Electrical Impedance Tomography in 3D: characterization and evaluation

Justin Wagenaar

A Master's Thesis
Master of Applied Science in Biomedical Engineering

Supervisor: Dr. Andy Adler, Carleton University

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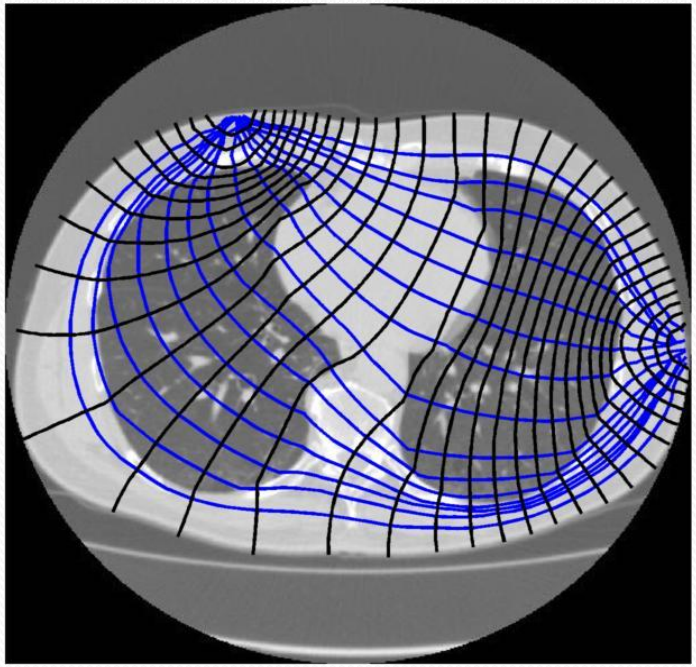
Carleton
UNIVERSITY

Outline

- Background
- Goals
- Reconstruction Method
- Simulations
- Tank Phantom Experiment
- Human Measurements
  - 3D EIT vs. Spirometry
  - Vertical Analysis of fEIT Images
- Conclusion

Introduction

- 2D imaging is typical in medical applications
- 3D imaging is more computationally intensive and image reconstruction is more complex
- Evaluation of 3D *in vivo* measurement strategy requires further development



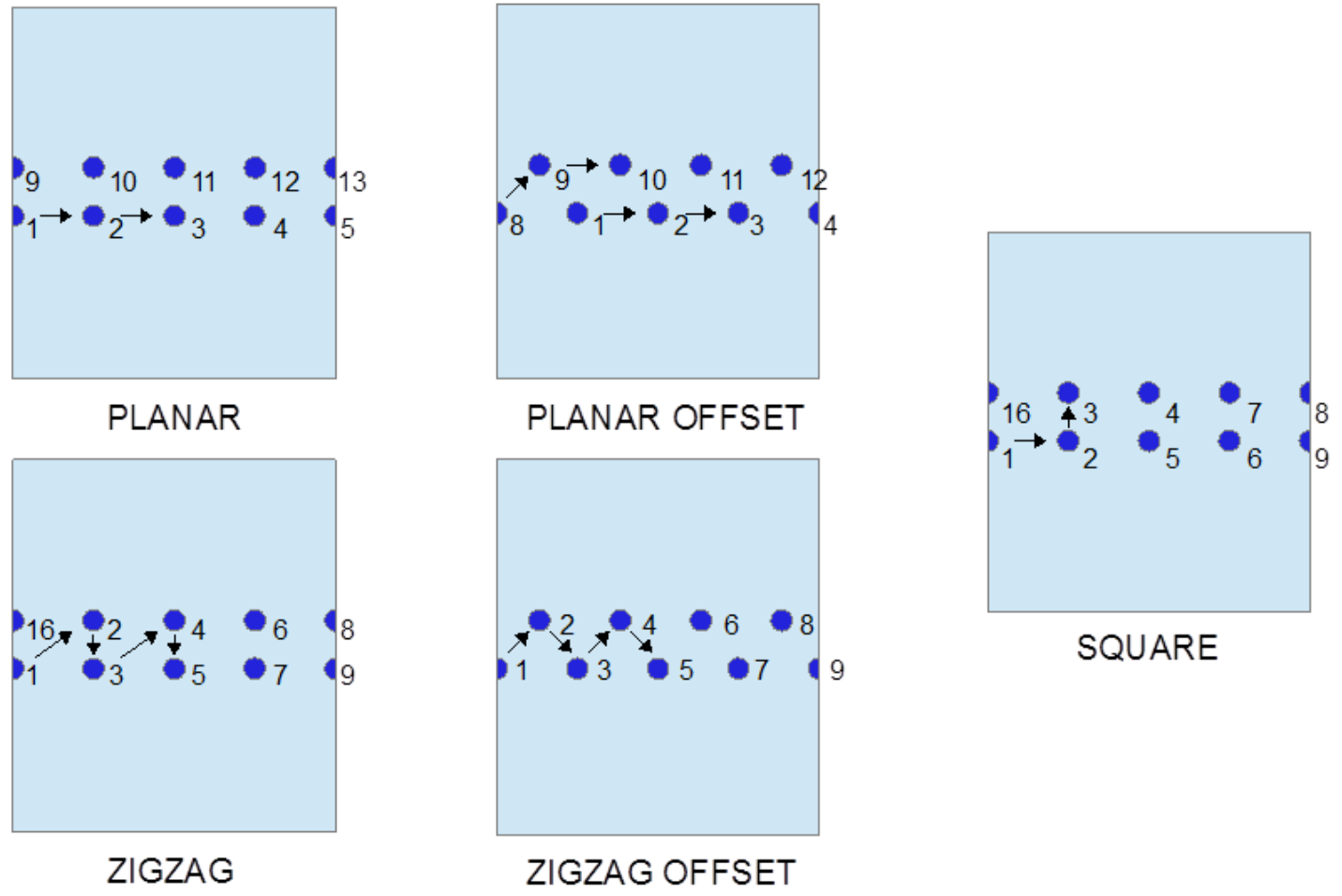
Source: [1]

Goals

1. **Compare 3D EIT measurement patterns** using image quality parameters through simulations, tank phantom experiment, and measurements on healthy human volunteers.
2. **Evaluate 3D EIT as a measurement technique for global lung volume change** in healthy human subjects.
3. **Observe regional inhomogeneities due to vertical gravitational effects** of subject posture (standing, sitting, supine, decline) on reconstructed 3D EIT images.

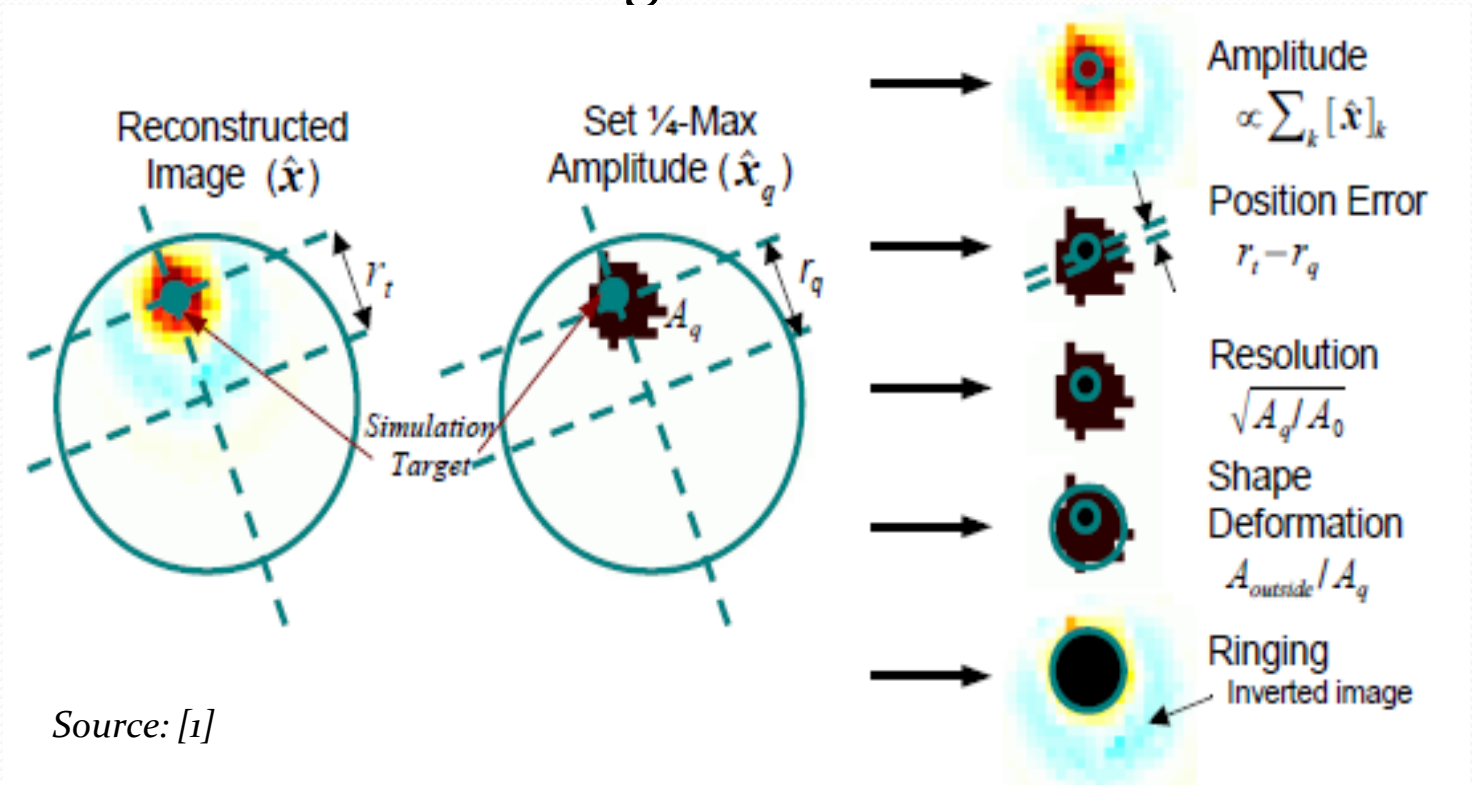
3D EIT Measurement Patterns

- Developed by B. Graham [2]



Reconstruction Method

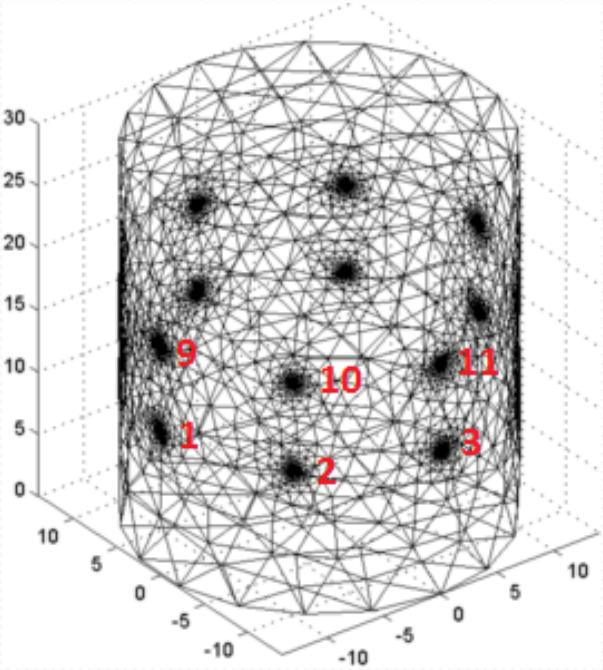
- GREIT (Graz consensus Reconstruction algorithm for EIT) [3]
- Extended to 3D by B. Grychtol [4]
- GREIT Performance Figures of Merit



Source: [1]

Simulations

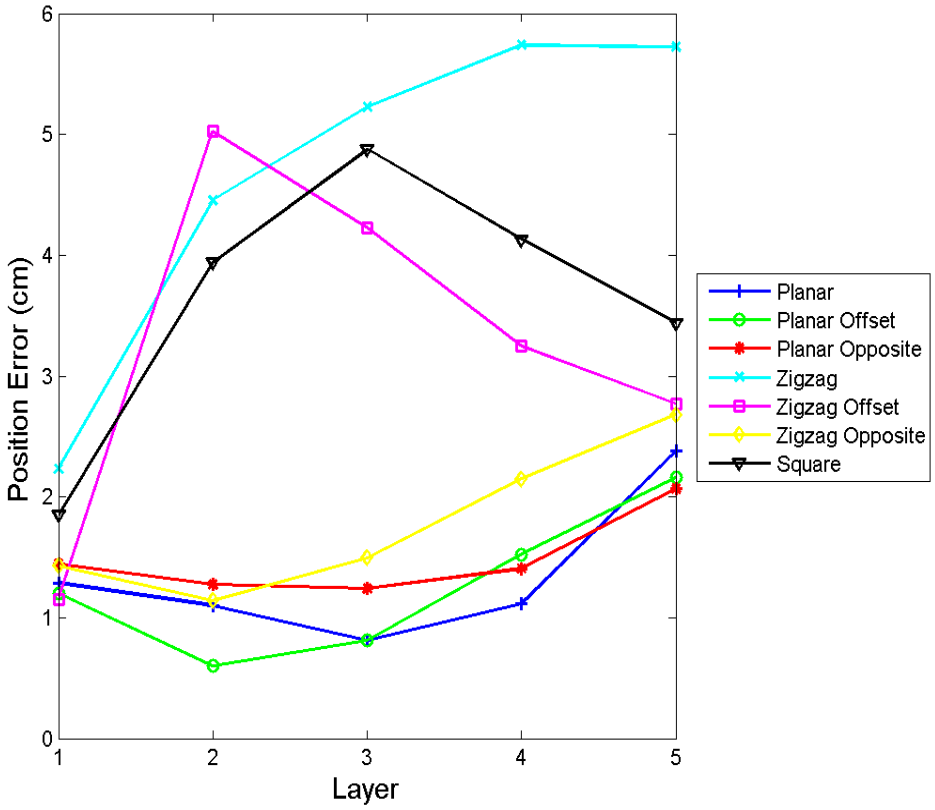
- Evaluate measurement pattern performance under noisy conditions
- Electrode placement error and contact impedance error
- Analyze using GREIT parameters and noise stability measure



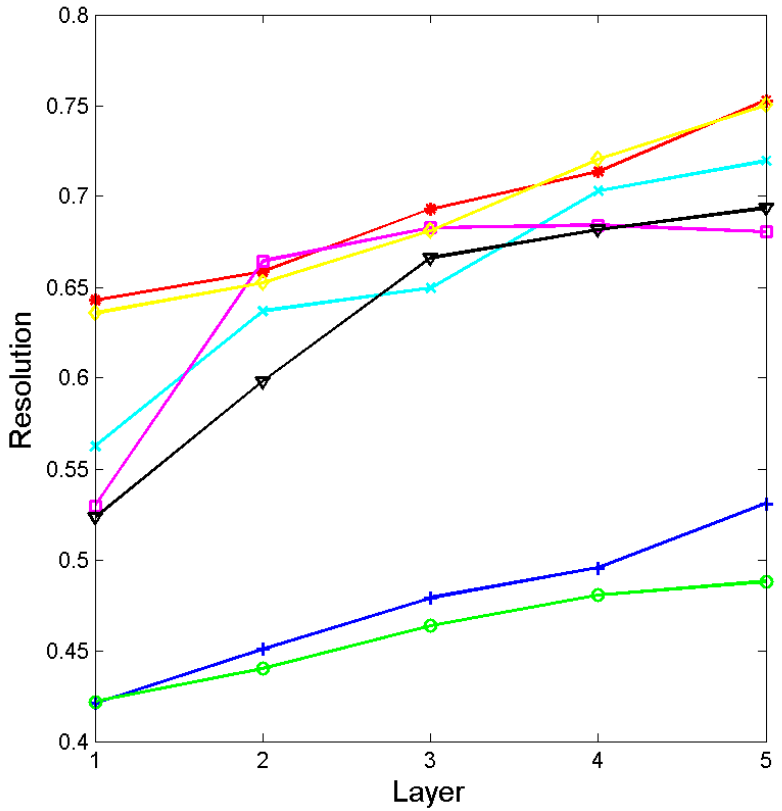
FEM mesh used for image reconstruction.

Results

Mean Position Error by layer for 8 degree Placement Error

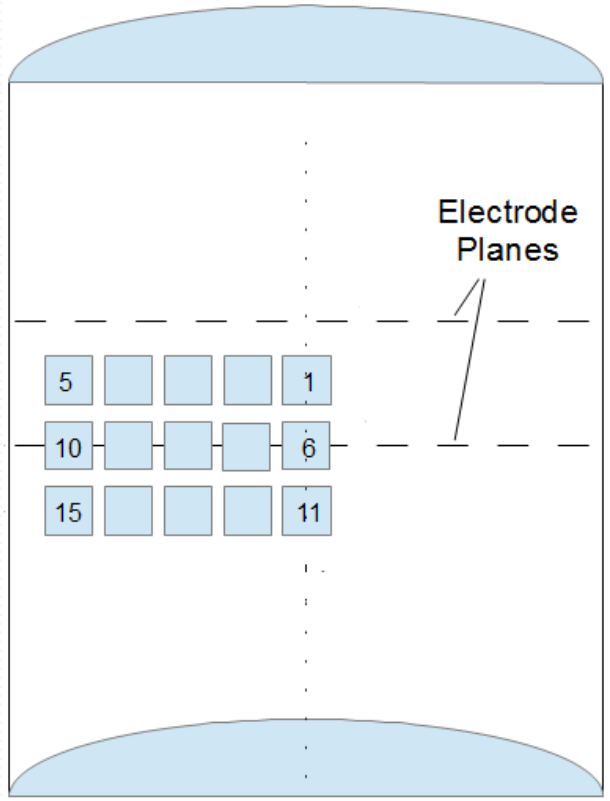


Mean Resolution by layer for 8 degree Placement Error

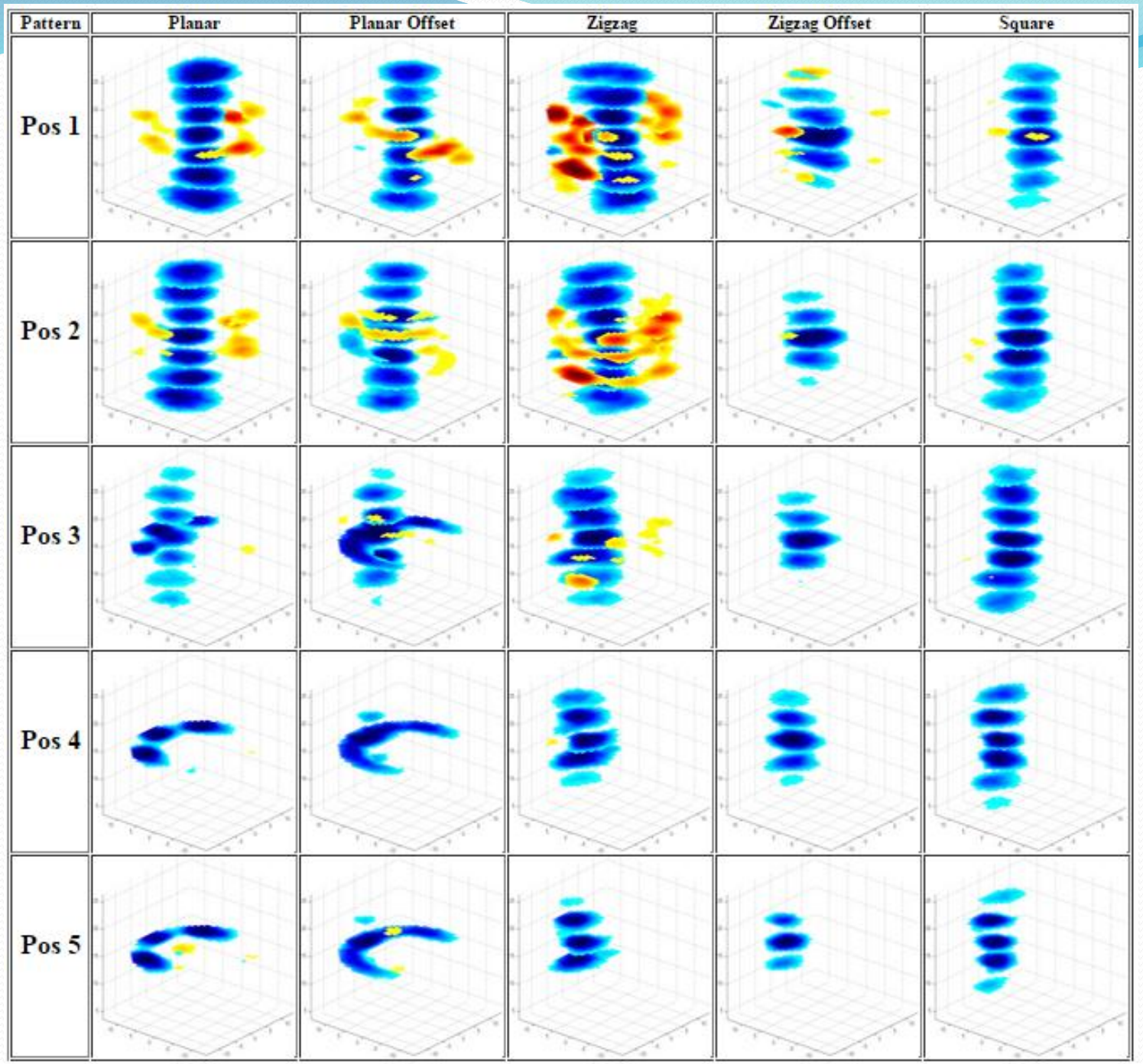


Tank Phantom Experiment

- Verify simulation results
- Evaluate measurement patterns using experimental data
- Select three best-suited measurement patterns for use in human measurements
- Analyzed using:
  - GREIT parameters
  - Z-Constraint: vertical object boundaries defined by quarter centred amplitude

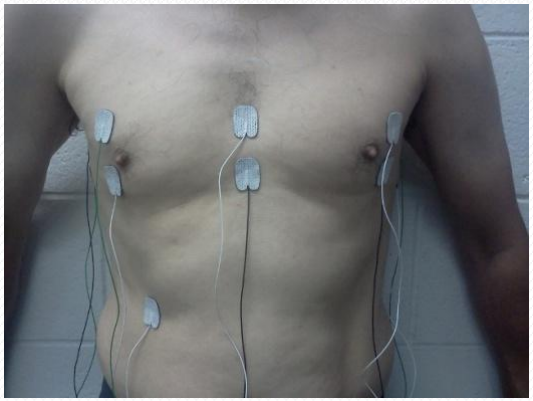


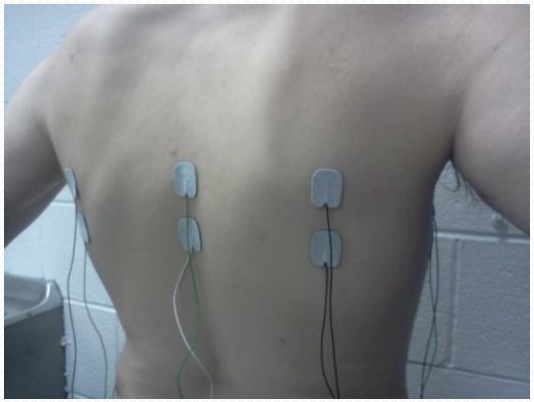
Layer 1 Block Images



Human Measurements

- Compare 3D EIT image amplitude to lung volume measurements from spirometer
- Observe vertical gravitational effects due to posture

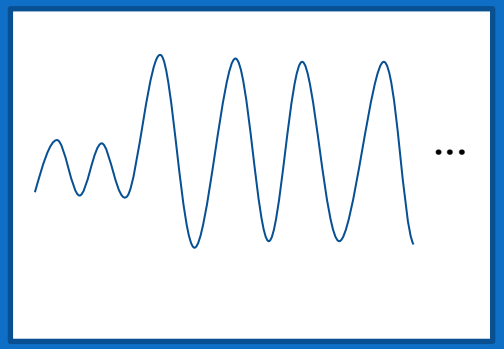




Volunteer with electrodes attached including ground reference.

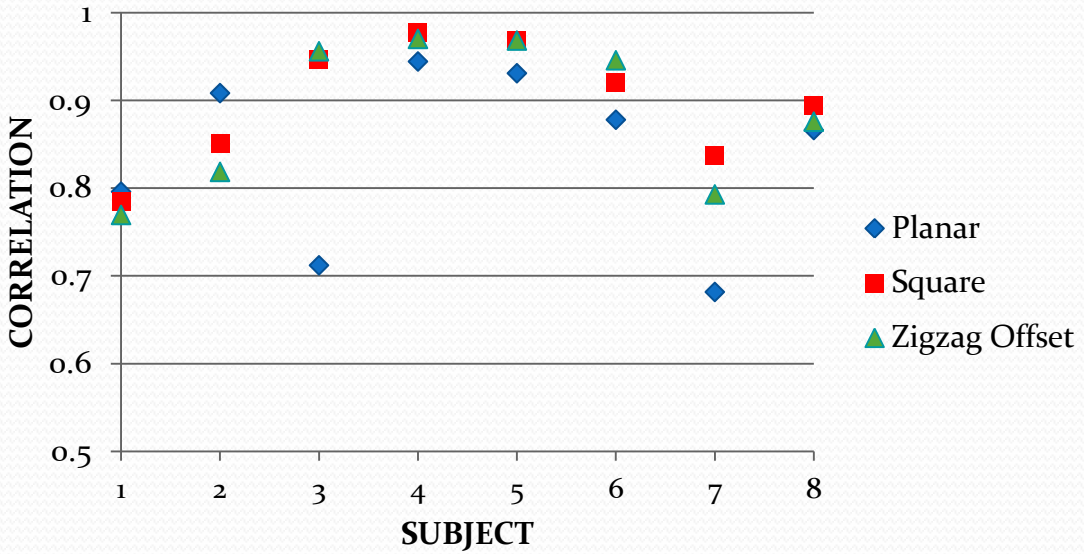
Experimental Protocol

- 8 healthy volunteers

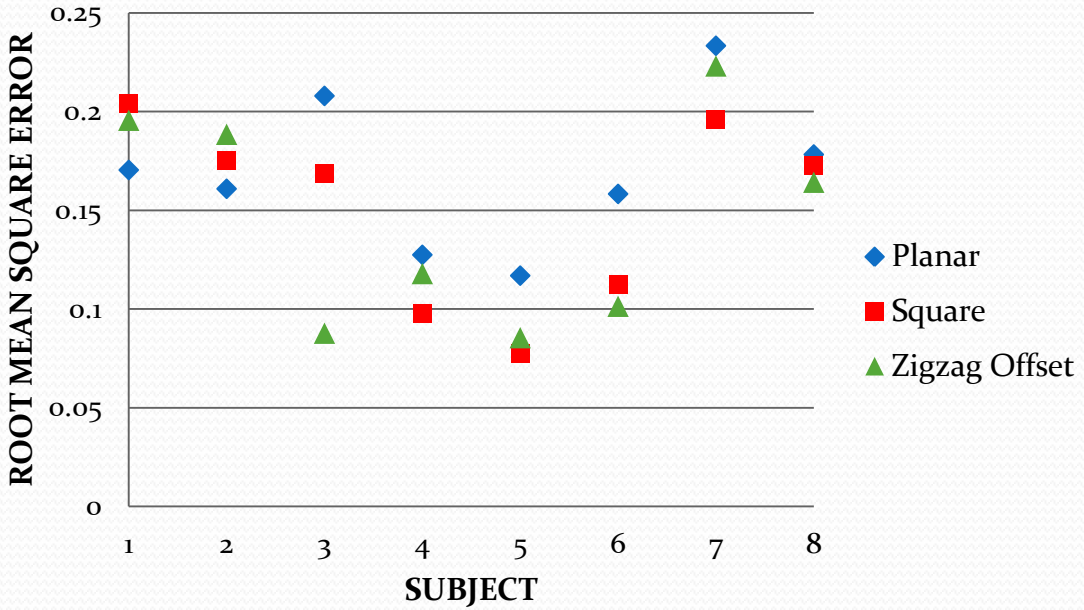
Postures	Breathing Protocol	Measurements
Standing ↑ Sitting ↱ Supine ← Decline ↙ Θ = 35⁰	 2 tidal breaths followed by vital capacity breathing for 60 seconds	3D Patterns: *-PLANAR* *-ZIGZAG OFFSET* *-SQUARE* Spirometry -change in airway pressure and lung volume

3D EIT vs. Spirometry

CORRELATION of 3D EIT AMPLITUDE SIGNAL vs. SPIROMETER LUNG VOLUME

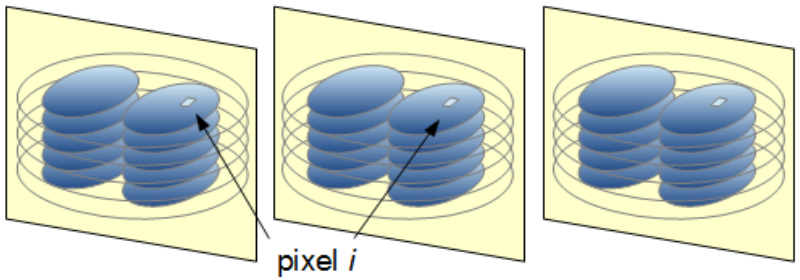


RMSE of 3D EIT AMPLITUDE SIGNAL vs. SPIROMETER LUNG VOLUME

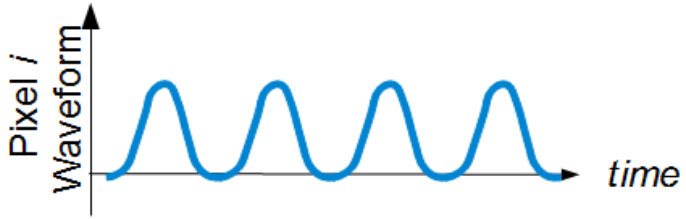


Vertical Analysis: Functional EIT Images

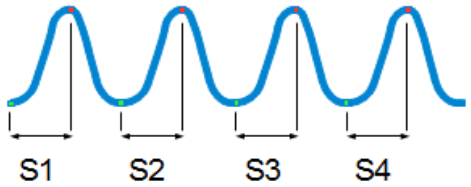
1. Reconstruct EIT Dataset using 3D GREIT Method



2. Time series vector for each pixel *i*

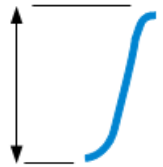


3. Segmentation by Inhalation



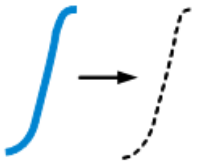
4. Feature Calculation

1. Amplitude Difference



f1 = ΔAmp

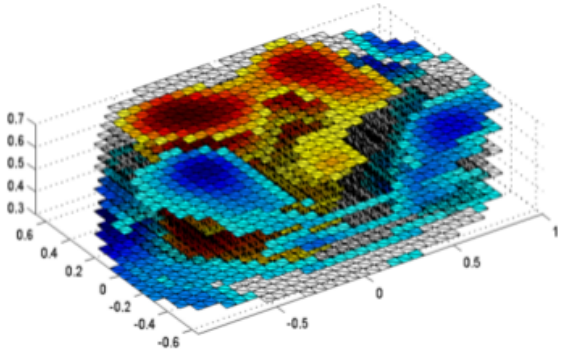
2. 3rd Order Polynomial Line Fit



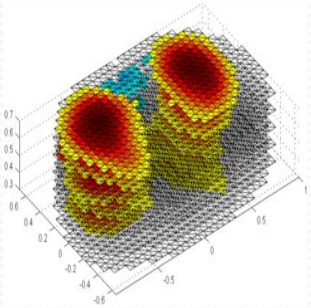
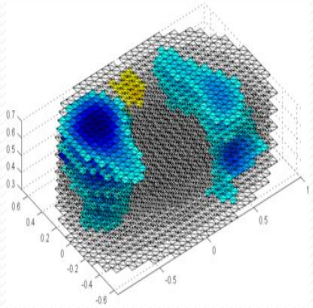
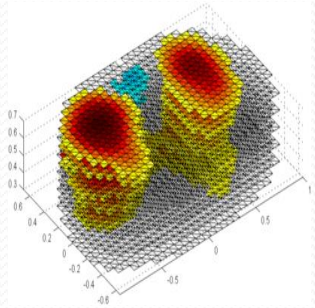
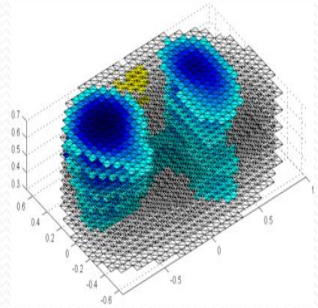
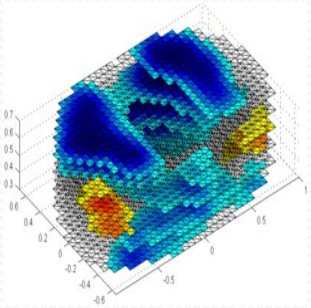
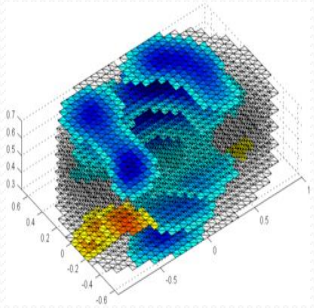
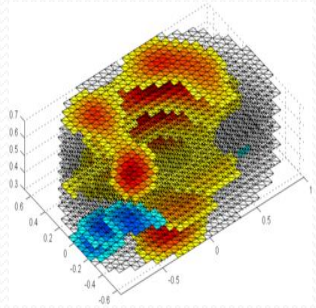
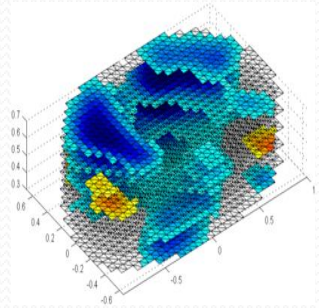
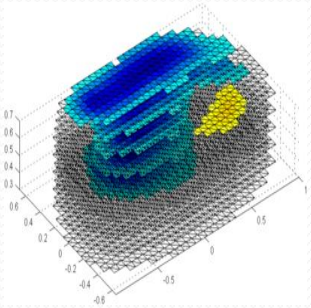
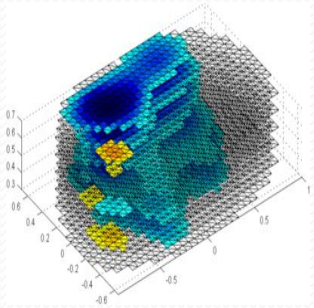
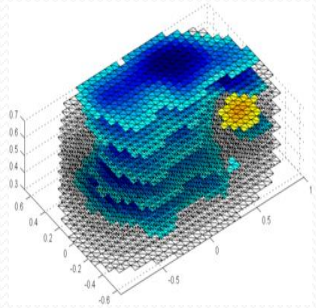
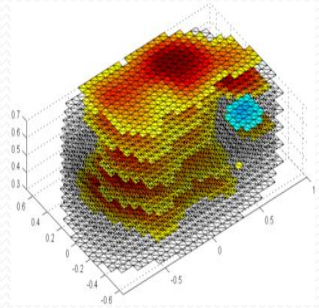
[f2 f3 f4] = polynomial coefficients [a0,a1,a2]

5. fEIT Images

An image is produced for each feature using the feature value of each pixel.

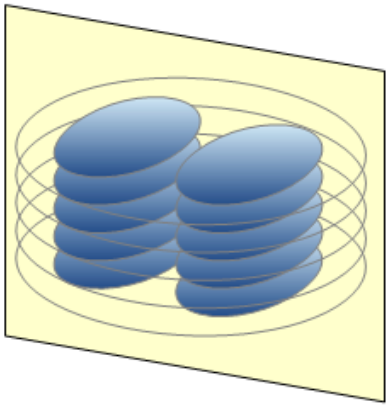


fEIT vs. Measurement Pattern

	f1	*f2*	*f3*	*f4*
Sample Planar Image Set (Standing)				
Sample Zigzag Offset Image Set (Standing)				
Sample Square Image Set (Standing)				

Vertical Analysis: %Activity

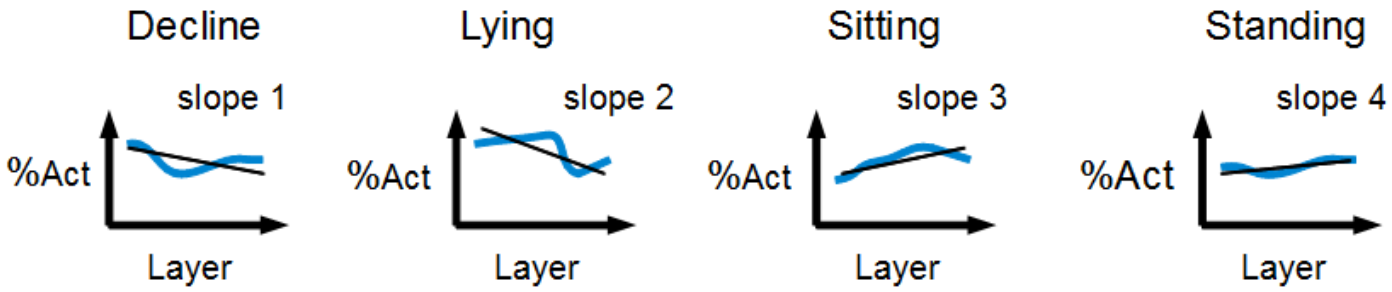
1. Calculate %Activity of each image layer



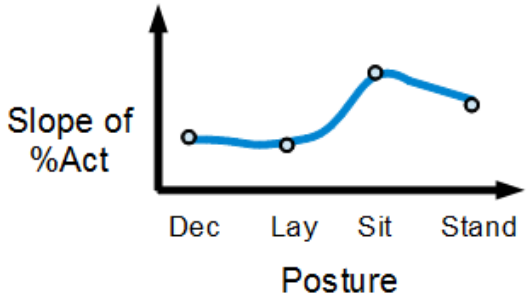
Layer 5 %Activity
Layer 4 %Activity
Layer 3 %Activity
Layer 2 %Activity
Layer 1 %Activity

$$\% \text{ Activity} = \frac{Nqmax_i}{\sum Nqmax}$$

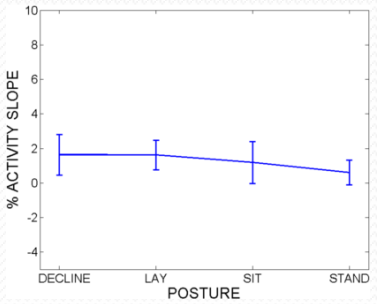
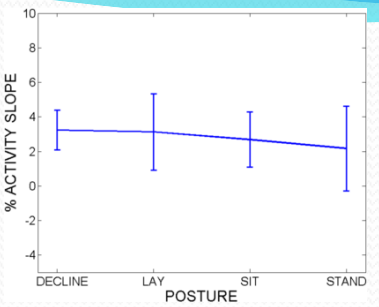
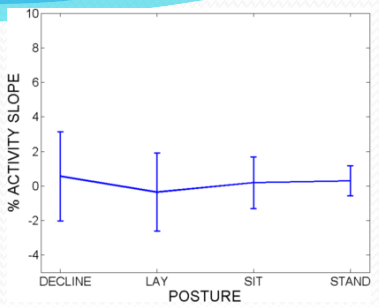
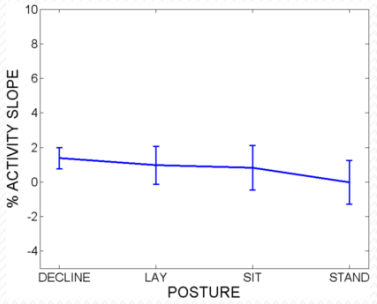
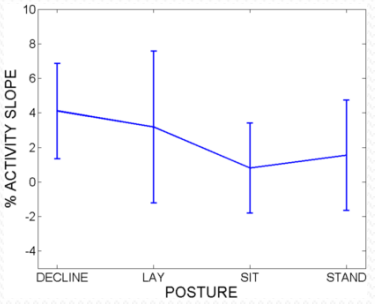
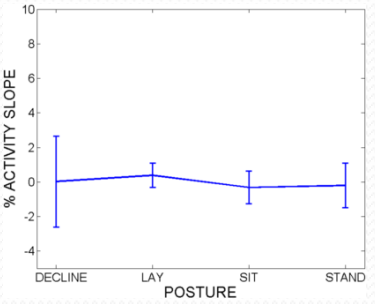
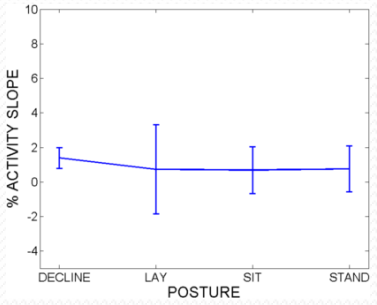
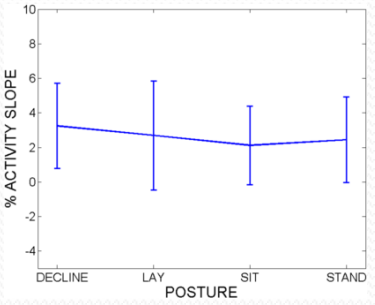
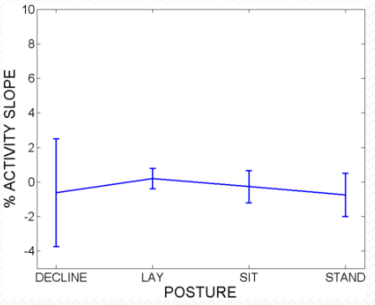
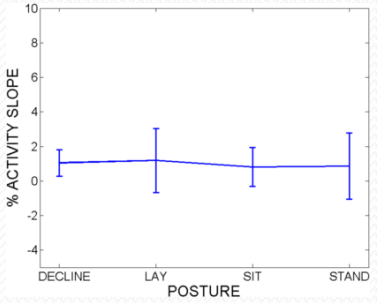
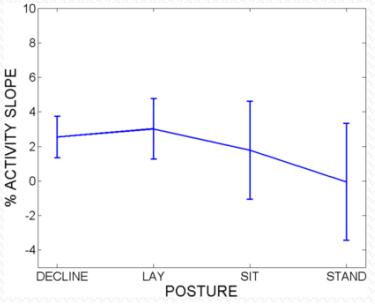
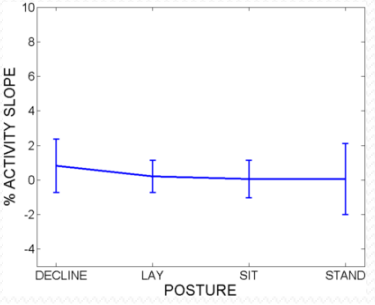
2. Calculate slope of %Activity vs. layer for each posture



3. Plot Slope vs. Posture



%Activity Slope vs. Posture

Feature	Planar	Zigzag Offset	Square
Amplitude Difference			
Coefficient 1			
Coefficient 2			
Coefficient 3			

Conclusions

- 3D EIT is shown to be a suitable measurement technique for global change in lung volume
- Results suggest a relationship between regional lung activity and posture but error is too high to be conclusive
- Planar pattern has the strongest resolution in the XY plane, but poor consistency
- Square pattern is most reliable with highest resistance to noise

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References

1. A. Adler, "Modeling EIT current flow in a human thorax model," EIDORS, 03 11 2010. [Online]. Available: http://eidors3d.sourceforge.net/tutorial/netgen/extrusion/thoraxmdl.shtml. [Accessed 11 04 2015].
2. B. Graham, A. Adler, "Electrode Placement Configurations for 3D EIT," *Physiol Meas,* vol. 28, no. 7, pp. S29-44, 2007.
3. J. Wagenaar, B. Grychtol and A. Adler, "An Approach to Extend GREIT Image Reconstruction to 3D," in *EIT2014*, Gananoque, 2014.
4. A. Adler et. al., "GREIT: a unified approach to 2D linear EIT reconstruction of lung images," *Physiol Meas,* vol. 30, no. 6, pp. S35-55, 2009.
5. I. Frerichs, et. al., "Gravity effects on regional lung ventilation determined by functional EIT during parabolic flights," *Journal of Applied Physiology,* vol. 91, no. 1, pp. 39-50, 2001.