Interpreting Impedance Images
. . . *Interesting* or *Irrelevant?*

MIRAN Workshop, U. Manchester, UK:
Chest EIT: Vision, Status & Priorities
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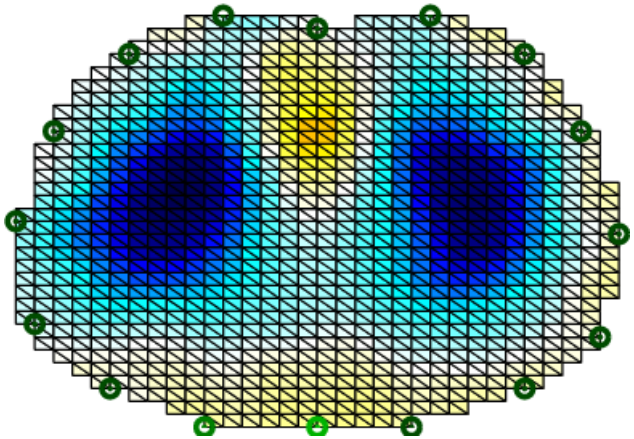
EIT Images: *Interesting or Irrelevant*?

- Movivating Question:

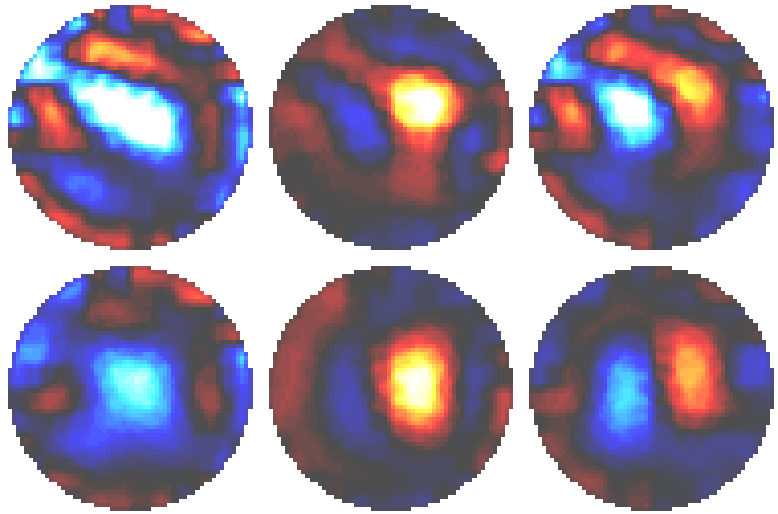
  What do we need from the engineers?
- Recent advances
- Requirements for clinical EIT
  - current work to address them
- What should be our priorities?

Recent Advances

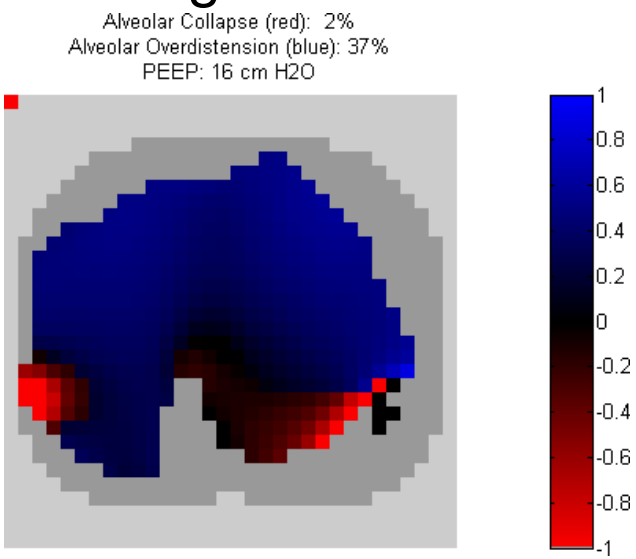
GREIT



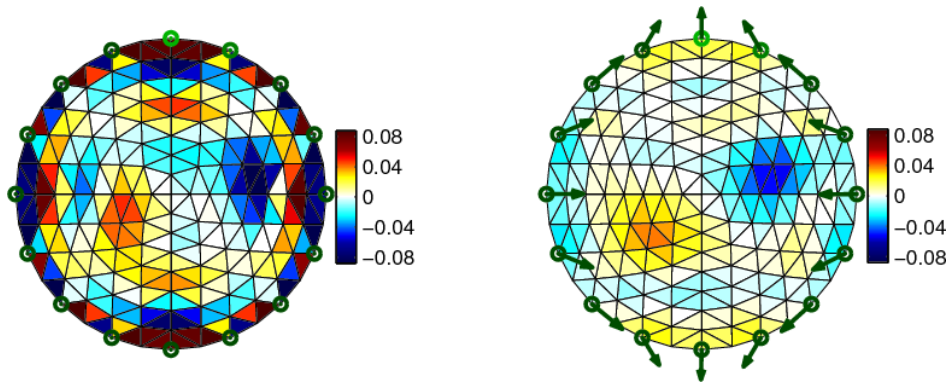
Electrode Errors



Lung Parameters



Electrode Movement



Requirements for clinical EIT

From “Whither EIT” *Phys. Meas.* (2012)

- Availability of EIT devices
- Standards
- Robustness
- Useful software
- Useful paramters
- Standardized procedures

Requirements: *availability*

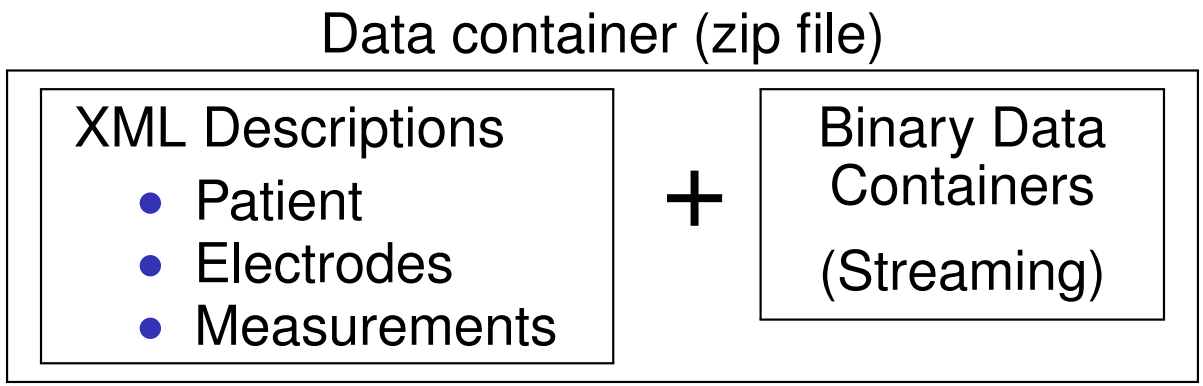
EIT devices must be readily available at a reasonable cost. Since EIT uses components common to consumer electronics, increases in volume should strongly reduce costs.

- Some progress
- Still a big problem

Requirements: *standard formats*

EIT data and images must be accessible in standard formats.
For images, the natural format is a DICOM class.

- It's not hard to do a DICOM class for EIT
- Work on a data format

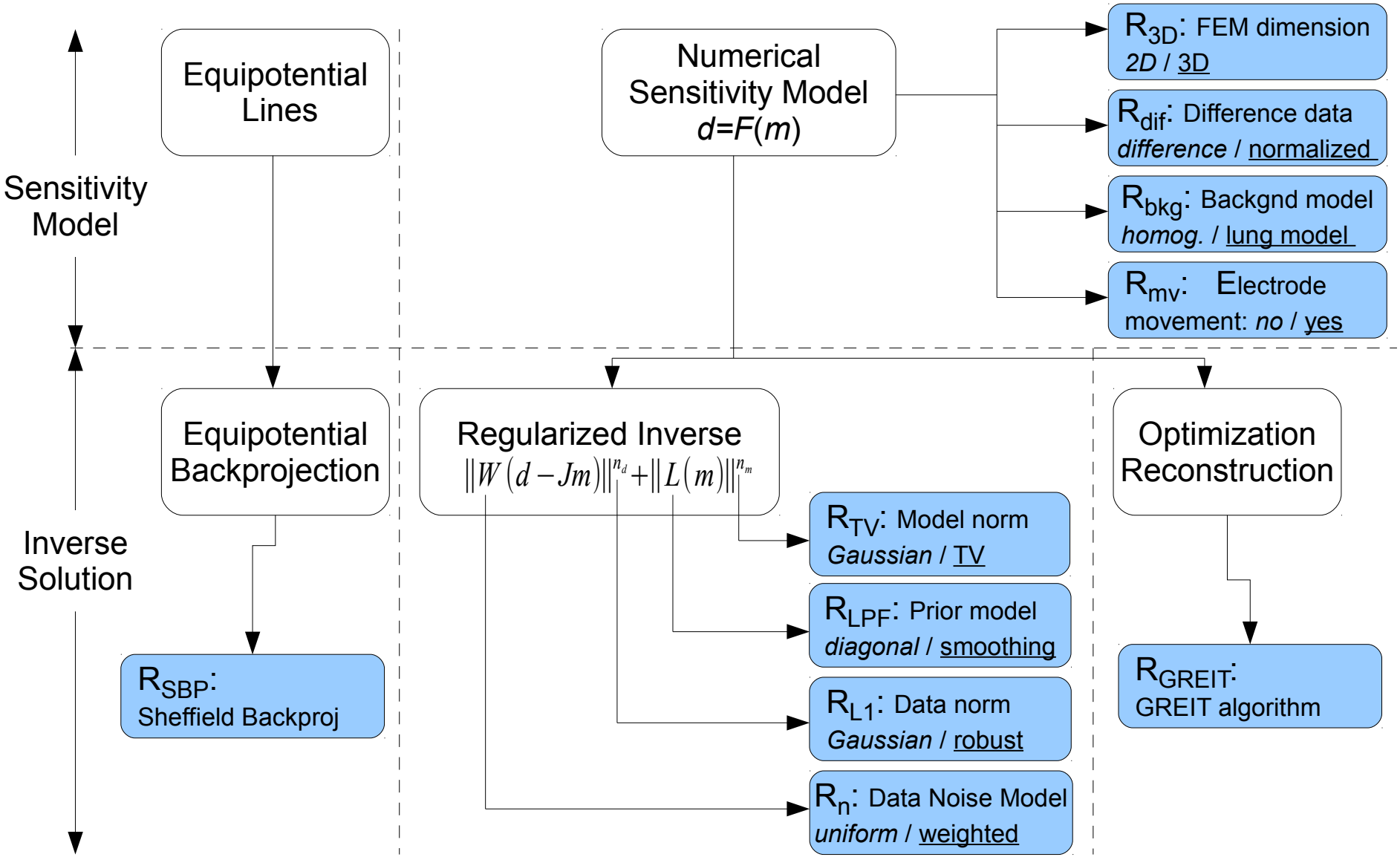


Requirements: *robustness:*

EIT systems must be robust against electrode contact problems and electrical interference. Systems must automatically compensate (if possible) for electrode errors or give appropriate warnings.

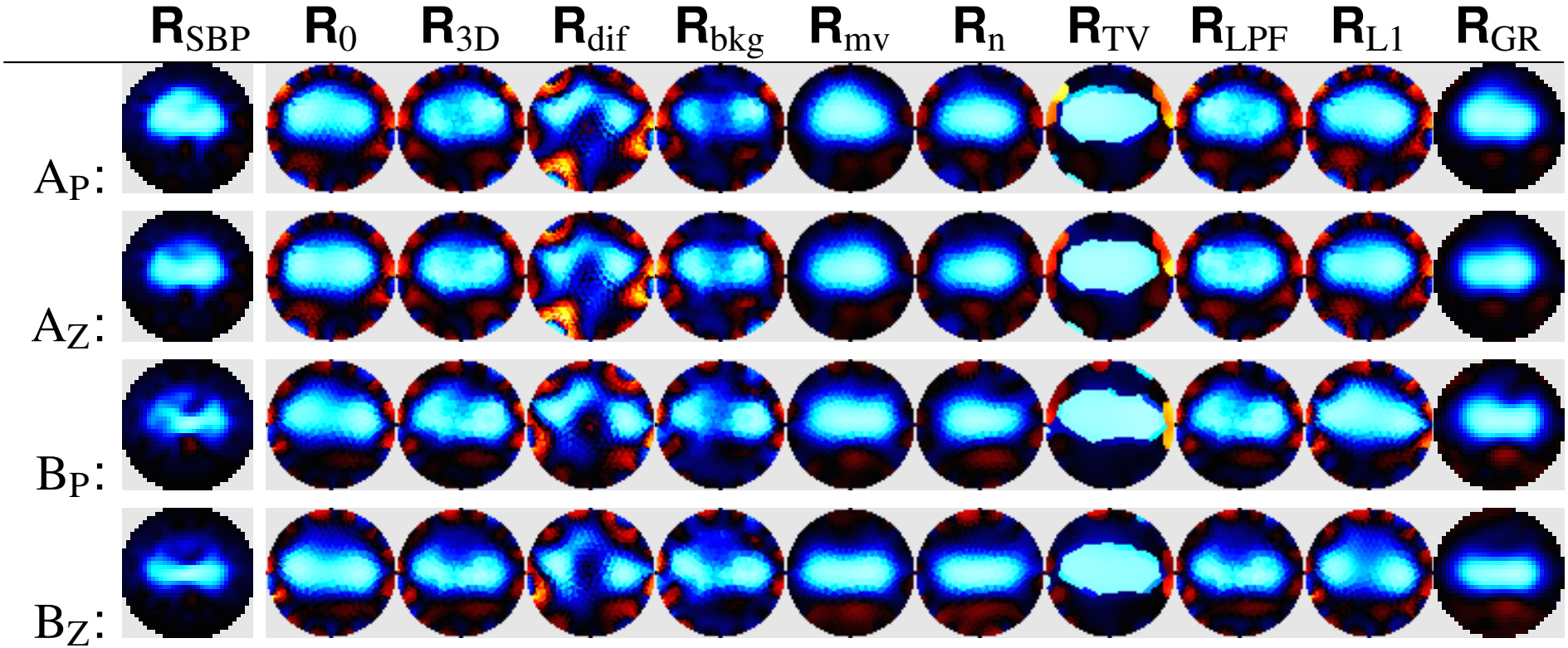
- Algorithm Evaluations
- Electrode error compensation
- Data quality measures
- Robust Algorithms

robustness: Algorithm Evaluations



Taxonomy of direct EIT reconstruction algorithms, classified in terms of the selection of forward and inverse model parameters.

robustness: Algorithm Evaluations



EIT images for all algorithms from two animals (A&B). For each animal, images of $\mathrm{V_T}$ at PEEP ($\cdot_{\mathrm{P}}$) and ZEEP ($\cdot_{\mathrm{Z}}$) are shown individually normalized to the maximum amplitude in each image (*Blue*: decrease in conductivity, *Red*: increase in conductivity).

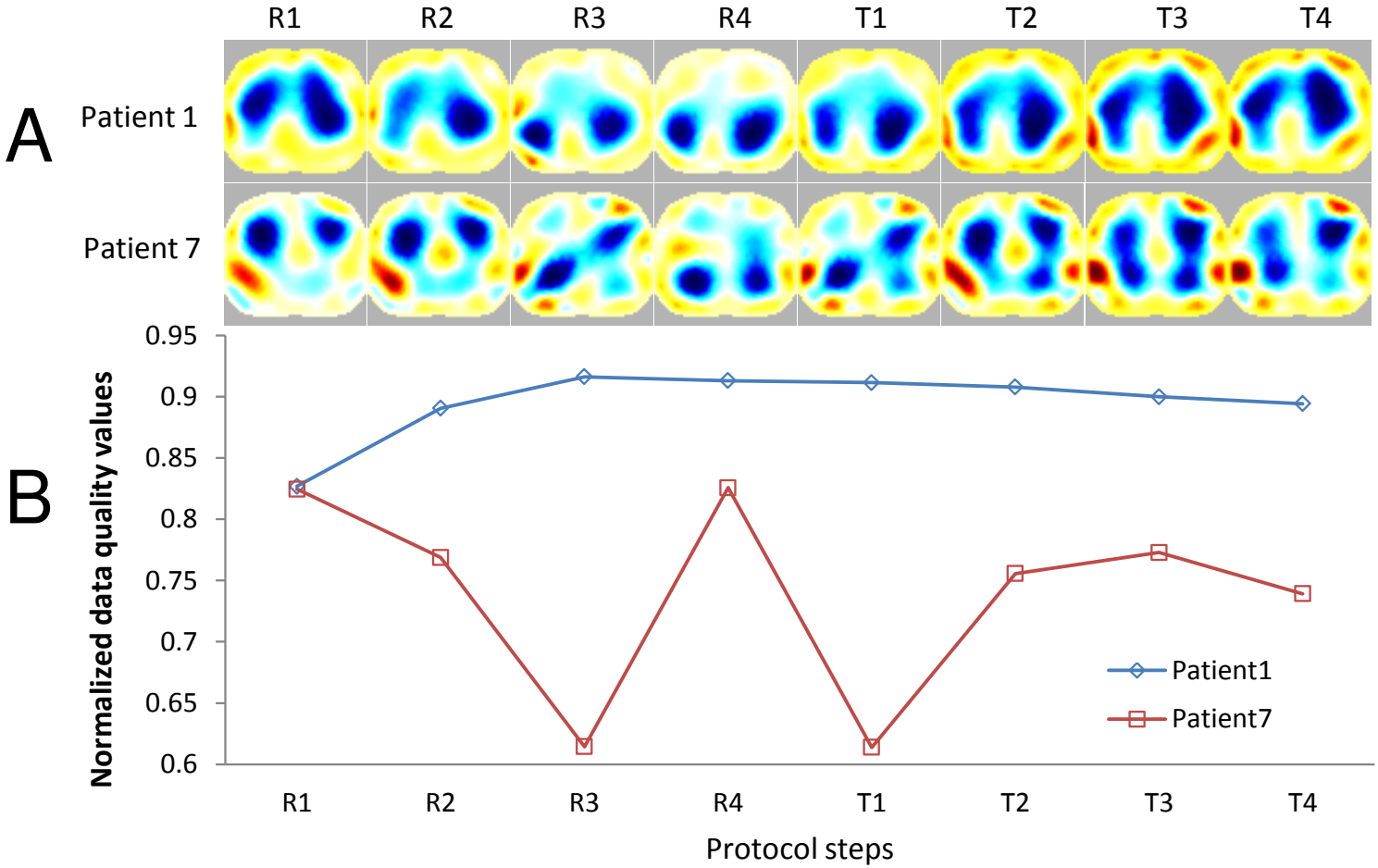
robustness: Algorithm Evaluations

Performance of different image reconstruction algorithms during mechanical ventilation with constant tidal volume and variable end-expiratory pressure and O_2 fraction – detection of global and regional tidal and end-expiratory lung volumes

Expected finding	R_{SBP}	R_0	R_{3D}	R_{dif}	R_{bkg}	R_{mv}	R_n	R_{TV}	R_{LPF}	R_{L1}	R_{GR}
V_T is independent of PEEP											
$V_{T,E,Z,21} = V_{T,E,P,21}$	0.021*	0.332	0.175	0.203	0.387	0.014*	0.001*	0.845	0.172	0.000*	0.006*
$V_{T,E,Z,100} = V_{T,E,P,100}$	0.009*	0.041*	0.027*	0.052	0.062	0.008*	0.009*	0.208	0.027*	0.001*	0.008*
V_T is independent of F_IO_2											
$V_{T,E,Z,21} = V_{T,E,Z,100}$	0.031*	0.015*	0.018*	0.001*	0.008*	0.044*	0.035*	0.111	0.017*	0.000*	0.041*
$V_{T,E,P,21} = V_{T,E,P,100}$	0.003*	0.007*	0.006*	0.026*	0.009*	0.003*	0.001*	0.134	0.005*	0.000*	0.002*
V_T is reproducible											
$V_{T,E,Z1} = V_{T,E,Z2}$	0.002*	0.006*	0.004*	0.000*	0.003*	0.003*	0.001*	0.018*	0.004*	0.001*	0.002*
$V_{T,E,P1} = V_{T,E,P2}$	0.000*	0.000*	0.000*	0.001*	0.000*	0.000*	0.000*	0.002*	0.000*	0.000*	0.000*
CoG is PEEP dependent											
$CoG_{,E,Z,21} > CoG_{,E,P,21}$	0.069	0.097	0.094	0.156	0.138	0.064	0.050	0.090	0.094	0.138	0.051
$CoG_{,E,Z,100} > CoG_{,E,P,100}$	0.024*	0.032*	0.032*	0.049*	0.045*	0.025*	0.022*	0.030*	0.032*	0.056	0.022*
CoG is F_IO_2 dependent											
$CoG_{,E,Z,21} < CoG_{,E,Z,100}$	0.006*	0.007*	0.006*	0.015*	0.010*	0.006*	0.006*	0.007*	0.006*	0.014*	0.006*
$CoG_{,E,P,21} < CoG_{,E,P,100}$	0.552	0.526	0.529	0.458	0.539	0.526	0.581	0.556	0.528	0.493	0.530
CoG is reproducible											
$CoG_{,E,Z1} = CoG_{,E,Z2}$	0.007*	0.016*	0.020*	0.192	0.017*	0.039*	0.010*	0.017*	0.018*	0.008*	0.017*
$CoG_{,E,P1} = CoG_{,E,P2}$	0.001*	0.001*	0.002*	0.002*	0.001*	0.008*	0.006*	0.002*	0.002*	0.000*	0.007*

E, Measures by EIT; V_T, tidal volume; PEEP (P), positive end-expiratory pressure; ZEEP (Z), zero end-expiratory pressure; F_IO_2, fraction of O_2 in inspired gas; 21, F_IO_2 equal to 21%; 100, F_IO_2 equal to 100%; indices 1 and 2 identify the first and the second measurements at identical ZEEP or PEEP levels; Up, upper or nondependent lung regions; Lo, dependent lung regions

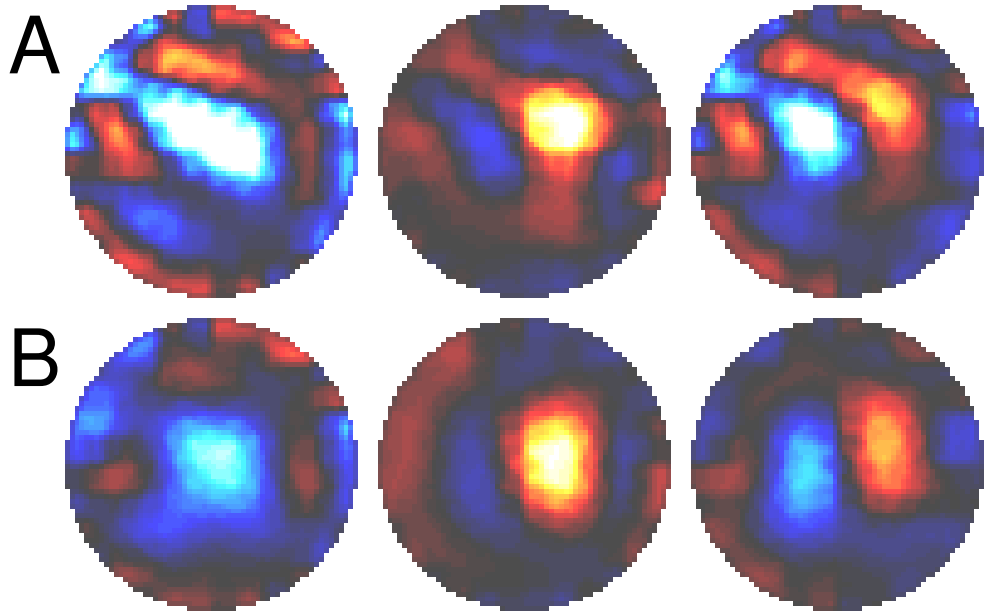
robustness: Data quality measures



Clinical data and data quality metric for each stage of the protocol (R1–R4 — recruitment: PEEP⇑, T1–T4 — titration: PEEP⇓).
A: EIT images (one-step Gauss-Newton solver with a 2D forward model), *B*: Calculated data quality.

robustness: 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

robustness: Robust Algorithms

- ℓ_1 norm for the image prior allows “blocky” reconstructions
- ℓ_1 norm for the data mismatch gives improved robustness to outliers

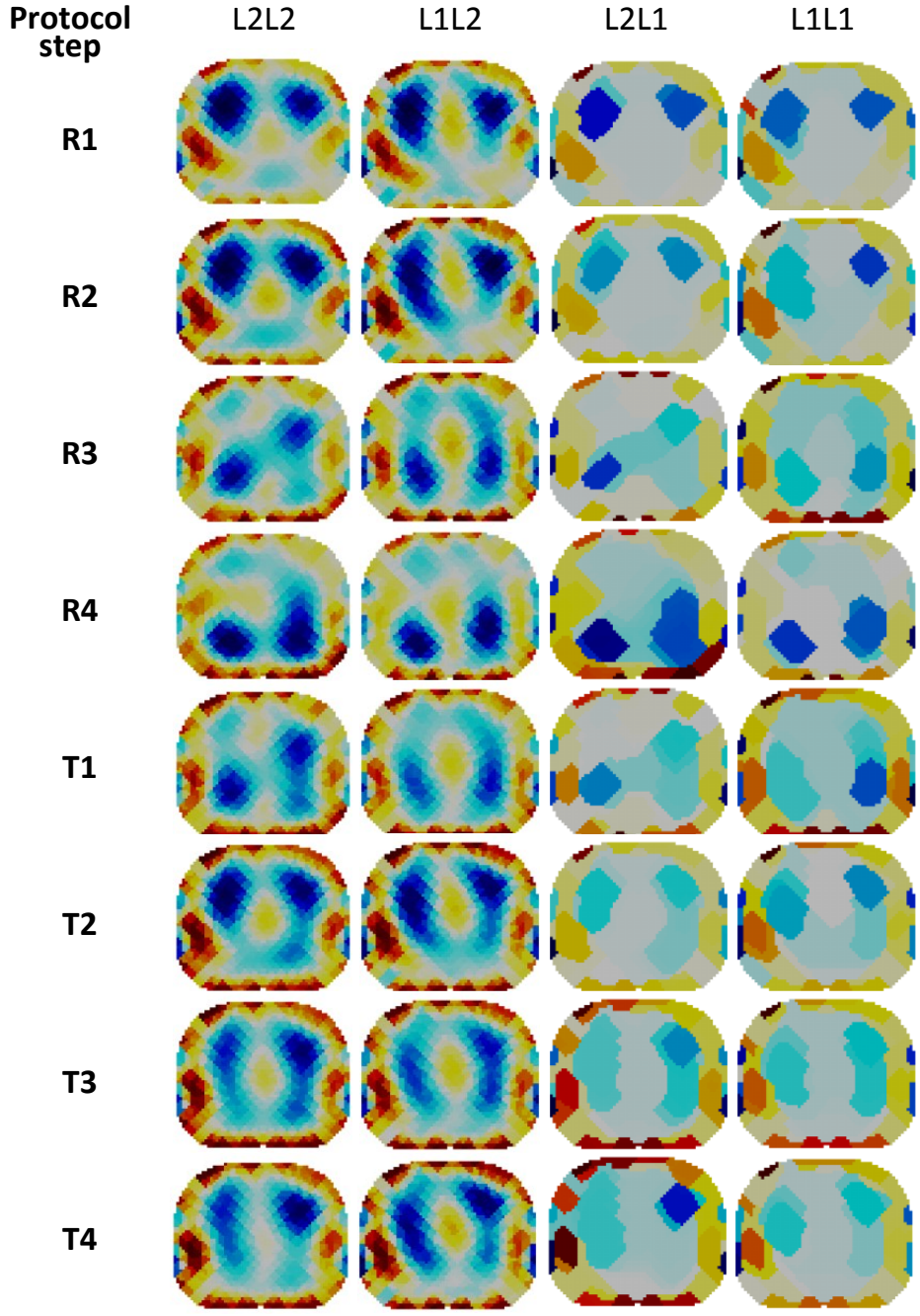
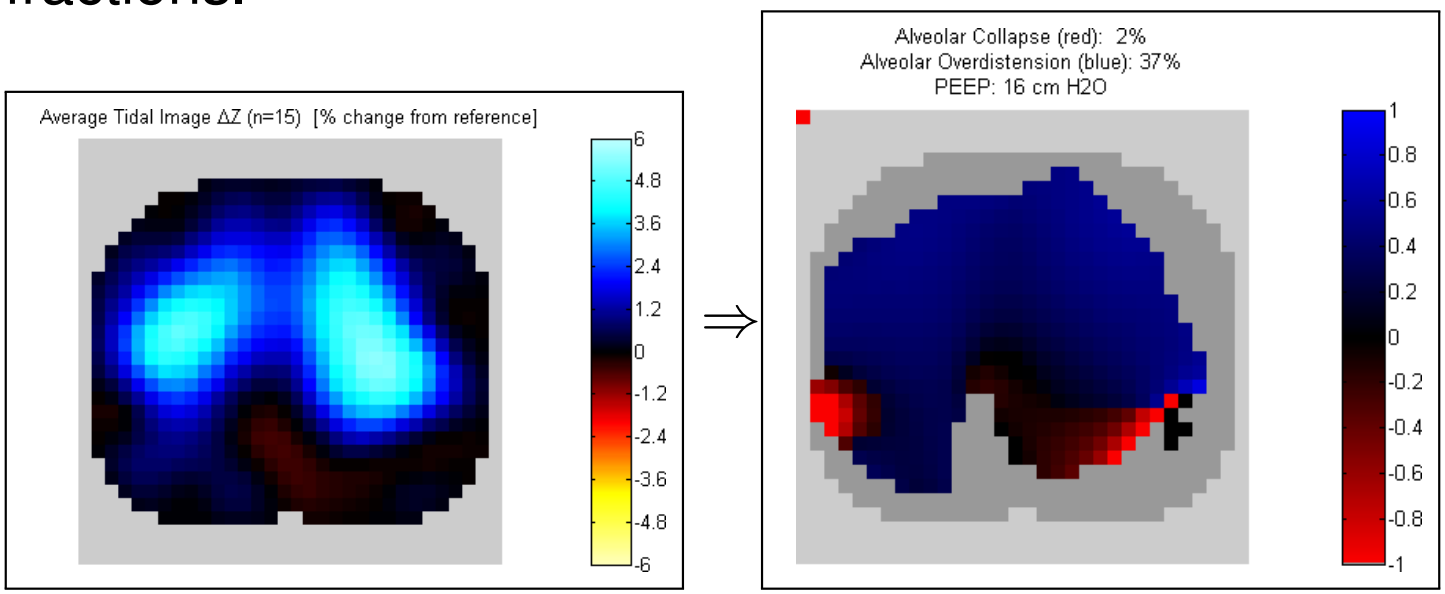


Figure: Reconstructions with mixed (data/image) norms for clinical data for each stage of the protocol (R1–R4 — recruitment: PEEP$\Uparrow$, T1–T4 — titration: PEEP$\Downarrow$).

Requirements: *useful software:*

Software must have an intuitive interface focused on the clinical user. EIT parameters should related to those commonly used: pressures, volumes, time, or fractions (not ΔZ). Analysis must be on-line (not retrospective).

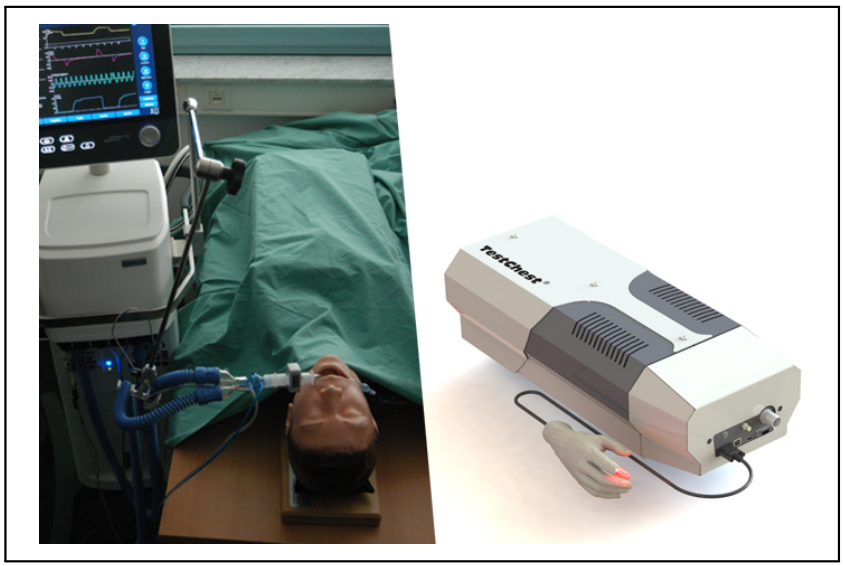
- Agreement that we need *overdistention* and *collapse* fractions.



Requirements: *standardized procedures:*

Standardize EIT protocols (e.g. duration of PEEP steps, magnitude of steps, type of ventilation, EIT frame rates, additional measurements). . . . automated approaches for data analysis and interpretation should be included.

- Which information from EIT impacts care?
  How to present information?



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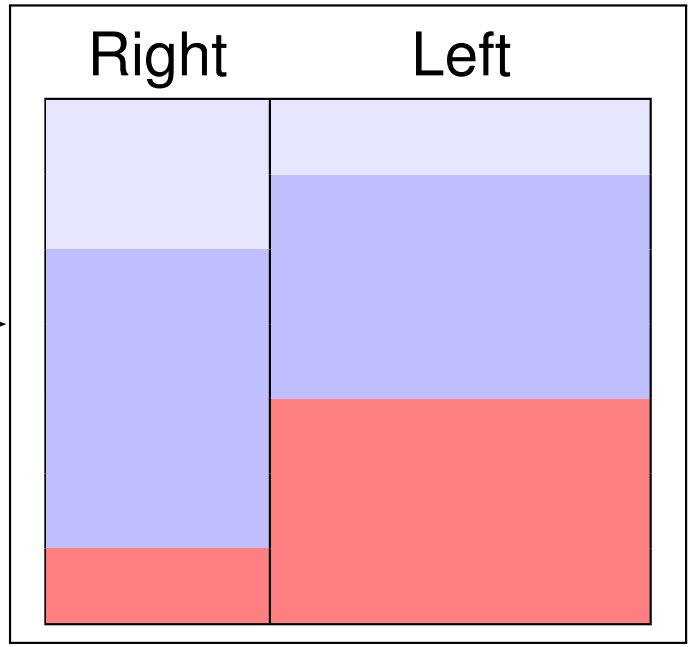


Thoughts (from “Whither EIT”)

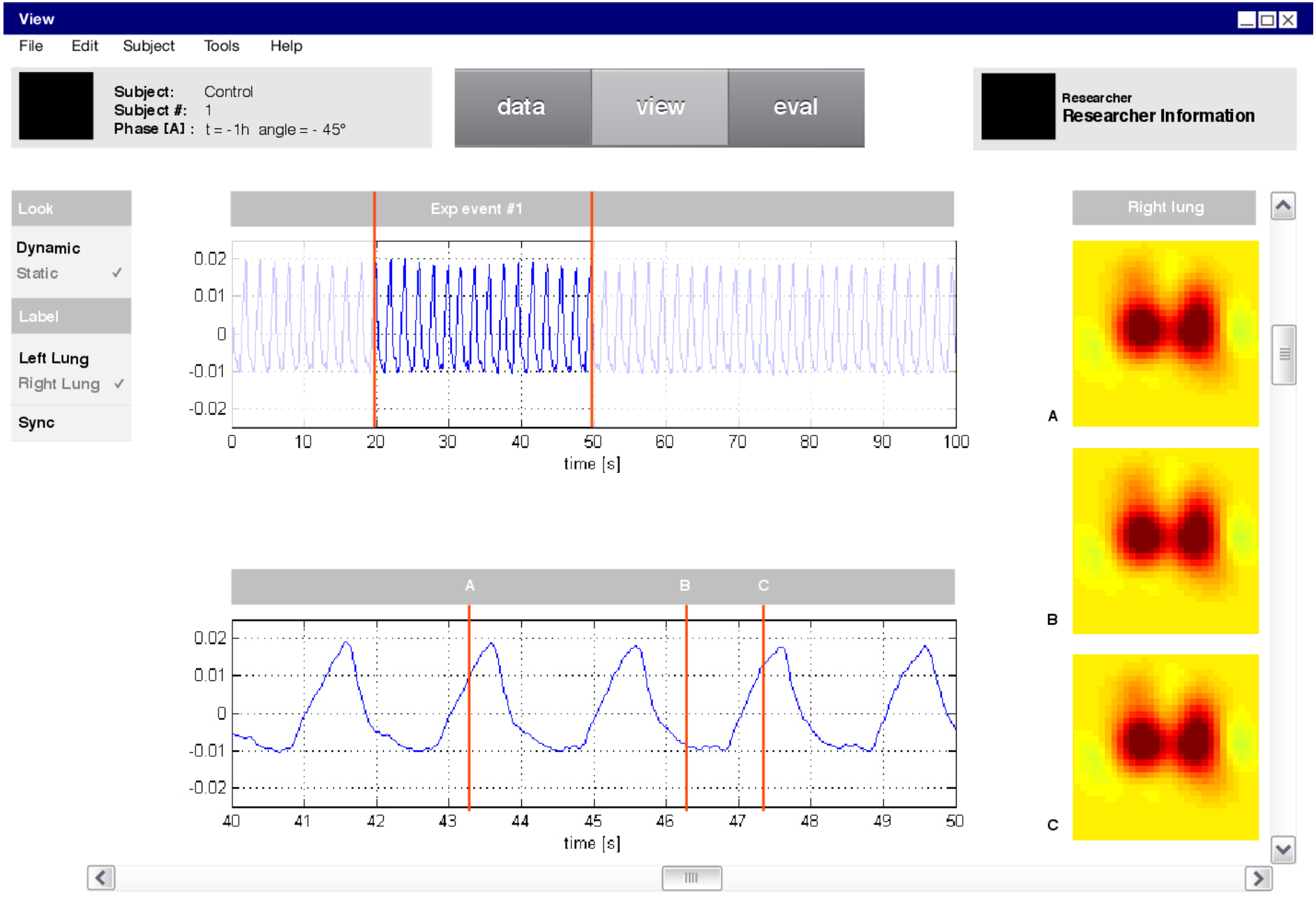
- EIT is at a critical time.
  - a large and growing clinical interest
  - commercial devices on the market.
- Risk: enthusiasm dissipates, as new clinical researchers unable to reliably use EIT,
  - unable to usefully interpret the images generated
  - images ruined by errors.
- Is EIT “another technology too complicated for the clinic”?

So, we need good advice (for beginners) on how to

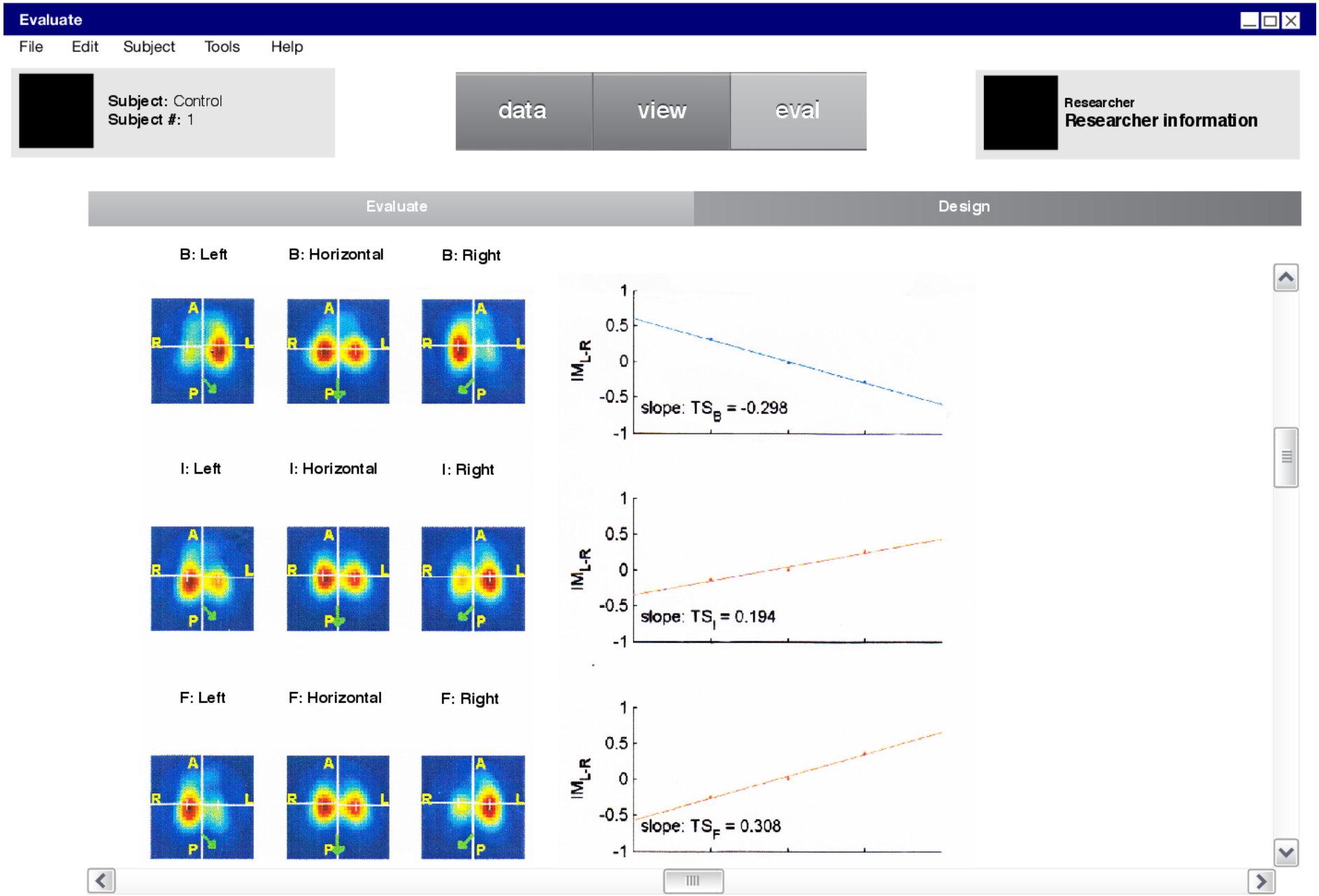
- conduct
- analyse

simple EIT experiments/clinical protocols

Concept for Graphical Analysis tool *(View Screen)*



Concept for Graphical Analysis tool *(Eval Screen)*



Recommendations: “Whither EIT”

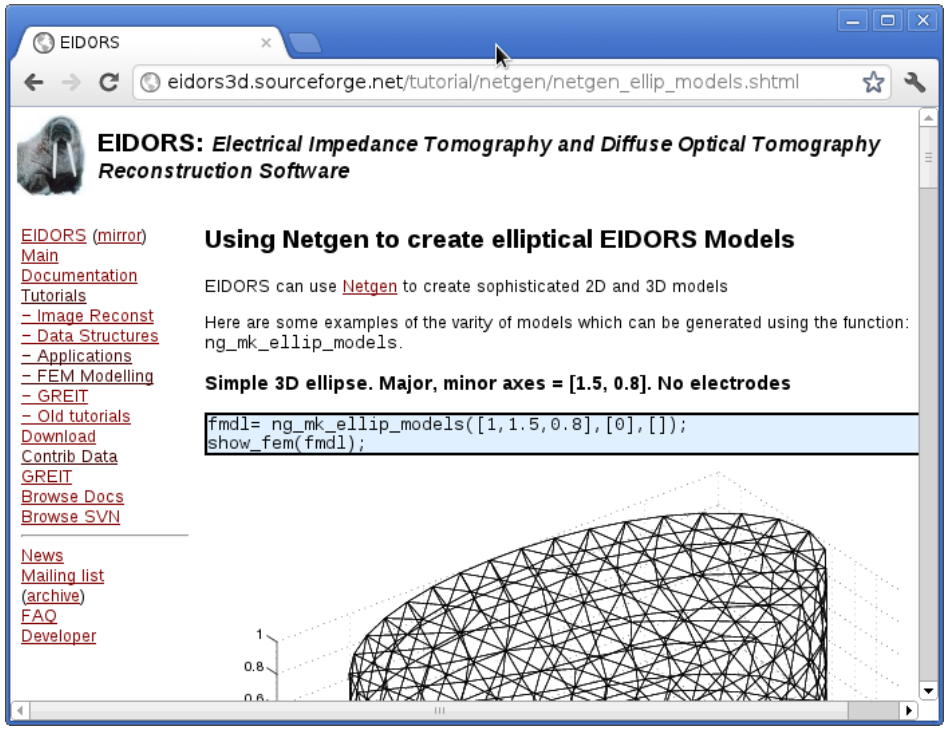
- think about the physiology;
  - e.g. EIT measure “my patient’s lungs are 30% collapsed” provides insights which lead to interventions
- analyze EIT images in creative ways
  - exploit the parameter “time” and many of sophisticated signal processing algorithms to generate new parameters.

- To solve these problems, we must work in *interdisciplinary teams* (clinical, engineering and mathematical experts).

Requirements: *collaboration*

EIDORS $\Rightarrow$ ...

Sharing Code



Sharing Data