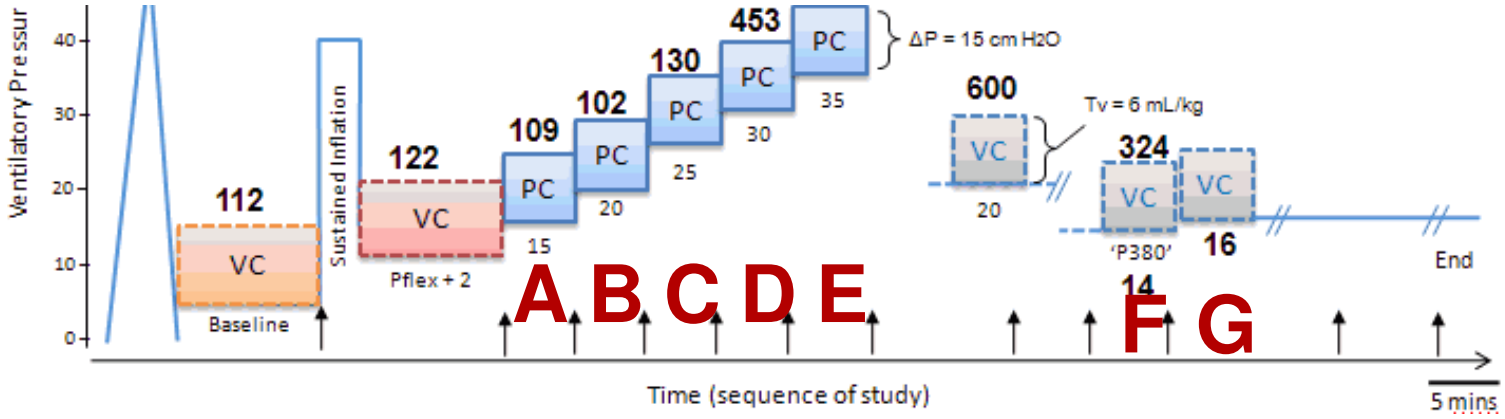
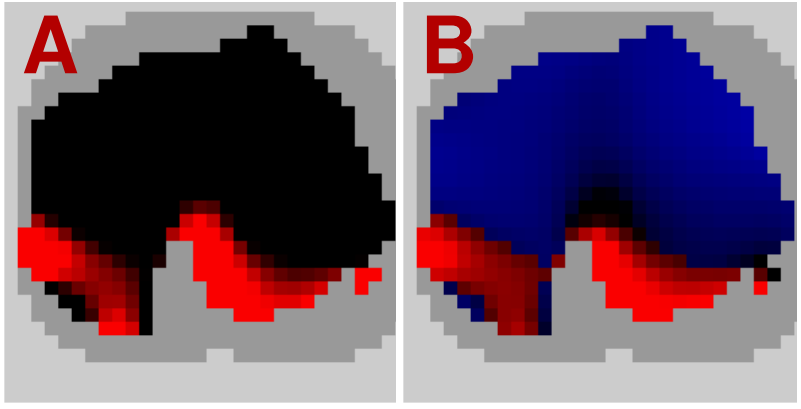




EIT + Lung State





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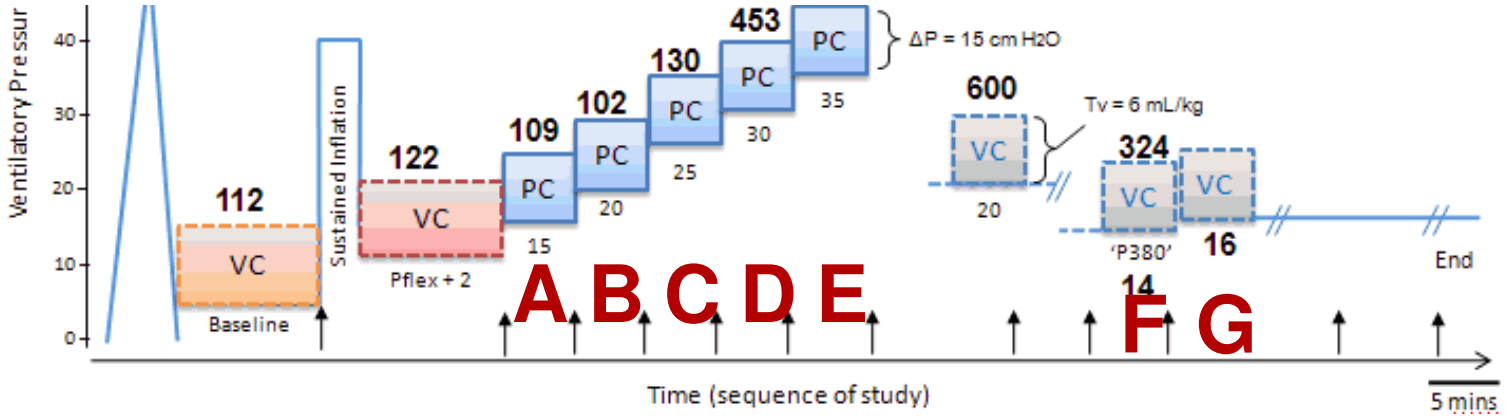

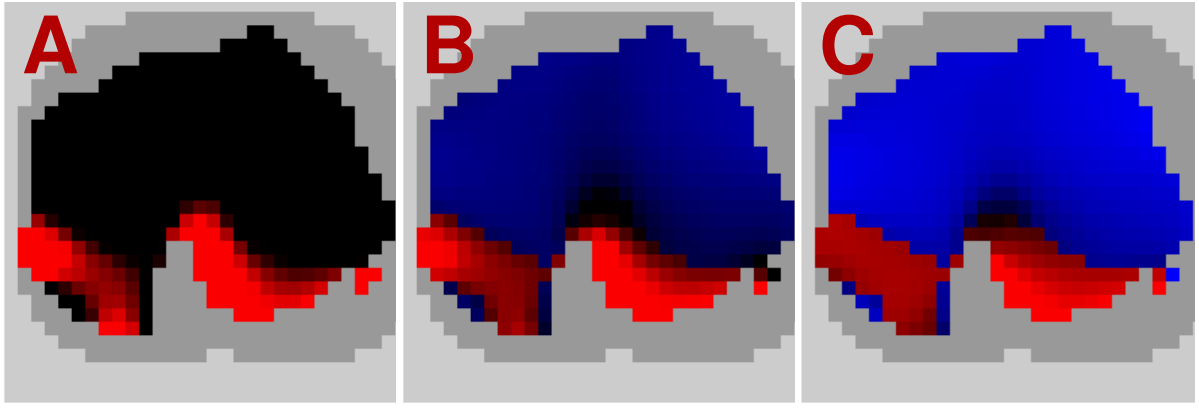

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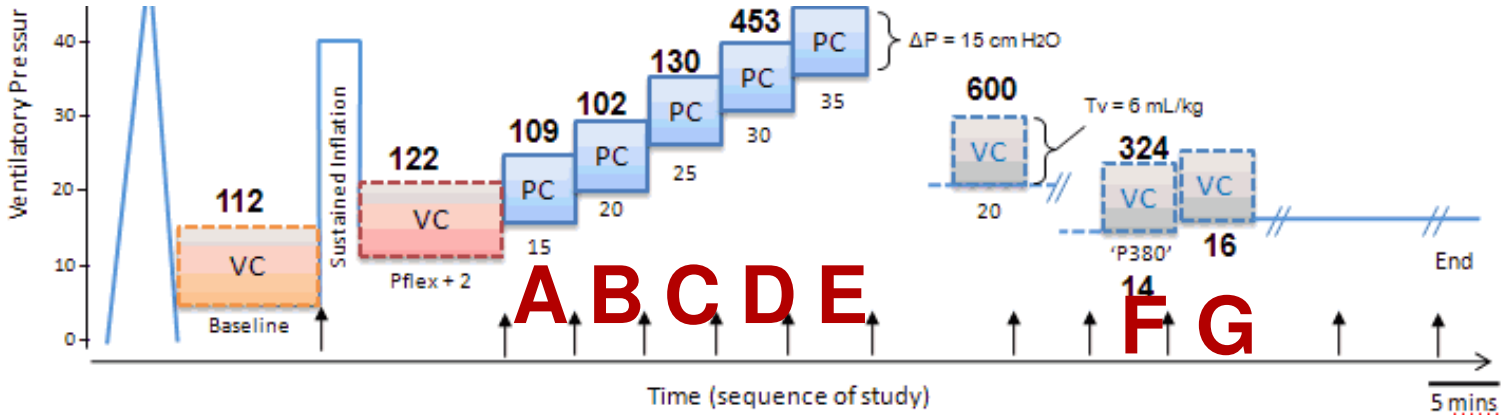

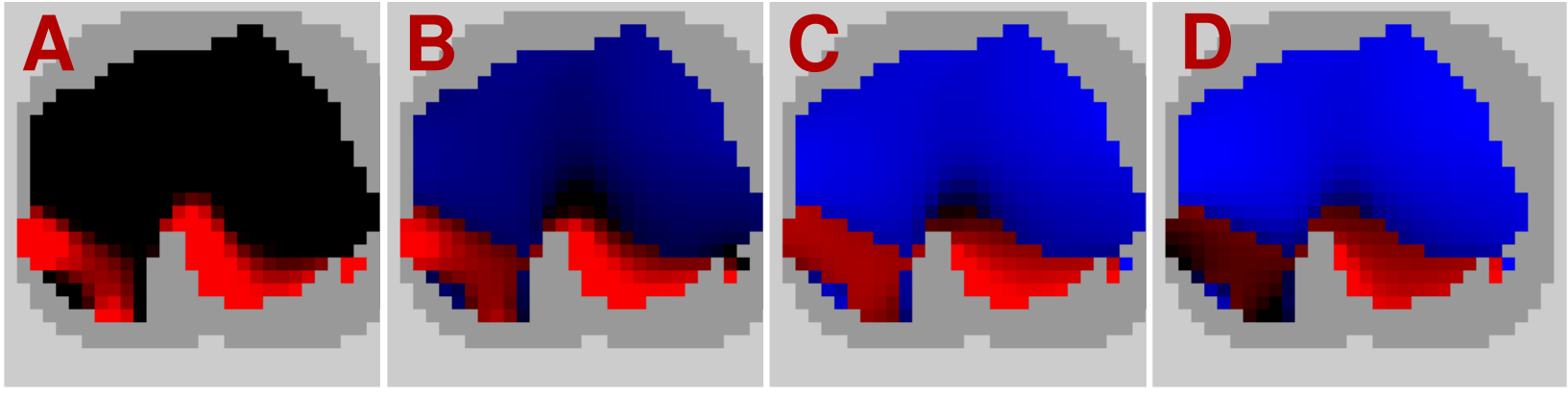

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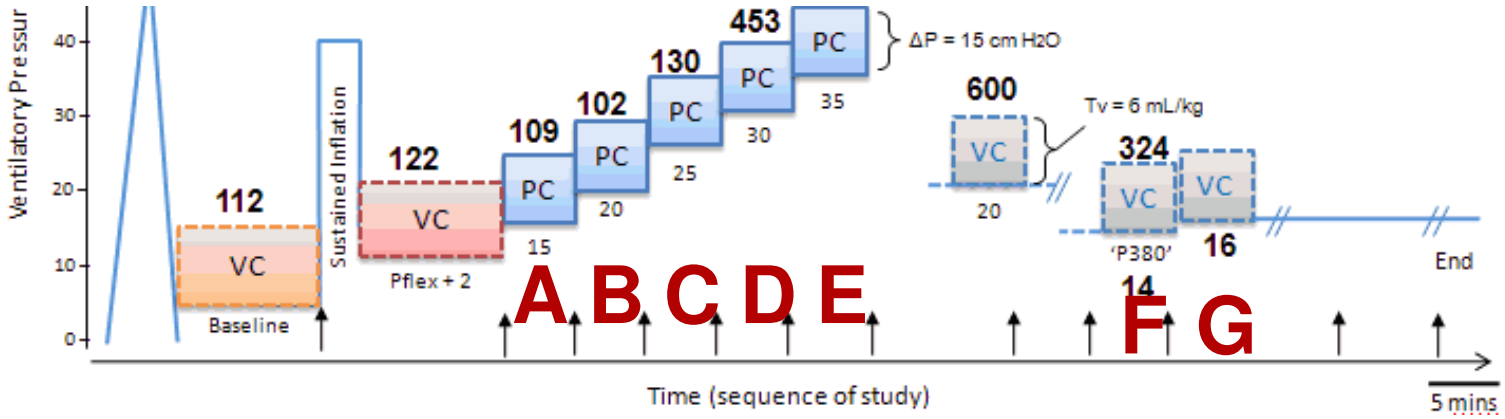

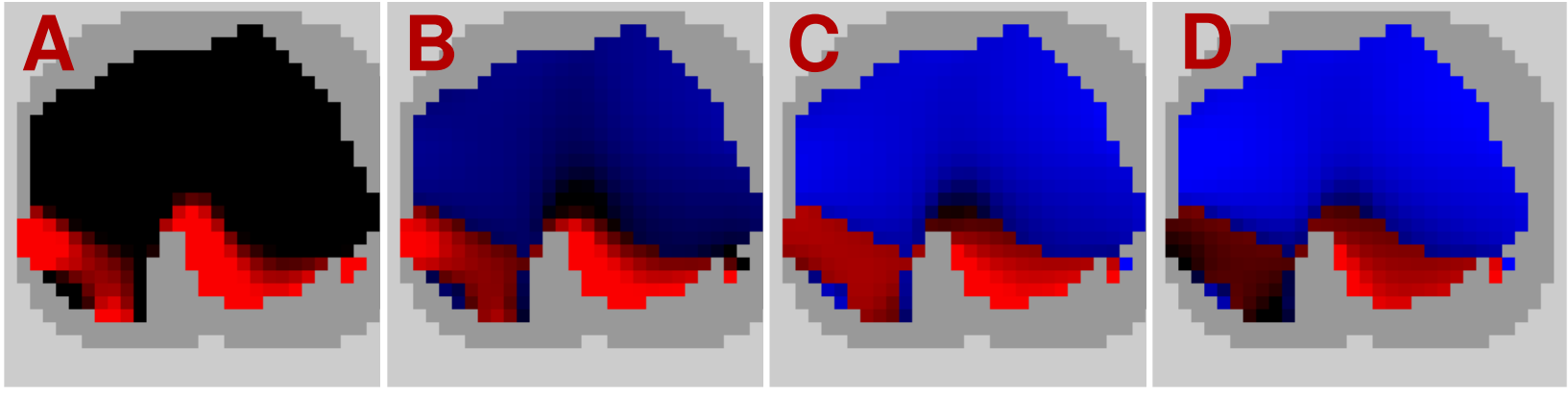

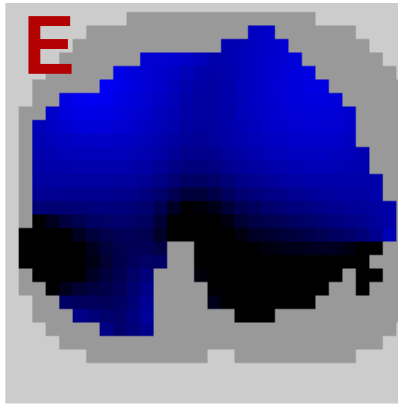

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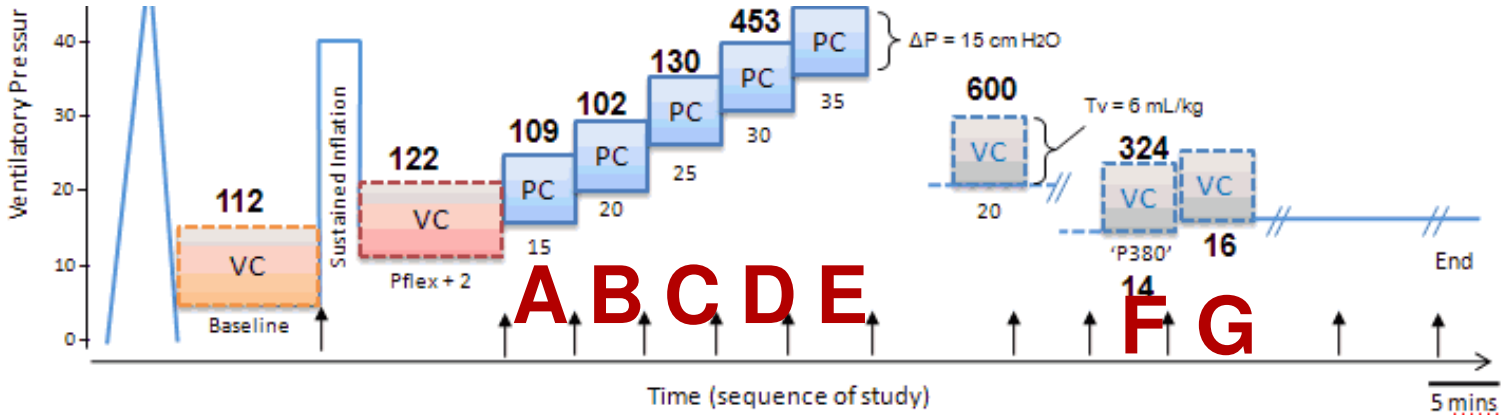

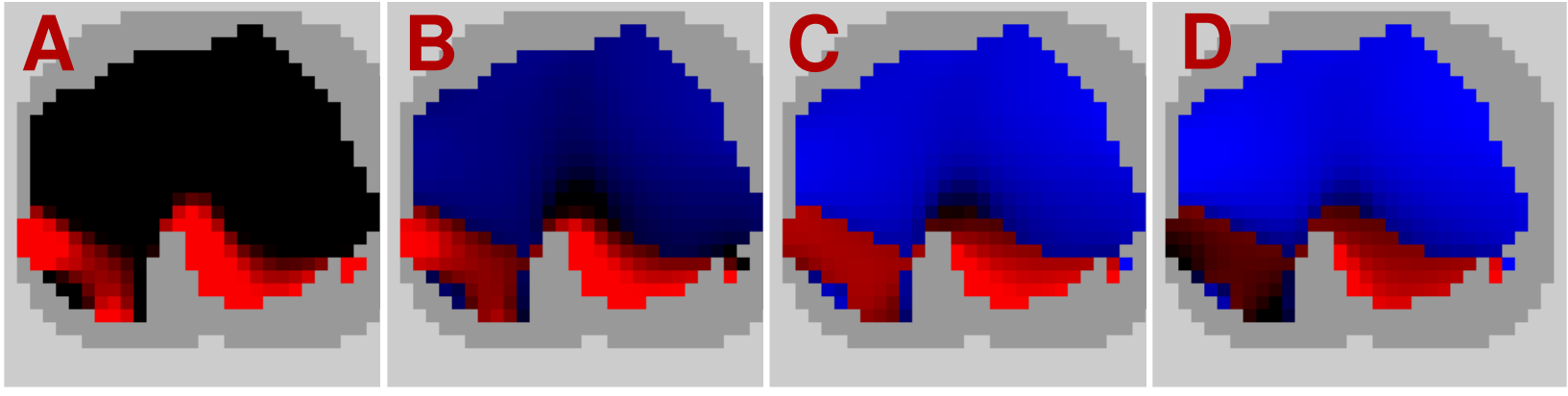

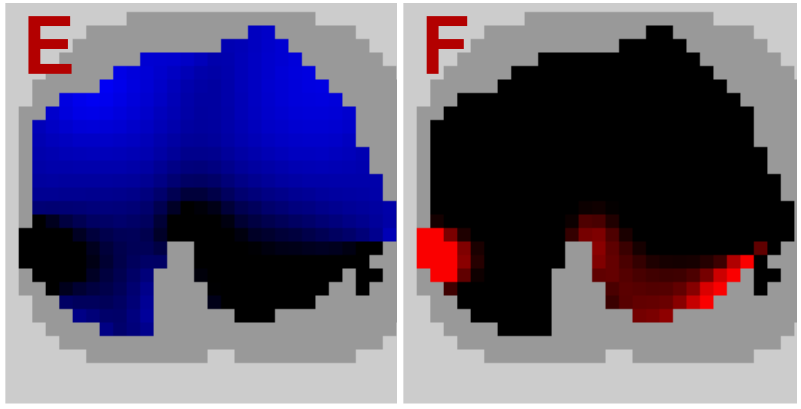

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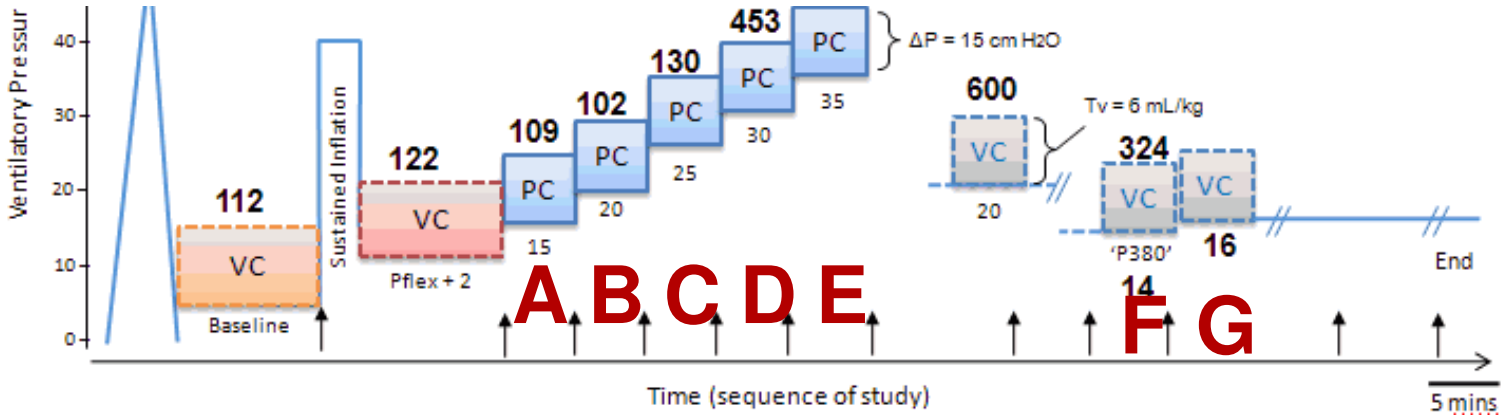
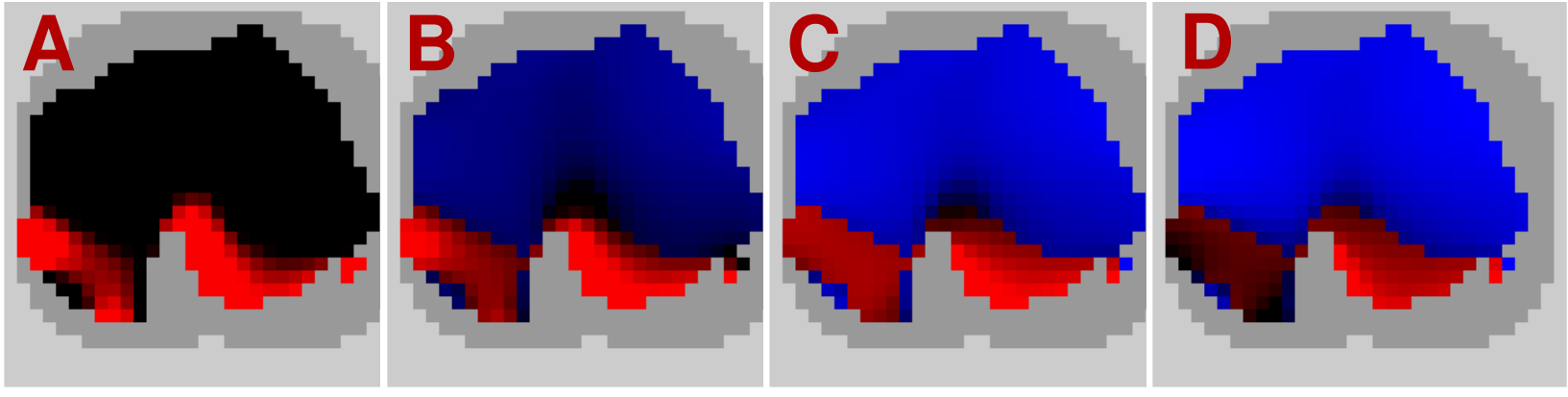
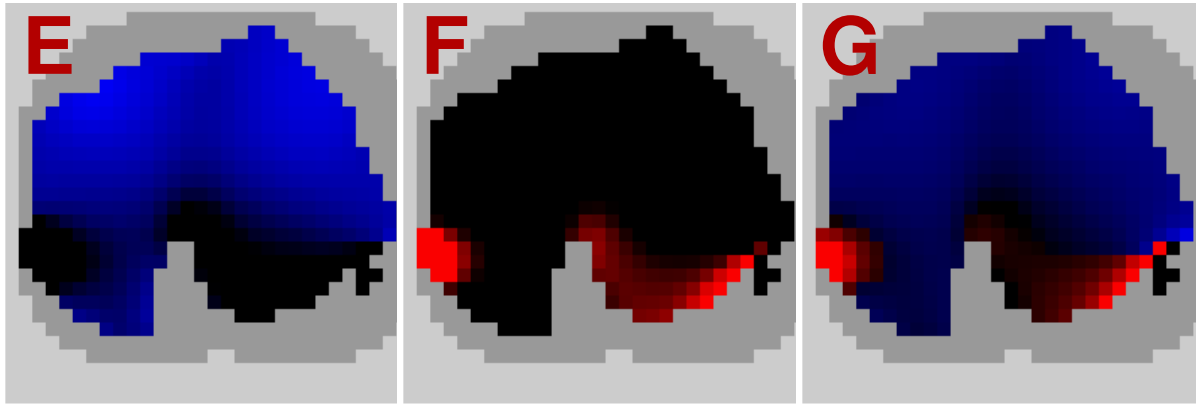






EIT for Non-Invasive Blood Pressure

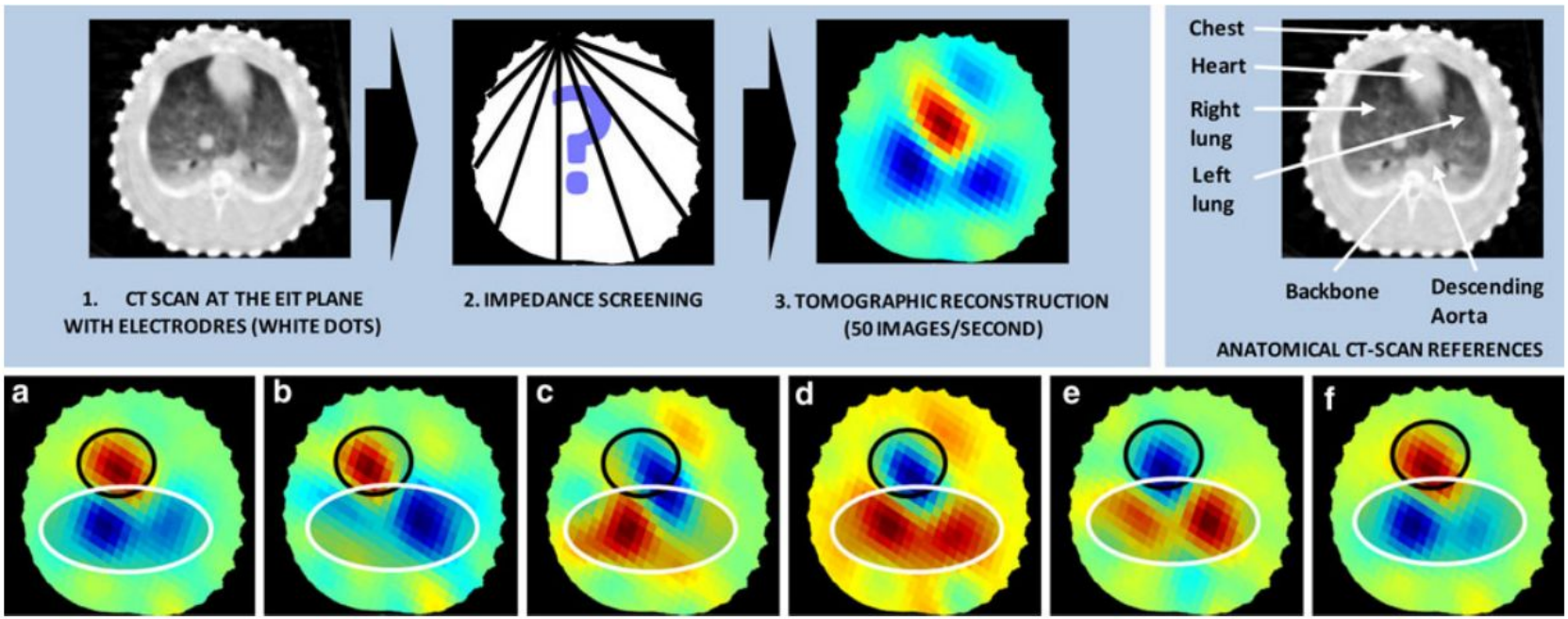


Fig. 1 Tracking the propagation of arterial pressure pulses by EIT: After placing several electrodes around the chest (*1*), impedance measurements are performed for each electrode pair (*2*) and used to construct a tomographic impedance image (*3*). A CT-scan of pig chest is provided as anatomical reference. *Lower panel* shows an example of pulse propagation during an entire cardiac cycle: **a** and **b** the filling of the heart is observed (*black* ROI). **c** The heart empties while the right lung (here on the *left hand side*) is starting to be perfused with conductive blood. **d** and **e** Both lungs are perfused (*white* ROI). Finally, **f** the cardiac cycle starts again

Pulse transit time from heart to descending aorta using EIT

Source: Sola *et al, Med. Biol. Eng. Comput.*, 2011

Neonatal Breathing

- Preterm newborns have complex, unstable physiology
- Ventilatory support is often essential
- Currently, no adequate monitors of breathing
- These data are from a lamb model of neonates

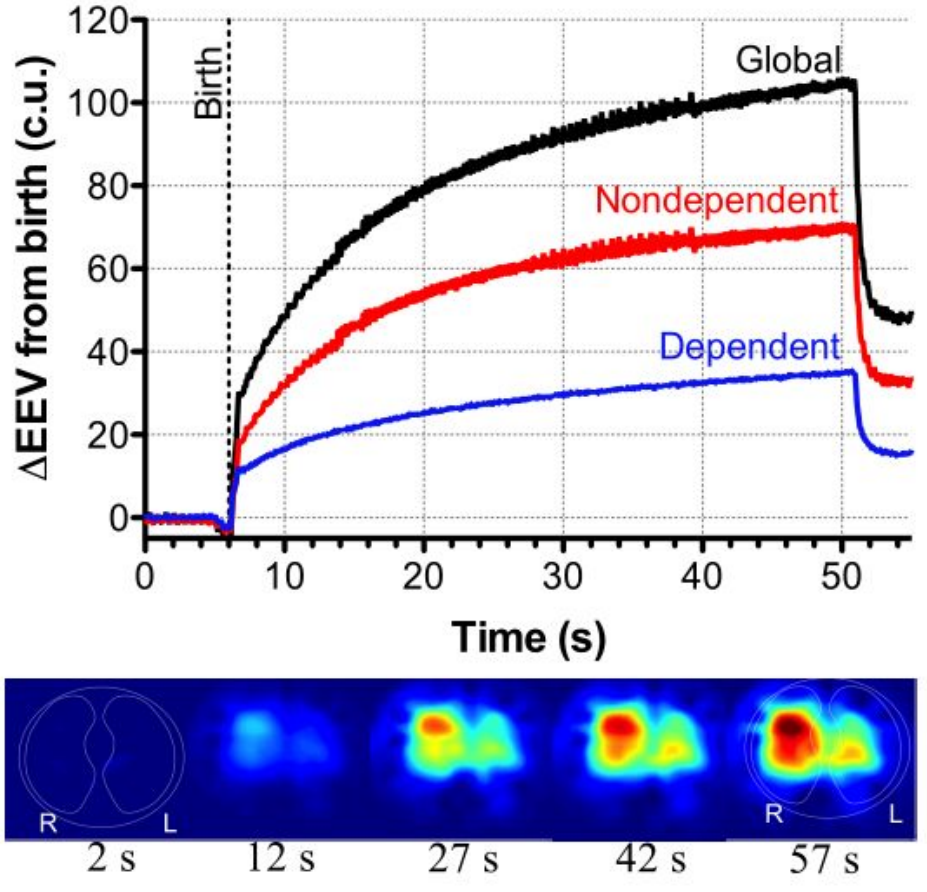


Figure 1. Exponential pattern of volume change during a SI, as measured by EIT, in global thorax and gravity-dependent

Source: D. Tingay *et al*, In Press

EIT for Brain Imaging

Applications:

- Epileptic foci
- Stroke (Ischaemic vs. Haemoragic)
- Fast Neural Imaging

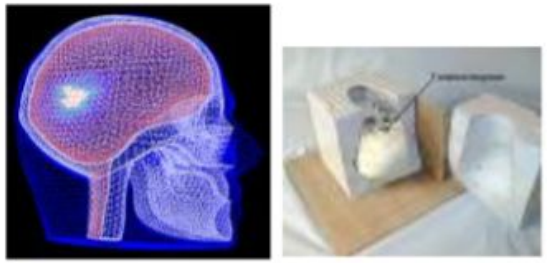
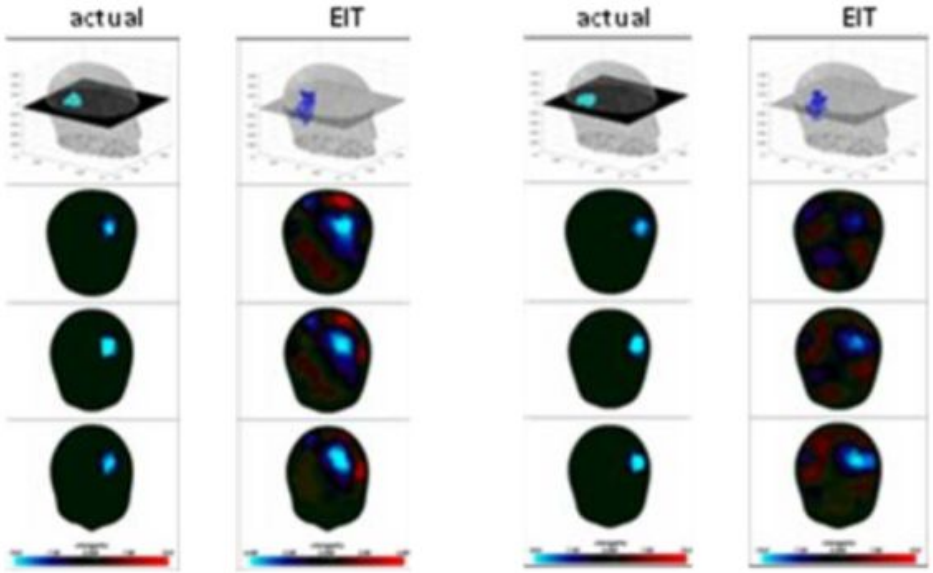


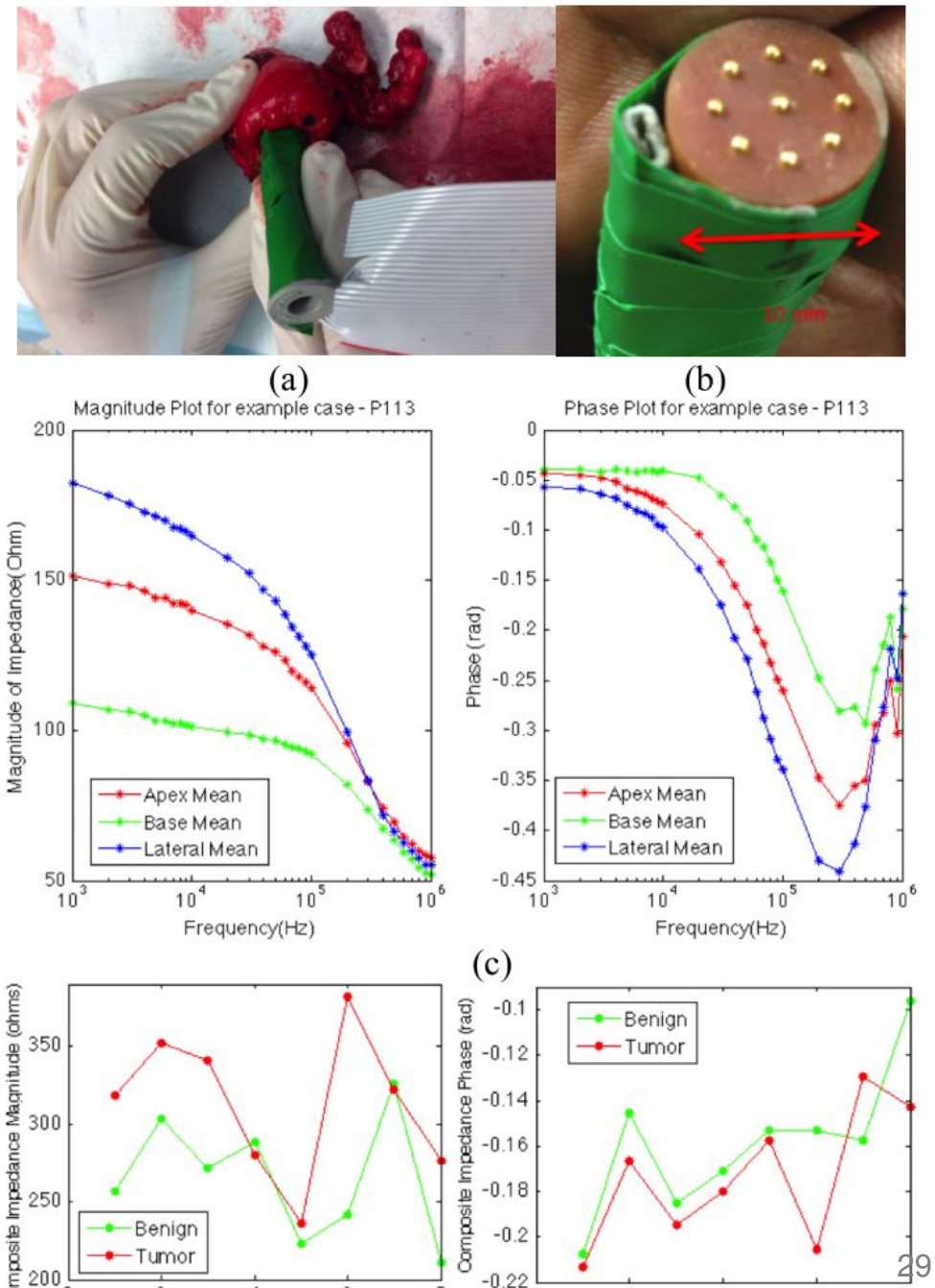
Fig. 2. Left : Finite element of the head used to produce images. Right: Example of EIT images produced in a saline filled tank



Source: Holder, www.ucl.ac.uk/medphys/research/eit/pubs/brain_EIT_over

EIT for Cancer Imaging: Breast/Prostate

- Cancerous tissue has different electrical properties
- Image tissue
- Image increased vascularization



Source: Khan, Mahara, Halter *et al*, Conf. EIT, 2014

Non-medical applications

- Flow in pipes
- Mixing tanks
- Imaging metalic ores
- Hydro-geology

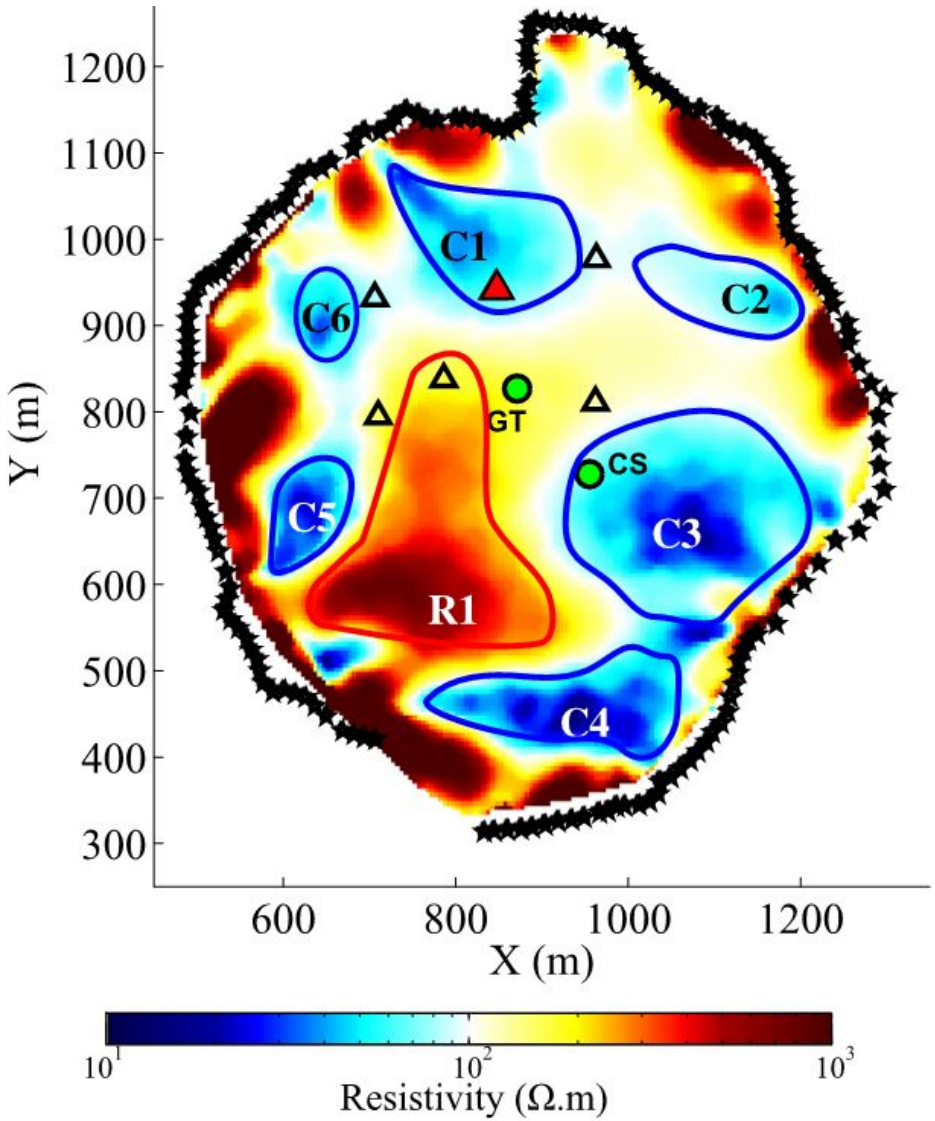
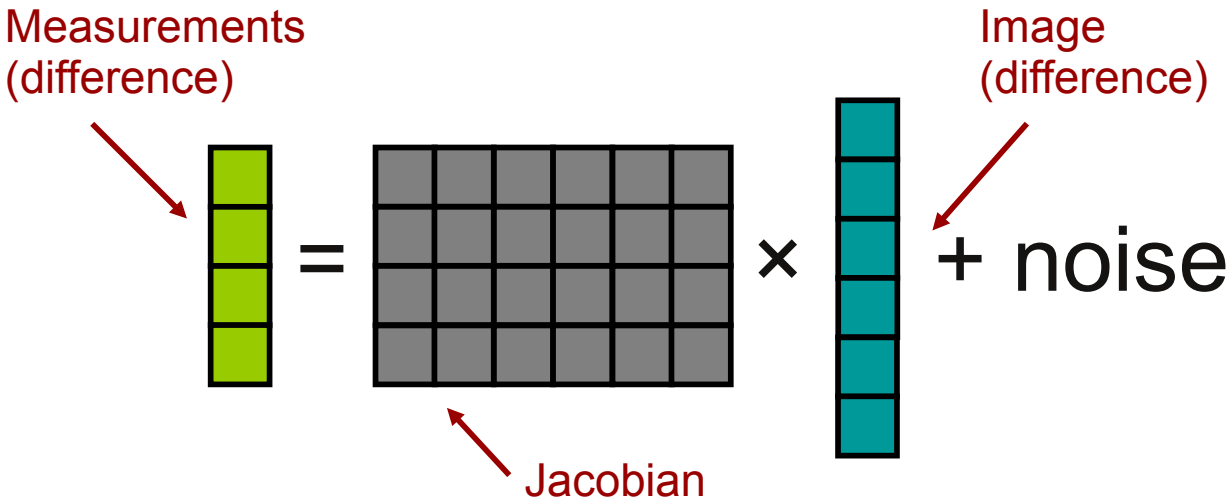


Figure shows resistivity in a cross-section of La Soufrière de Guadaloupe volcano.

Source: N. Lesparre *et al*, Conf. EIT, 2014

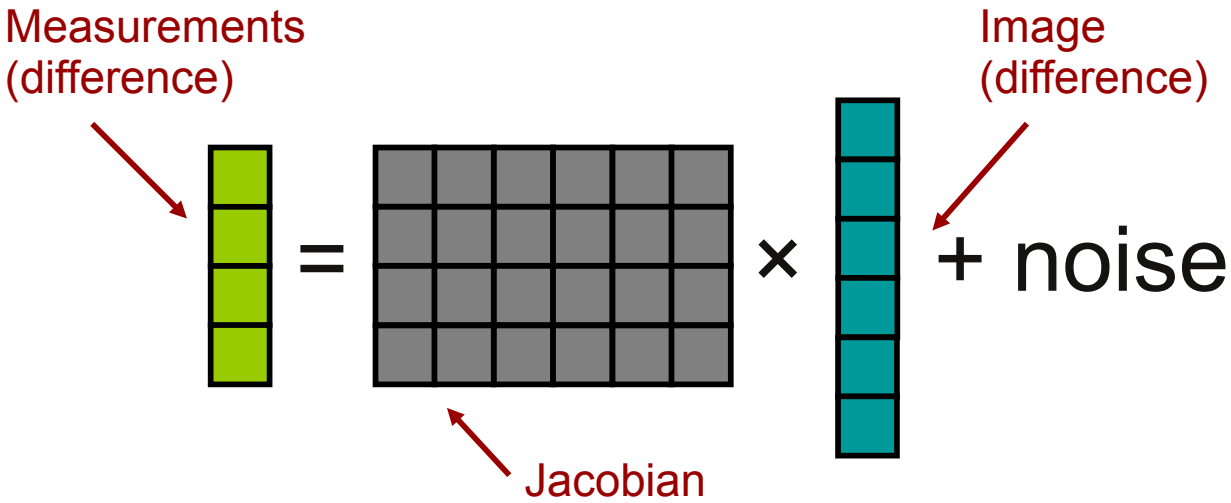
Reconstruction in Pictures

- Forward Problem

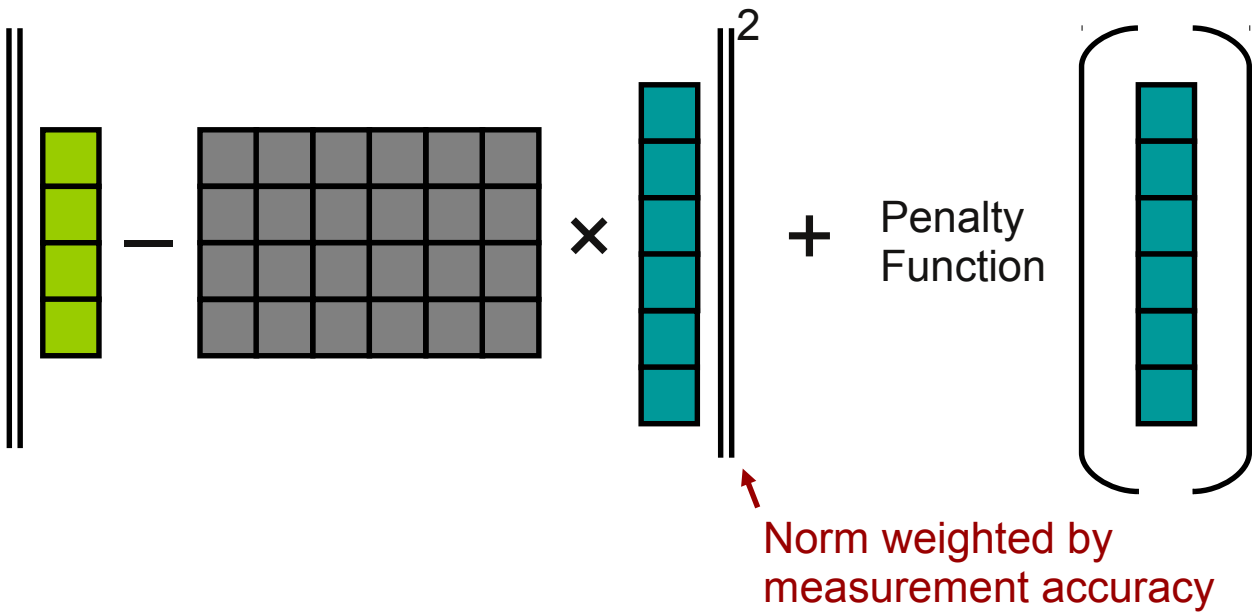


Reconstruction in Pictures

- Forward Problem

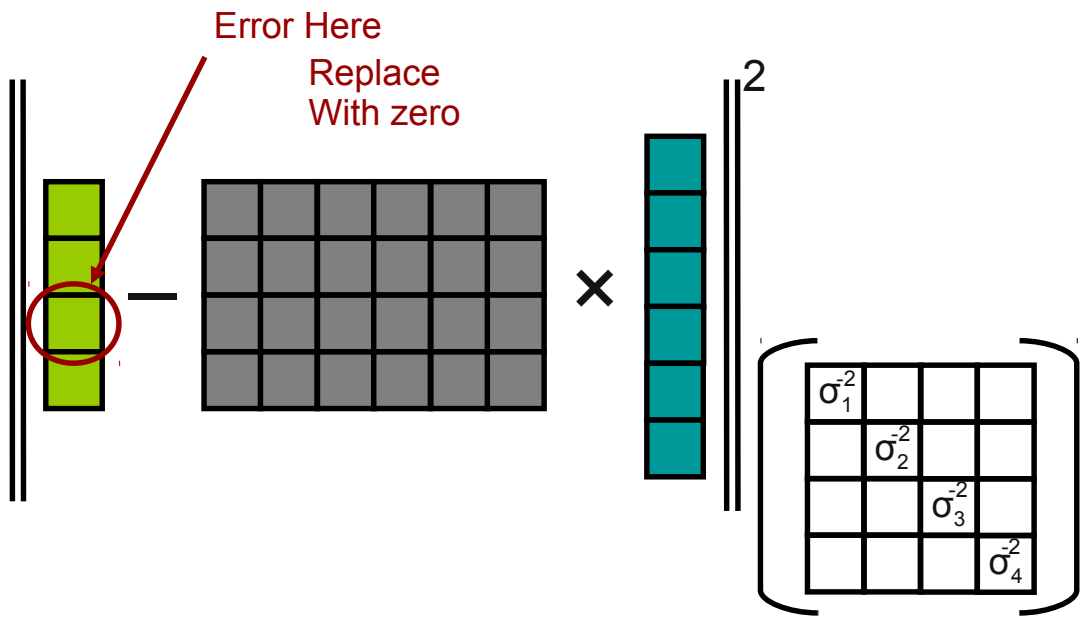


- Linear Solution: Minimize norm



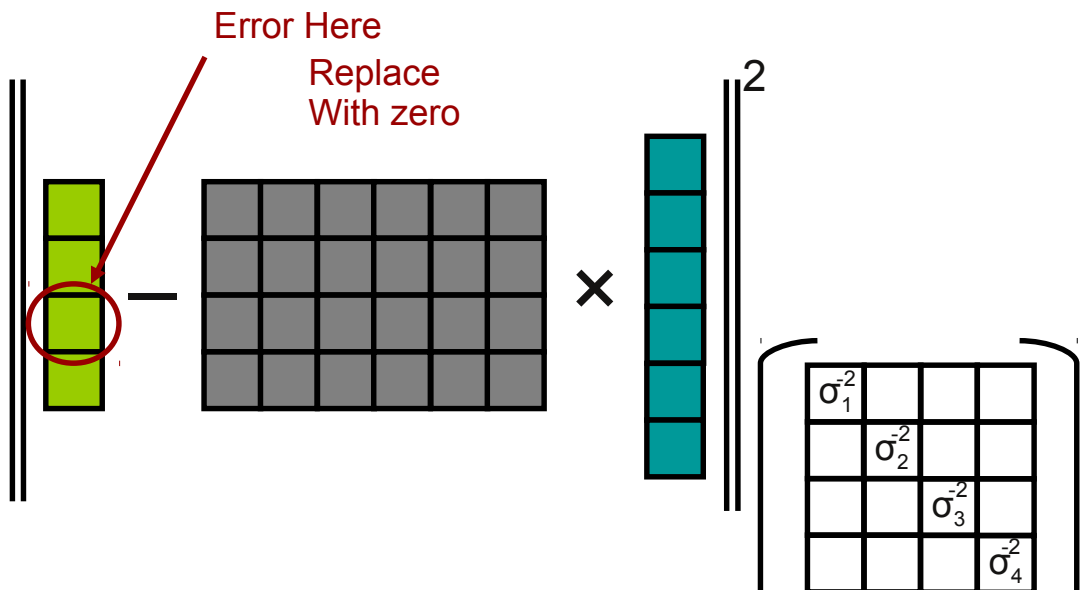
Idea #1: Reconstruction with Data Errors

"Traditional" Solution

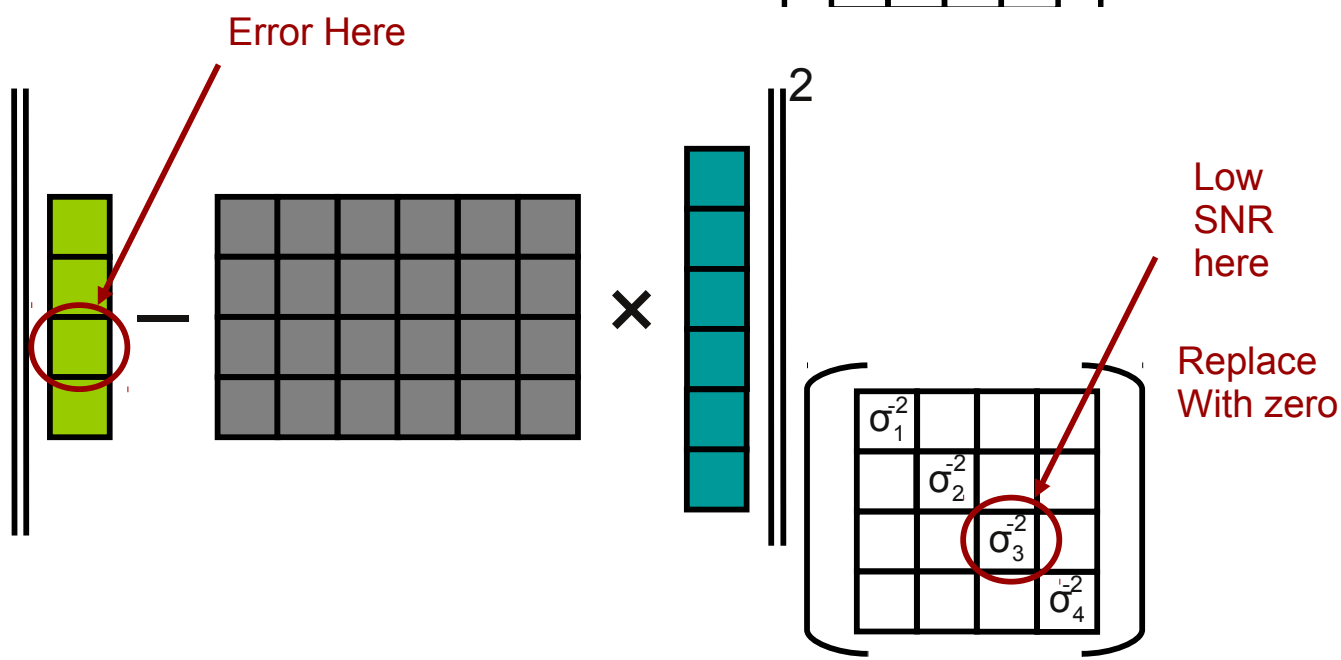


Idea #1: Reconstruction with Data Errors

"Traditional" Solution

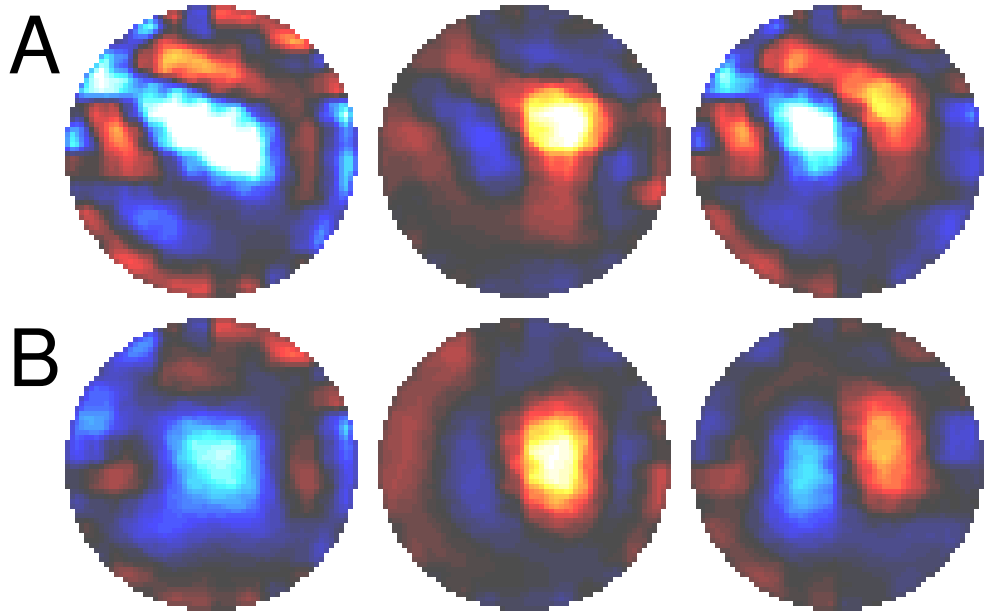


Error Model Solution



Electrode Error compensation

- Offline compensation using “jack-knife” approach (2005)

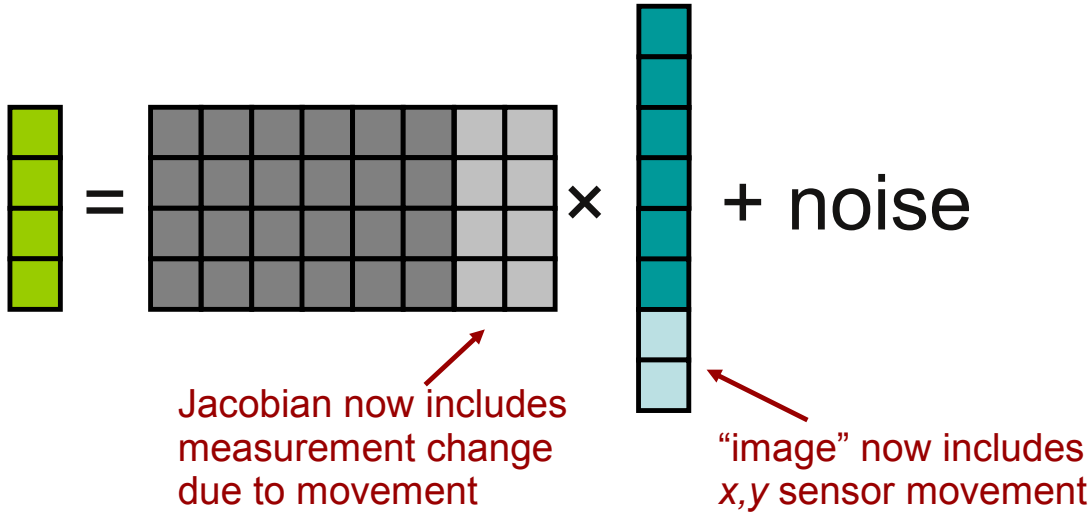


EIT images in anaesthetised, ventilated dog
A: uncompensated, *B*: compensated. *Left*: ventilation *Centre*: saline (right lung) *Right*: ventilation and saline

- Automatic detection (via reciprocity comparison) (2009)
- New work to speed online calculation & use data quality

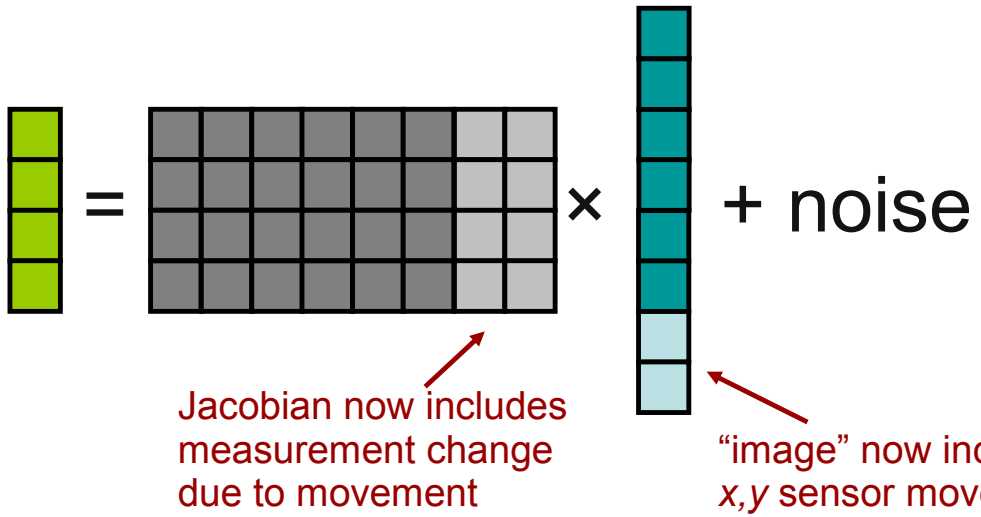
Idea #2: Electrode movement

Sensitivity to sensor movement

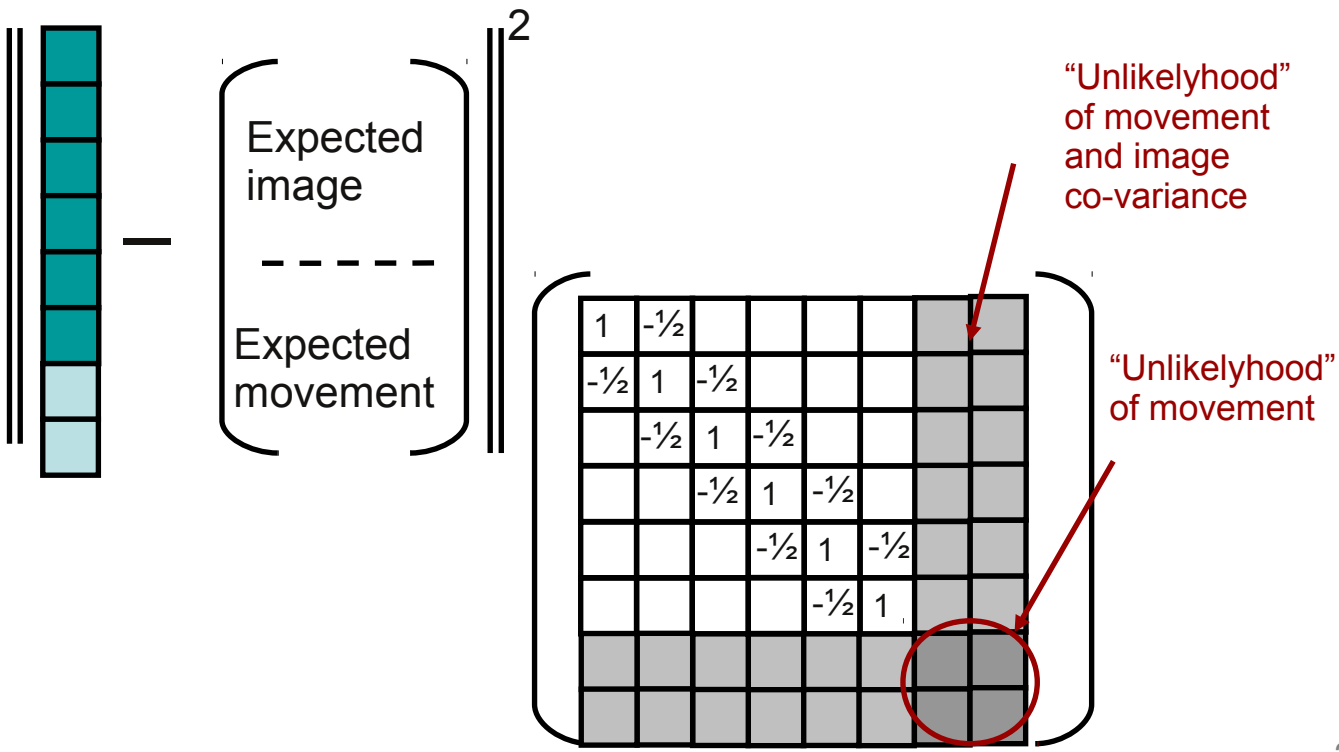


Idea #2: Electrode movement

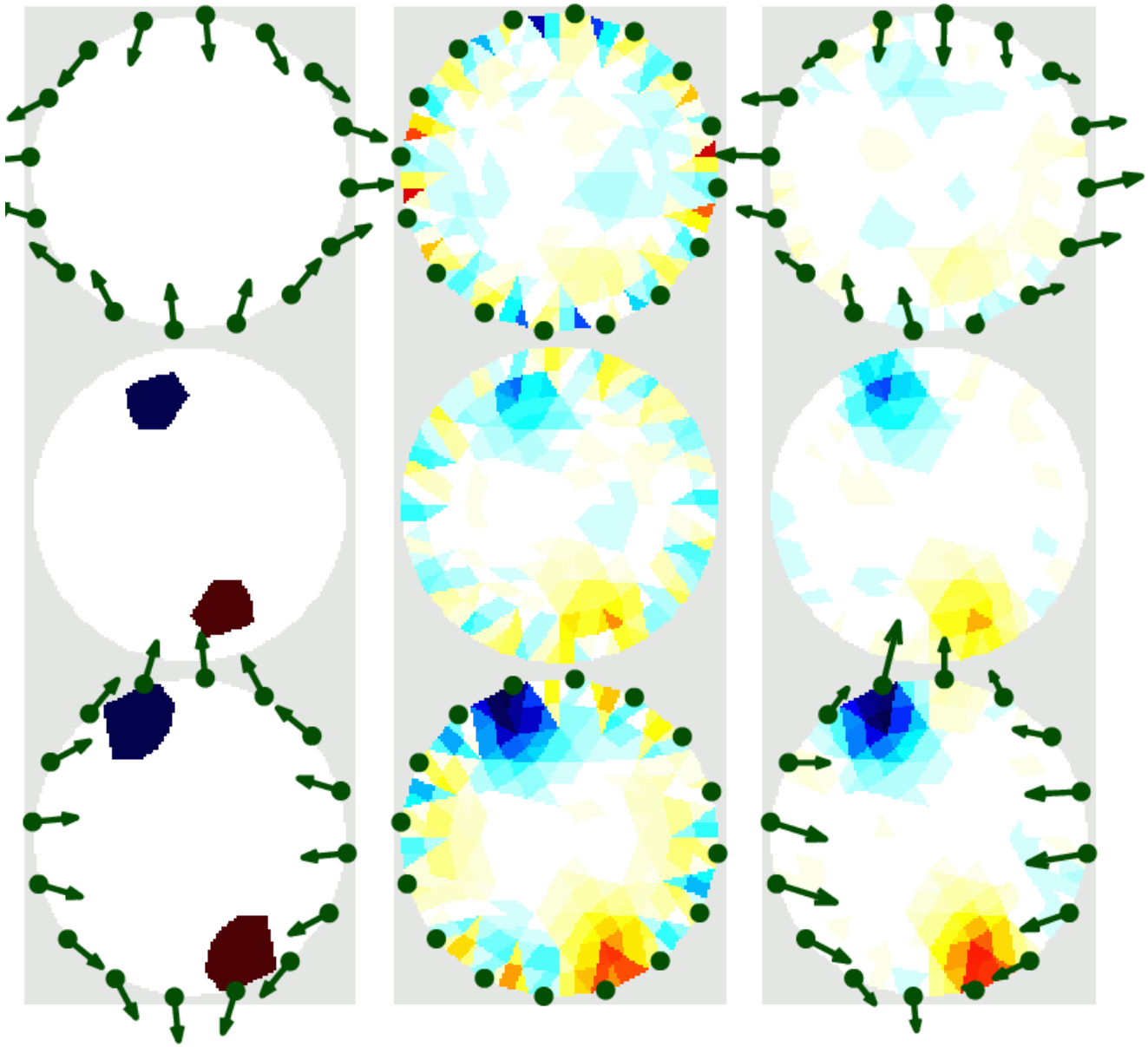
Sensitivity to sensor movement



Adapted penalty function



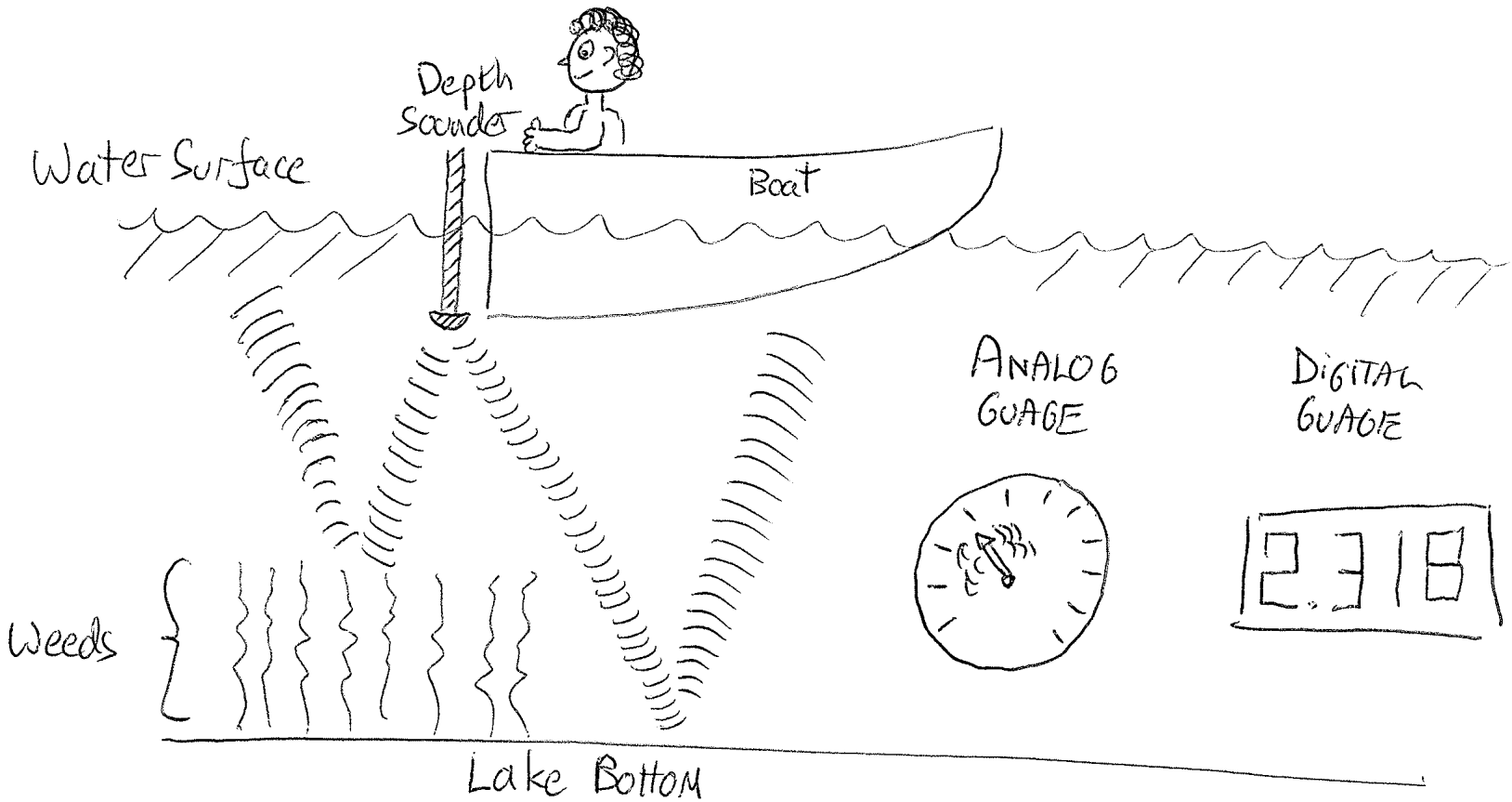
Electrode movement compensation



Source: Gómez-Laberge *et al*, Phys. Meas., 2006

Idea #3: Data Quality

Idea #3: Data Quality



Depth Sounder – with analog and digital guages

What's the problem?

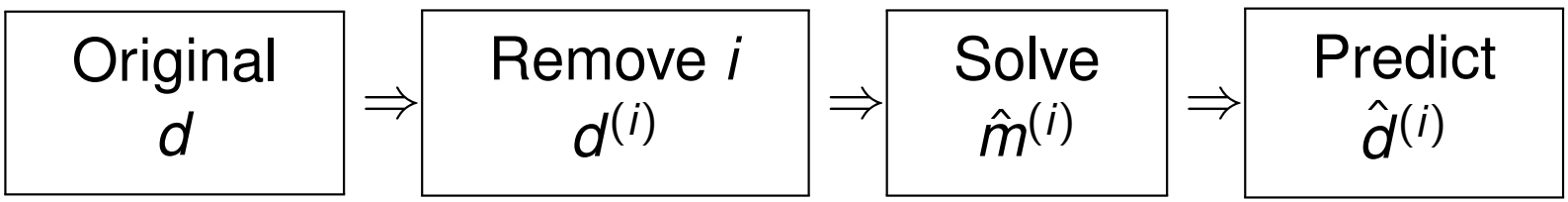
With strong priors and complex algorithms, algorithms give us pretty pictures, even when they are irrelevant.

Question:

- how can we know when to trust a pretty picture?
- how can we know when the data are junk?

Data Quality Measure: Concept

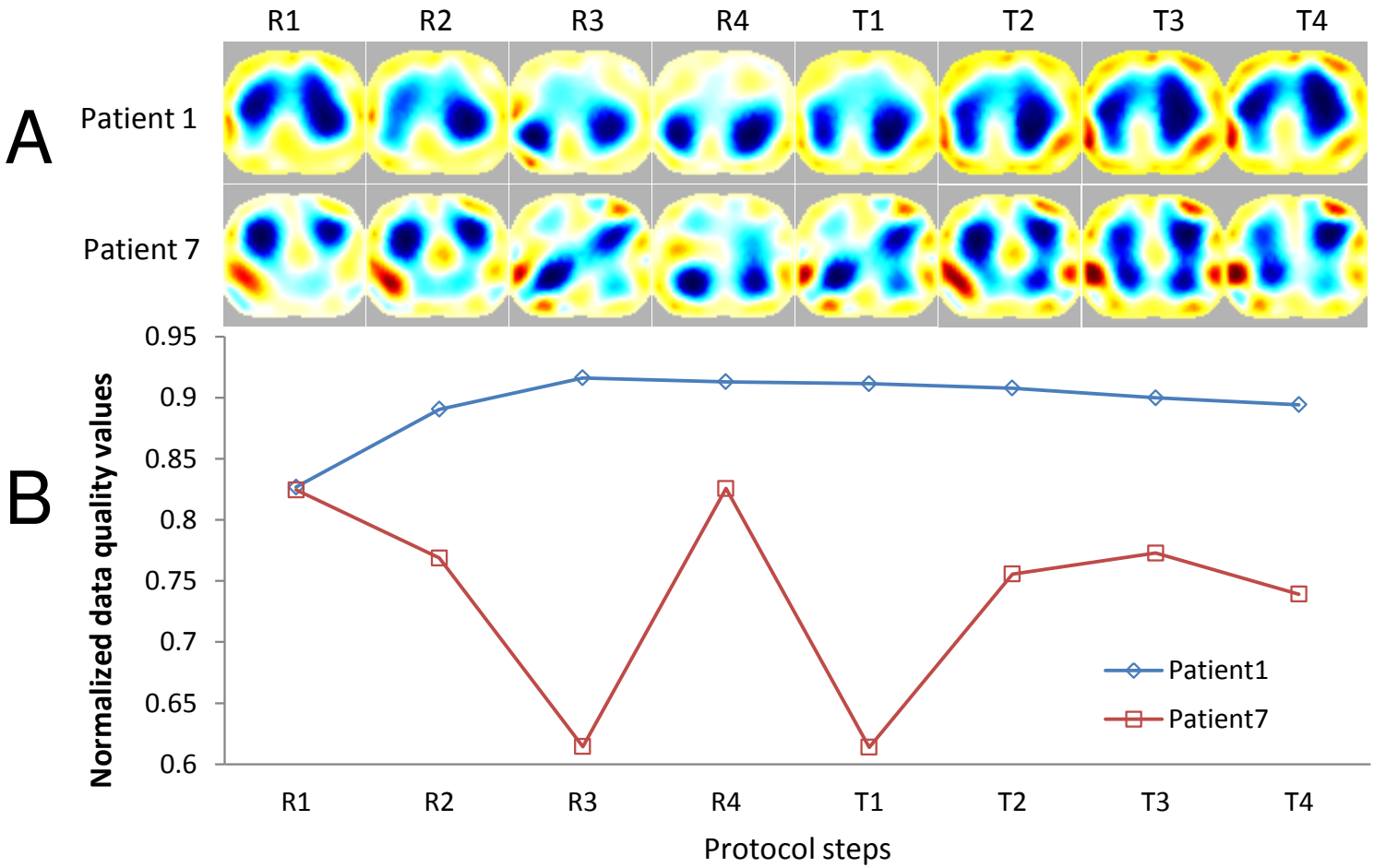
- *Concept:* High Quality Data is Consistent
- *Idea:* Use IP to predict each data point from all others



- Calculate error

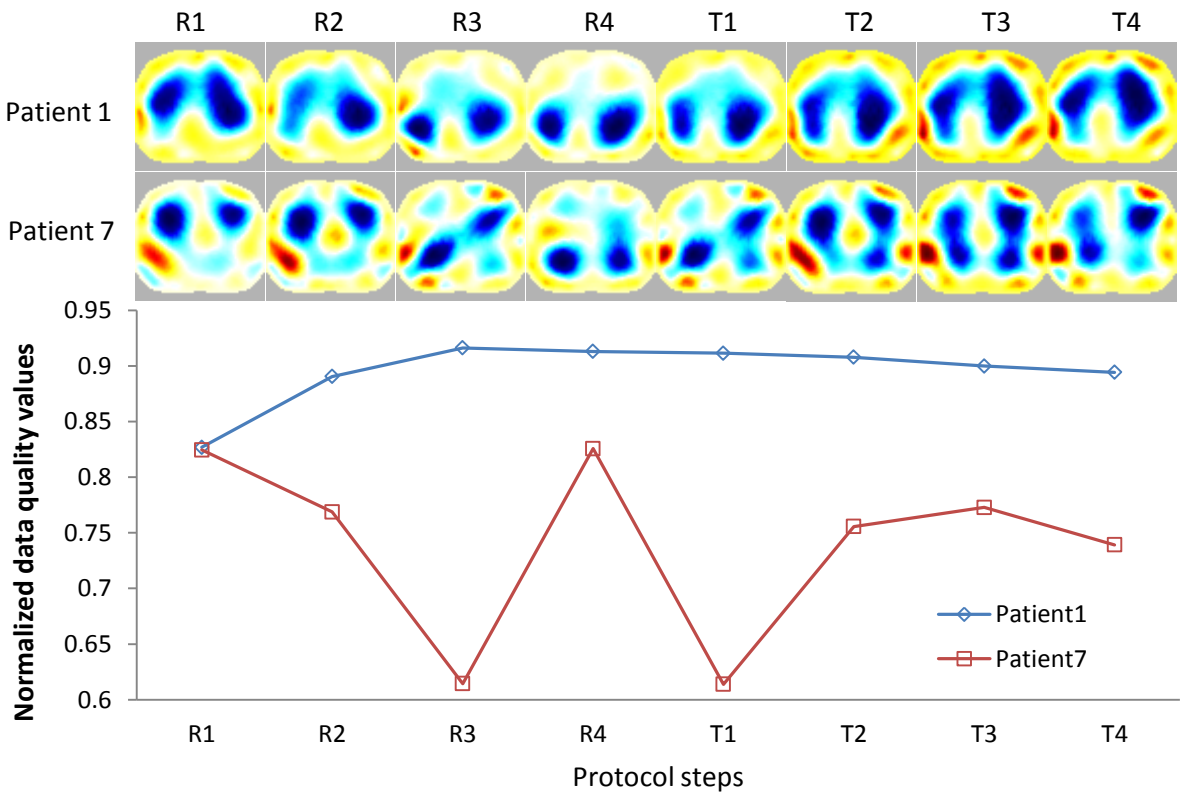
$$\epsilon_i = d_i - \hat{d}_i^{(i)}$$

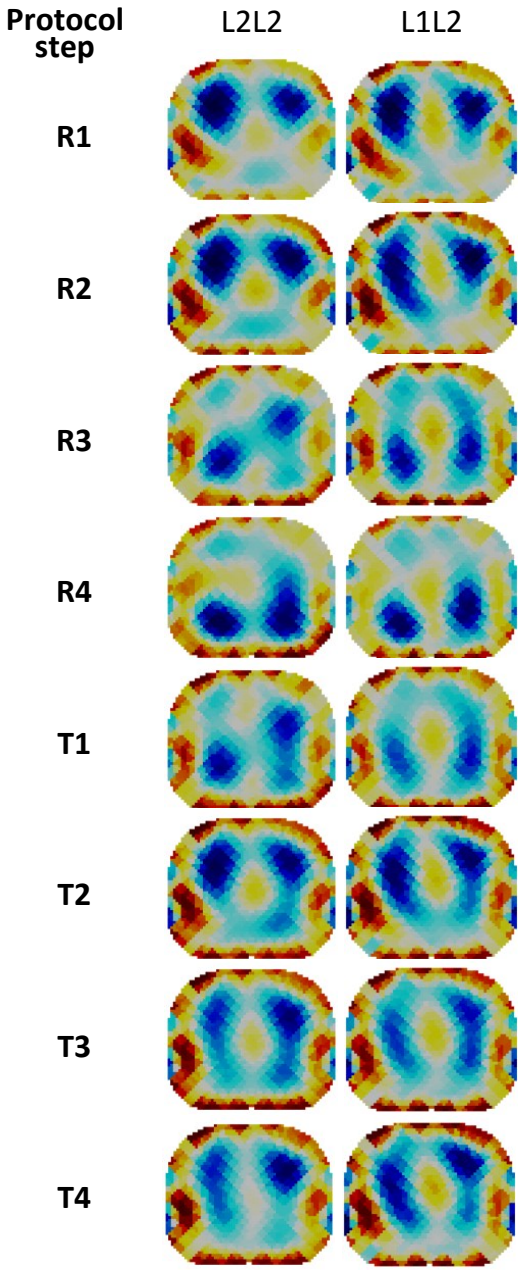
Example: Data quality measures



Clinical data and data quality metric for each stage of the protocol (R1–R4 — recruitment: PEEP⇑, T1–T4 — titration: PEEP⇓).
A: EIT images *B*: Calculated data quality.

Data Quality vs. Robust Algorithms





Perspectives

- Data analysis is hard
- powerful algorithms are useful
- we live in a world of big data
- complex systems fail in complex ways
- users like pretty pictures

So . . . the situation will get worse

Solutions?

Solutions?

Solutions?

$\Rightarrow$

Solutions?

$\Rightarrow$

Solutions?

$\Rightarrow$

Thus, we need

Solutions?

$\Rightarrow$

Thus, we need

- Open Data

Solutions?

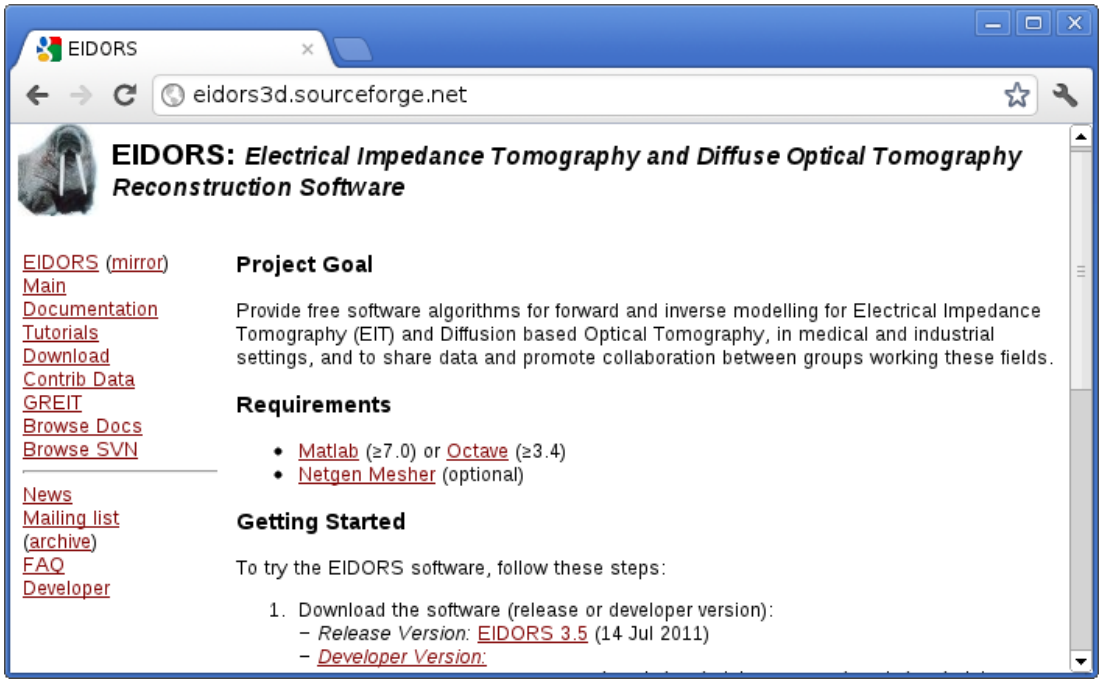
$\Rightarrow$

Thus, we need

- Open Data
- Open source analysis

For EIT . . .

For EIT . . .


EIDORS
eidors3d.sourceforge.net
EIDORS: Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software
EIDORS (mirror)
Main
Documentation
Tutorials
Download
Contrib Data
GREIT
Browse Docs
Browse SVN
News
Mailing list
(archive)
FAQ
Developer
Project Goal
Provide free software algorithms for forward and inverse modelling for Electrical Impedance Tomography (EIT) and Diffusion based Optical Tomography, in medical and industrial settings, and to share data and promote collaboration between groups working these fields.
Requirements
Matlab (≥7.0) or Octave (≥3.4)
Netgen Mesher (optional)
Getting Started
To try the EIDORS software, follow these steps:
1. Download the software (release or developer version):
– Release Version: EIDORS 3.5 (14 Jul 2011)
– Developer Version:

For EIT . . .

EIDORS

eidors3d.sourceforge.net

EIDORS: ***Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software***

EIDORS (mirror)
Main
Documentation
Tutorials
Download
Contrib Data
GREIT
Browse Docs
Browse SVN

News
Mailing list (archive)
FAQ
Developer

Project Goal

Provide free software algorithms for forward Tomography (EIT) and Diffusion based Opt settings, and to share data and promote c

Requirements

- Matlab (≥7.0) or Octave (≥3.4)
- Netgen Mesher (optional)

Getting Started

To try the EIDORS software, follow these s

1. Download the software (release or d
   - *Release Version:* EIDORS 3.5 (1
   - *Developer Version:*

EIDORS

eidors3d.sourceforge.net/data_contrib/if-neonate-spontaneous/index.

Contributed EIT Data:

Authors:	S. Heinrich, H. Schiffmann, A. Frerichs, A. Klockgether-Radke, I. Frerichs
Date:	2006
Brief Description:	10-day old spontaneously breathing neonate lying in the prone position with the head turned to left. Data were published in S. Heinrich, H. Schiffmann, A. Frerichs, A. Klockgether-Radke, I. Frerichs, Body and head position effects on regional lung ventilation in infants: an electrical impedance tomography study. Intensive Care Med., 32:1392-1398, 2006.
License:	Creative Commons Artistic License (with Attribution)
Attribution Requirement:	Use or presentation of these data must acknowledge Inéz Frerichs, and reference this publicat S. Heinrich, H. Schiffmann, A. Frerichs, A. Klockgether-Radke, I. Frerichs, Body and h position effects on regional lung ventilation in infants: an electrical impedance tomograp study. Intensive Care Med., 32:1392-1398, 2006.
Format:	EIT data were acquired with the Göttingen Goe-MF II device, 220 frames, 13 frames/s. Data ar .GET file format.
Methods:	Neonate in prone position, with electrode #1 at the front of the chest, electrode #5 on the left s the chest, electrode #9 on the back and electrode #13 on the right side of the chest
Data:	Data (zip format)
Image of Experimental Configuration:	

Traffic jam on the way to Carleton