Practical use of EIT data

Seminar on clinical uses of EIT: bedside ventilation made easy!

EIT 2015, Neuchâtel, Switzerland
2 June 2015

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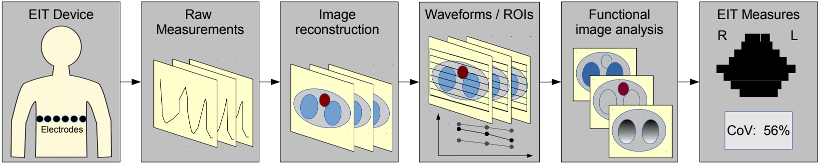
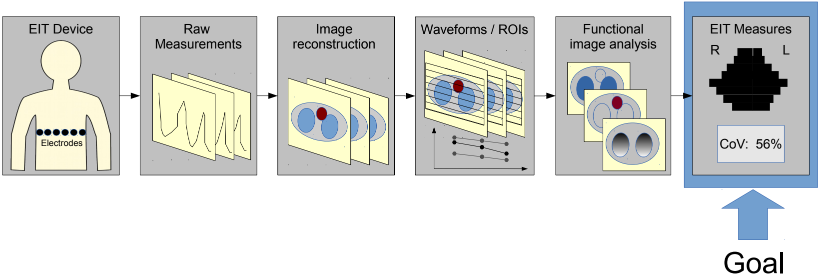
EIT data analysis



Start with the goal . . .



Why use EIT?

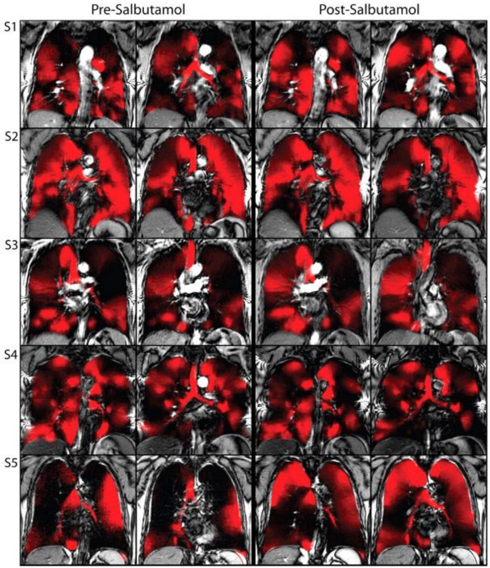
⇒ gain regional insights into patient's lungs

Why images . . .

Imaging Drives new clinical insights

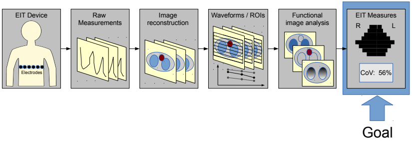
- Imaging has changed cardiac medicine
- Many anatomical imaging modalities (X-ray, CT, MRI)
- For the lungs, few functional ones

Lung inhomogeneity



Source: Kirby et al, Radiology 261.1 (2011)
Pre- and post-salbutamol ^3He MR images (red) registered to two center coronal thoracic ^1H MR images (gray scale) for five representative patients with COPD (S1, S2: GOLD stage II disease, S3, S4: stage III disease, S5: stage IV disease).

EIT measures



EIT Measures

1. Average regional fEIT measures
2. Characterizations of the spatial distribution of ventilation
3. Examination-specific measures

1. Average regional fEIT measures

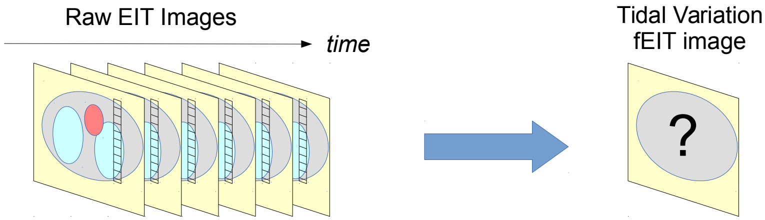


Diagram of calculation of a function EIT image

fEIT image types (example)

1. Tidal variation fEIT image
2. Standard deviation fEIT image
3. Aeration change fEIT image
4. Ventilation delay fEIT image
5. Time constant fEIT image

1. Average regional fEIT measure

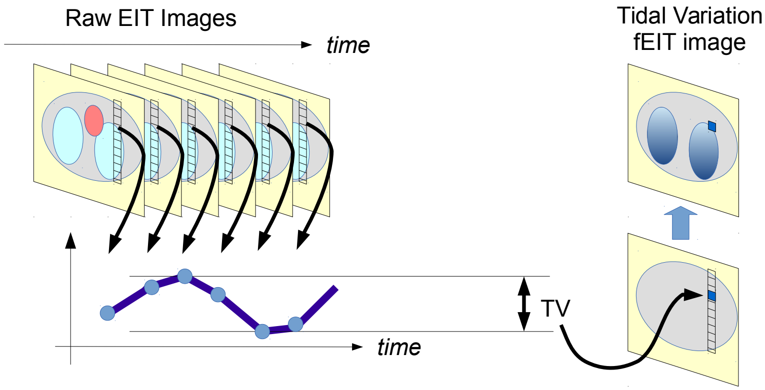
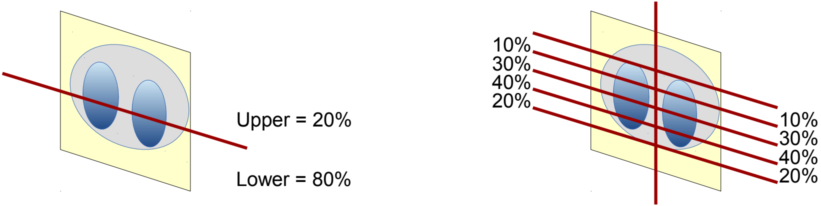


Diagram of calculation of a *Tidal Variation* EIT image

(aside: not *Tidal Volume* because image not in mL units)

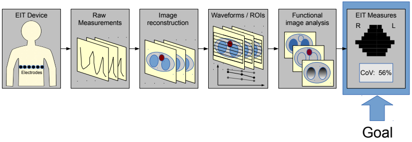
1. Average regional fEIT measure



Regions of interest in fEIT measures

1. Global image ROIs
2. Lung region ROIs

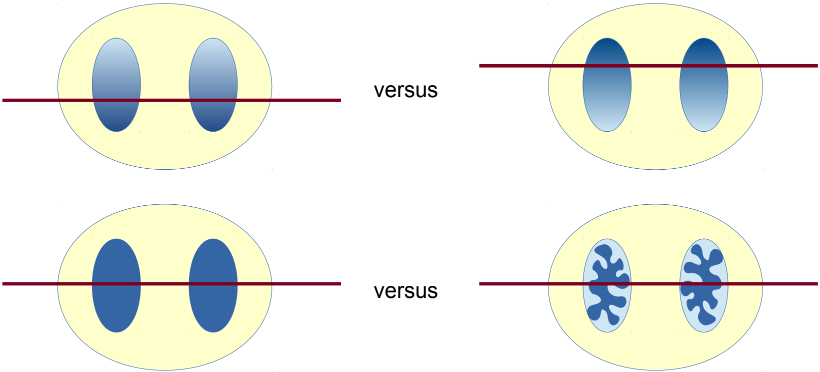
EIT measures



EIT Measures

1. Average regional fEIT measures
2. Characterizations of the spatial distribution of ventilation
3. Examination-specific measures

2. Characterize: spatial distribution of ventilation

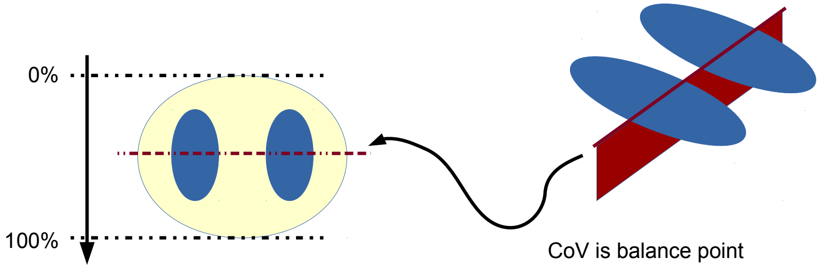


Statistical measures of distributions

a measures of central tendency (mean, median)

b measures of distribution (variance, std)

2a. Characterize: center of distribution of ventilation



Measures of the anterioposterior distribution of ventilation

1. Center of Ventilation
2. Upper to Lower Ventilation Ratio[1]

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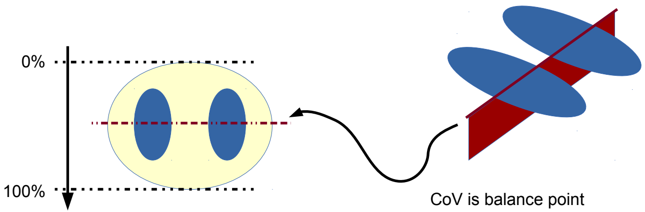
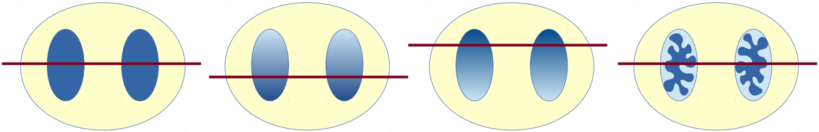
[1] not recommended

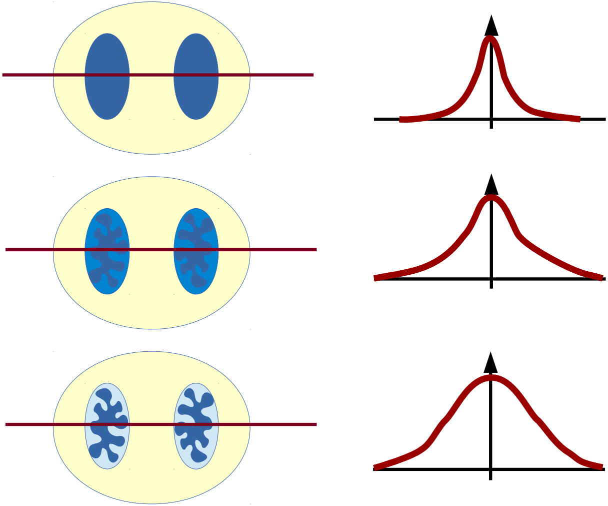
2a. Characterize: center of distribution of ventilation





Examples: Center of Ventilation

2b. Characterize: spatial distribution of ventilation



Heterogeneity

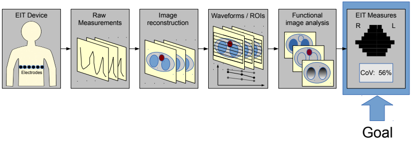
Low

Medium

High

Measure: Global hetergeneity index: $GI = \dfrac{\Sigma z_i - z_{i,\mathrm{median}}}{\Sigma z_i}$

EIT measures

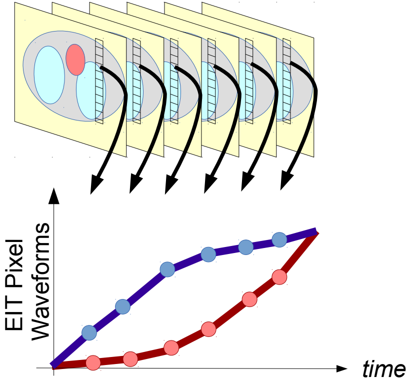


EIT Measures

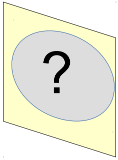
1. Average regional fEIT measures
2. Characterizations of the spatial distribution of ventilation
3. Examination-specific measures
   a EIT measures using simultaneously measured signals
   b EIT measures using specific examinations
   c Both

3c. Examination-specific measures

Raw EIT Images

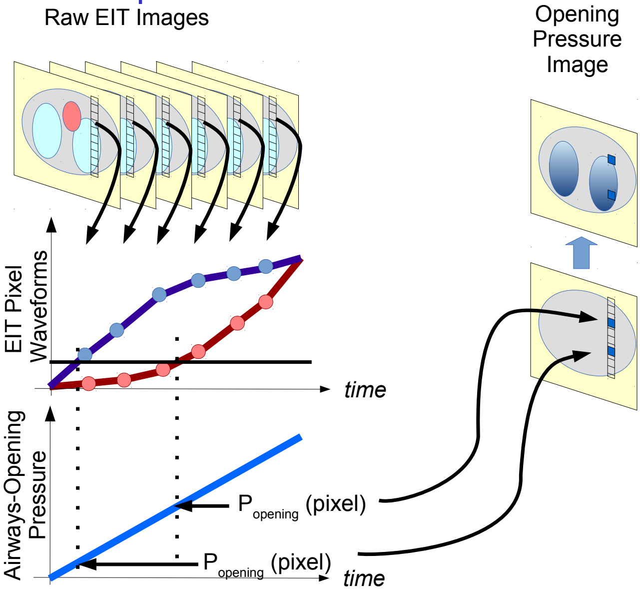


Opening
Pressure
Image



Regional opening pressure
$\Rightarrow$ requires measurement of $P_{\text{Airways-Opening}}$

3c. Examination-specific measures



Which EIT measure?

Depends on the

scientific hypothesis or

clinical question.

Which EIT measure?

What pressure do I need to keep the lung open?

Which EIT measure?

Will a prone position give a more uniform distribution of ventilation?

Which EIT measure?

Will I get more dorsal ventilation if I increase PEEP?

Which EIT measure?

How does pattern of breathing change after bronchodilator inhalation?

EIT data example

GK Wolf, C Gómez-Laberge, JN Kheir, D Zurakowski, BK Walsh, A Adler, JH Arnold (2009)

Description: data collected at Children's Hospital Boston in 2009 during a stepwise lung recruitment manoeuver and positive end-expiratory pressure (PEEP) titration of a patient with the acute respiratory distress syndrome as part of a clinical study (ClinicalTrials.gov identifier NCT00830284).

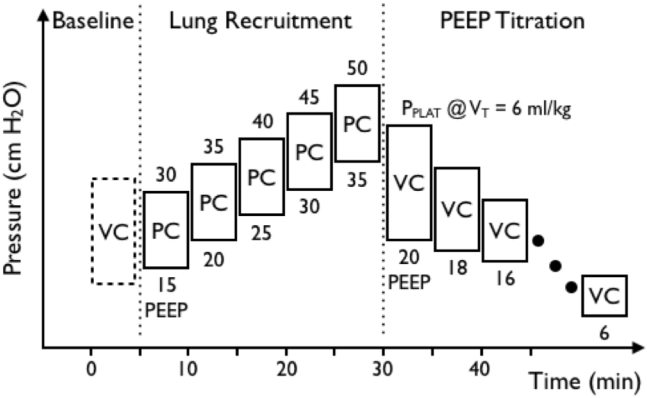
Patient: Gender: F; Age: 5.9 years, Weight: 20kg, Condition: Primary ARDS triggered by parainfluenza pneumonia.

Baseline	Recruitment				Titration			
b	c1	c2	c3	c4	d1	d2	d3	d4
14	15	20	25	30	20	18	16	14

Online: EIDORS.org/data_contrib/cg-2012-ards-recruitment

EIT data example

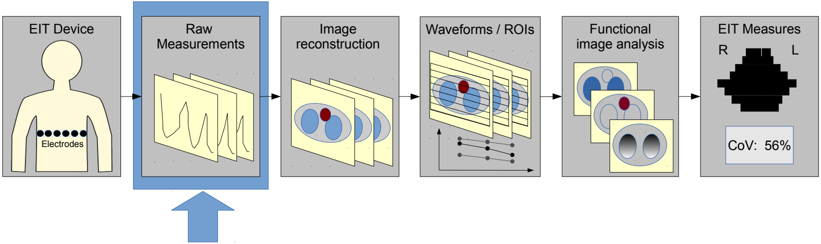
Recruitment Protocol:



Ref GK Wolf, C Gómez-Laberge, JN Kheir, D Zurakowski, BK Walsh, A Adler, JH Arnold (2012) *Pediatr Crit Care Med* 13:509–515

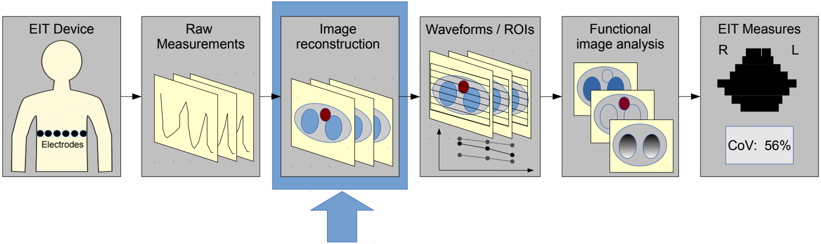
Fig. 1. The experimental protocol is divided in three stages. Baseline PEEP was determined according to clinical practice. During the "Baseline" and "PEEP Titration" stages, patients were ventilated in VC mode with $V_T = 6.0$ ml/kg, and ΔP_{awo} was measured by subtracting PEEP from the measured P_{PLAT}. During the "Lung Recruitment" stage, patients were ventilated in PC mode, and ΔP_{awo} was set to 15 cm H_2O for each step. VC: volume-controlled; P_{PLAT}: plateau pressure; PC: pressure-controlled.

Data Collection

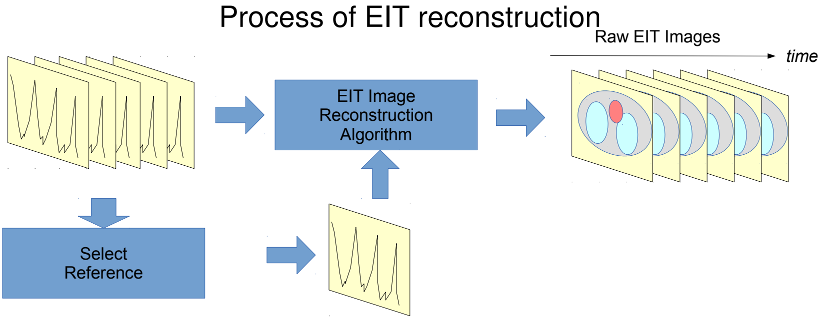


- Where to place electrodes?
- What frame rate to use?

Raw EIT images



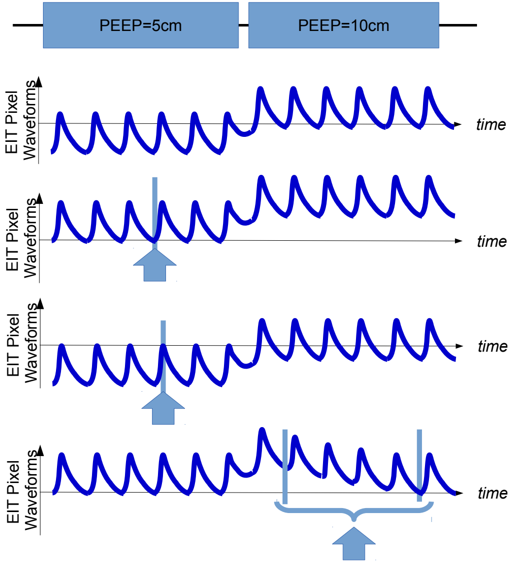
EIT image reconstruction



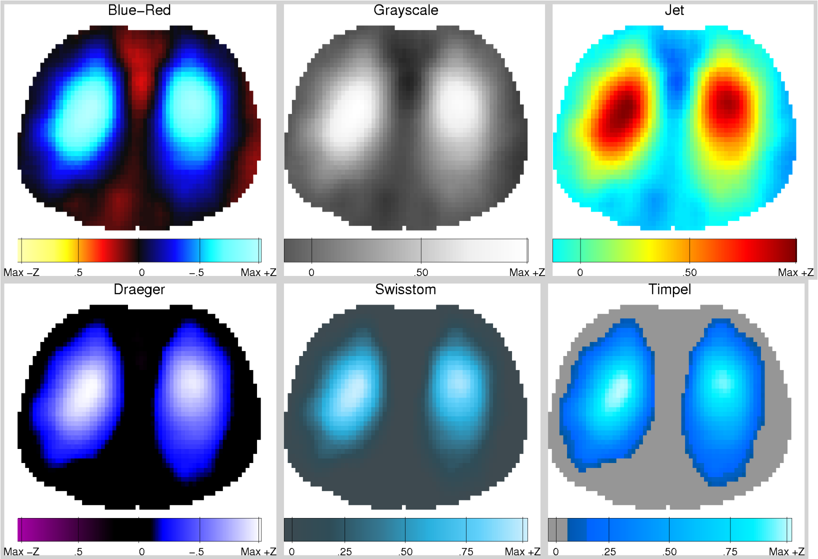
Raw images example

Reference selection

- Average
- End-expiration
- End-inspiration
- Dynamic end-expiration

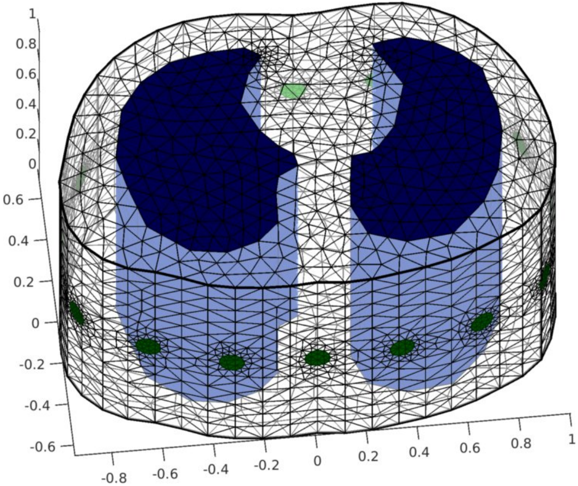


Colour representation of images



Raw images example

Step 1: Create Finite Element Model on which to reconstruct



Raw images example

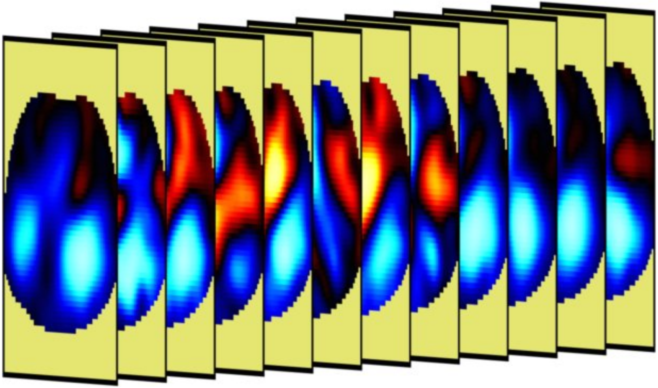
Step 1: Create Finite Element Model on which to reconstruct

CODE:

```
fmdl= mk_library_model('adult_male_16el_lungs');
img = mk_image(fmdl, 1); % background conductivity
img.elem_data(fmdl.mat_idx{2}) = 0.3;
img.elem_data(fmdl.mat_idx{3}) = 0.3;

[stim,msel] = mk_stim_patterns(16,1,[0,1],[0,1],{'no_meas_current'},1);
img.fwd_model.stimulation = stim;
img.fwd_model = mdl_normalize(img.fwd_model, 1);
   opt.imgsz = [64 64];
   opt.distr = 3;
   opt.Nsim = 500;
   opt.target_size = 0.03;
   opt.target_offset = 0;
   opt.noise_figure = .5;
   opt.square_pixels = 1;
imdl=mk_GREIT_model(img, 0.25, [], opt);
imdl.fwd_model.meas_select = msel;

clf; show_fem_enhanced(img);
view(-6,54)
print_convert analyse_step01a.jpg
```

Raw images example

Step 2: Reconstruct and show images



Raw images example

Step 2: Reconstruct and show images

CODE:

```
fname = 'DATA/STUDYNAME/SUBJECT_1/YYYYMMDD/Eit/Viasys/1001_c4.get';
vv= eidors_readdata(fname);
vr = vv(:,56);
img= inv_solve(imdl, vr, vv);

imgs= -calc_slices(img); % Negative to air is +

img.calc_colours.ref_level=0;
img.calc_colours.greylev=.01;
img.calc_colours.backgnd=[1,1,.5]*.9;
img.elem_data = img.elem_data(:,74:4:120);
imgc = calc_slices(img);
imgc([1,63],:,:)= 0; imgc(:,[1,63],:)= 0;

cla; hold on;
[yy,zz]=meshgrid(1:size(imgc,2),1:size(imgc,1));
for i = 1:size(imgc,3);
   ci = calc_colours(imgc(:,:,i), img);
%  ci(ci==1)= NaN;
   xx =  40*i + zeros(size(ci));
   hh = surf(xx,-yy-20*i,-zz-1*i,ci);
   set(hh,'EdgeAlpha',0);
end
hold off; axis off;
view(-74,22);
```

Reconstruction algorithms

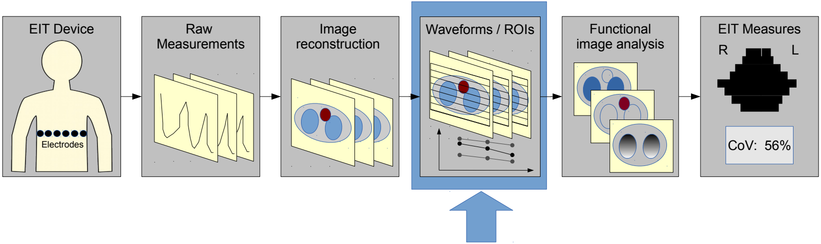
Good news: modern algorithms are good

I’ve spoken to each of the algorithm engineers!

- Dräger – Yvo Gärber
- Swisstom – Beat Müller
- Timpel – Raul Lima

Lots of interesting research still happening.

ROIs and Waveforms



Raw images example

Step 3: Calculate ROIs

Whole Thorax

Lungs

Raw images example

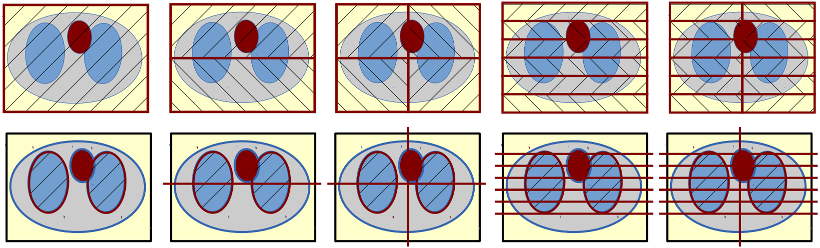
Step 3: Calculate ROIs

CODE:

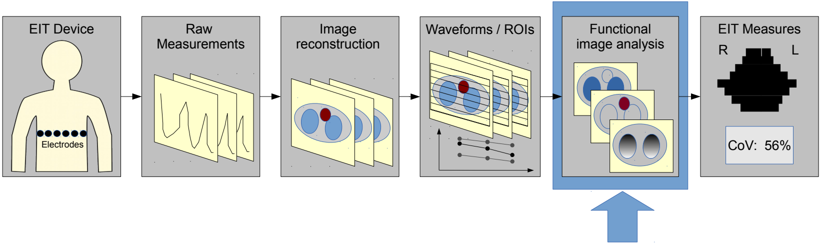
```
fmdl= mk_library_model('adult_male_16el_lungs');
img = mk_image(fmdl, 1); % background conductivity
img.calc_colours.backgnd=[1,1,.5]*.9;
img.calc_colours.ref_level=1;
cut_level = [inf,inf,0.5];

subplot(121);
show_slices(img,cut_level); view(2)

subplot(122);
img.elem_data(fmdl.mat_idx{2}) = 0.3;
img.elem_data(fmdl.mat_idx{3}) = 0.3;
show_slices(img,cut_level); view(2)

ROI = calc_slices(img,cut_level);
ROI = ROI*0 + (ROI == 0.3);
idx = [1:9,56:64]; % little smaller
ROI(:,idx) = ROI(:,idx)*0;

print_convert analyse_step03a.png
```

ROIs and Waveforms

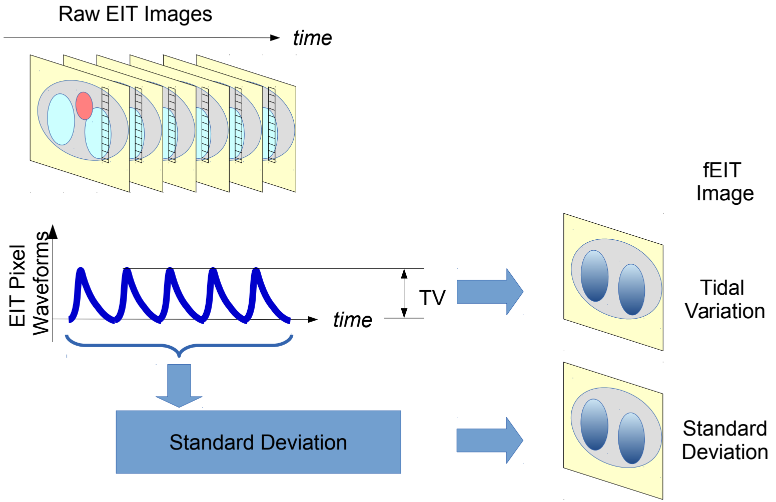
Commonly used ROIs



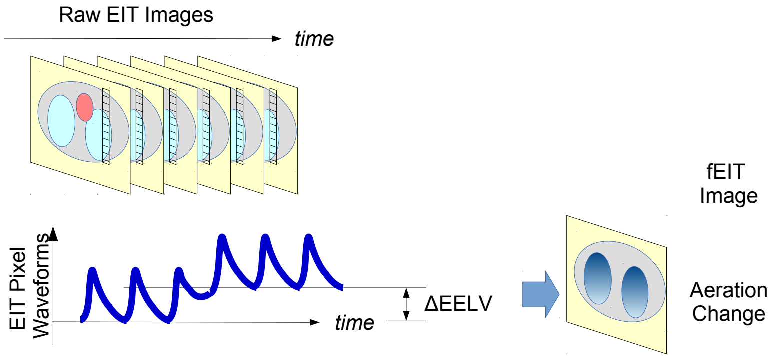
functional EIT (fEIT) images



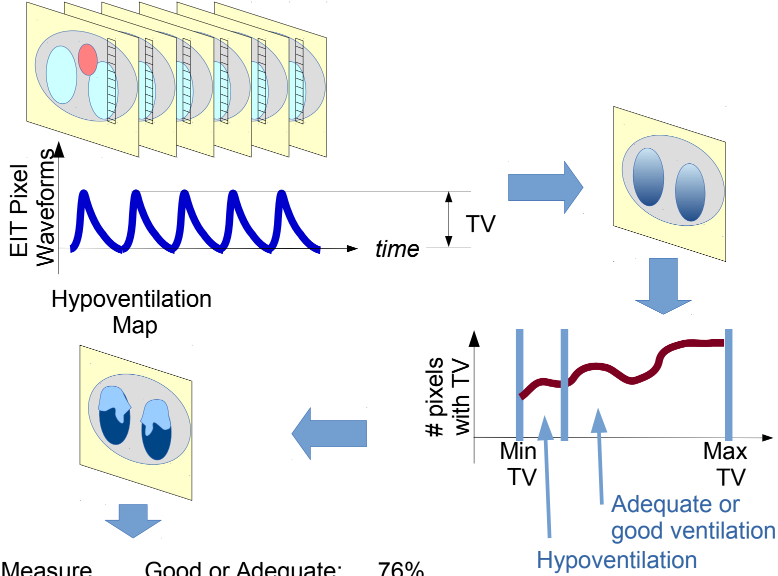
functional EIT (fEIT) images (Tidal Variation / Standard Deviation)



functional EIT (fEIT) images (Aeration Change)



functional EIT (fEIT) images (Hypo-ventilated lung)



EIT Measure	Good or Adequate:	76%
	Hypoventilated:	24%

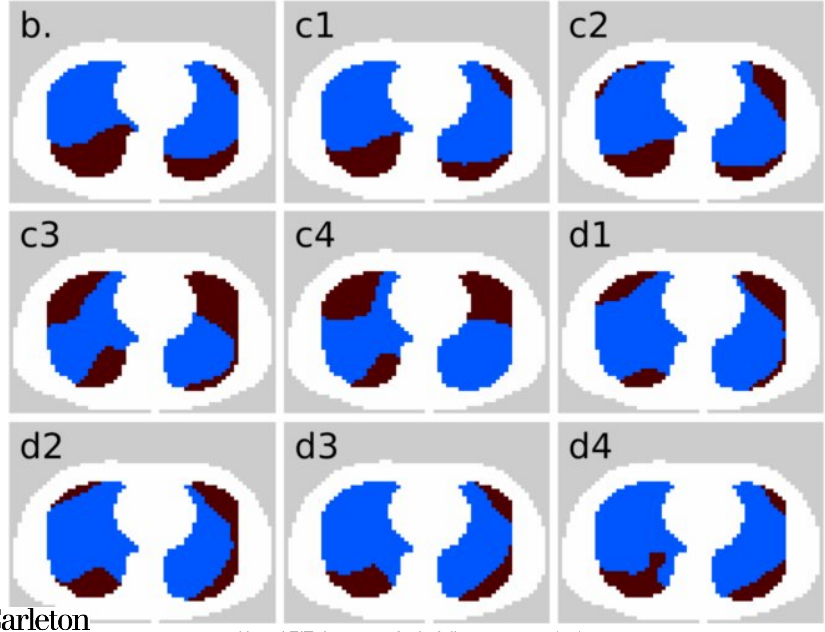
functional EIT (fEIT) images (Hypo-ventilated lung)

Calculate TV and threshold

CODE:

```
path= 'DATA/STUDYNAME/SUBJECT_1/YYYYMMDD/Eit/Viasys/'; dd= dir([path,'*.get']);
for idx = 1:length(dd);
   vv= eidors_readdata([path,dd(idx).name]);
   vr = mean(vv,2);
   img= inv_solve(imdl, vr, vv);
   img.calc_colours.backgnd=[1,1,1]*.8;
   ROI0 = ones(1,size(img.elem_data,1));
   [einsp,eexpi]= find_frc( img, ROI0, 13, '', 2);
   imgc = calc_slices(img); imgc(imgc==NaN) = 0;
   TV   = imgc(:,:,eexpi) - imgc(:,:,einsp);
   TV   = mean(TV,3).*ROI; % Air is +
   out = -ROI/2; % blue lungs
   out( (TV<.2*max(TV(:)))&(ROI==1) ) = 1;
   out = calc_colours(out, img); out(55:64,:)= [];
   subplot(3,3,idx); image(out); axis off
   text(3,7,dd(idx).name(6:7),'FontSize',16);
end

opt.vert_cut = 10; opt.vert_space = 5;
opt.horz_cut = 10; opt.horz_space = 5;
print_convert('analyse_step04a.jpg',opt);
```

fEIT image: Hypo-ventilated lung



Thank you

Traffic jam on the way to Carleton