Electrical Impedance Tomography

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Part 1.
Adaptive Current Tomography and Eigenvalues

With help from

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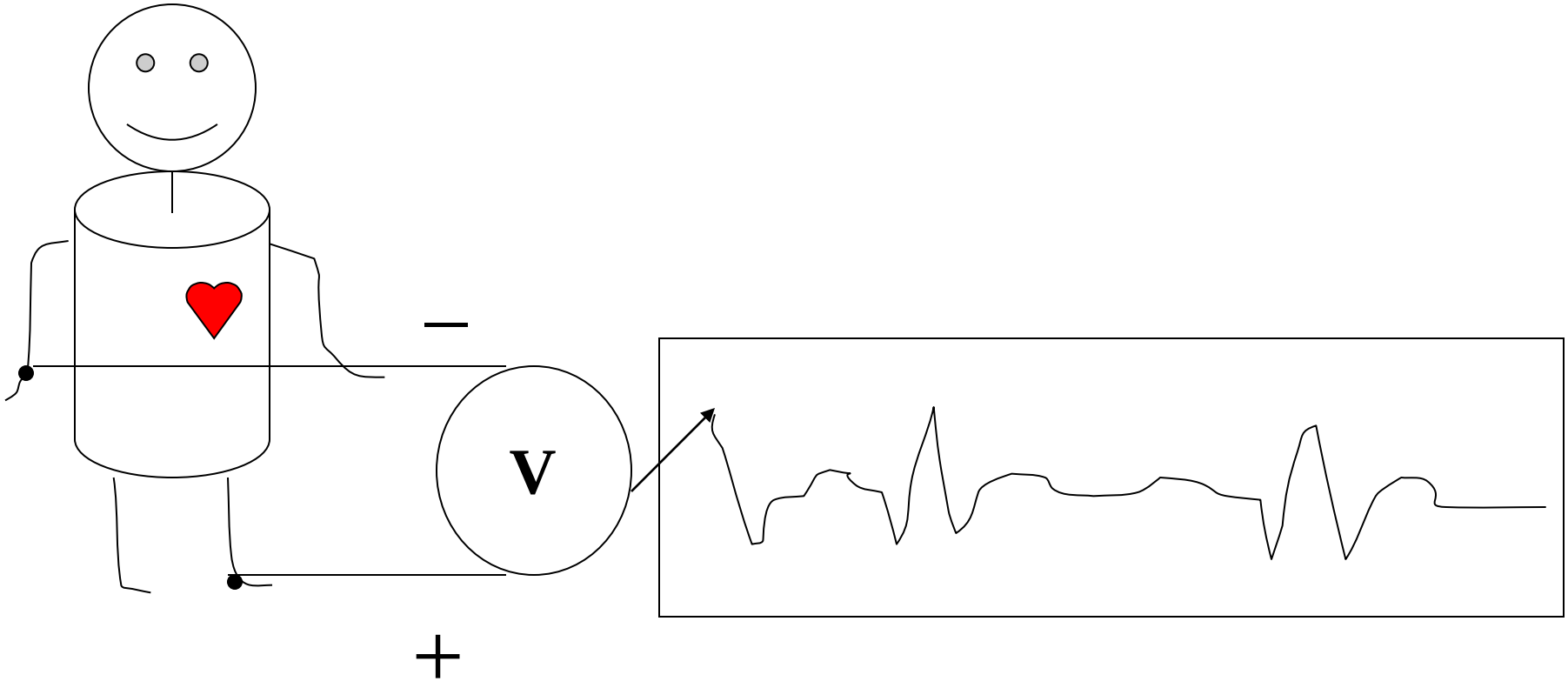
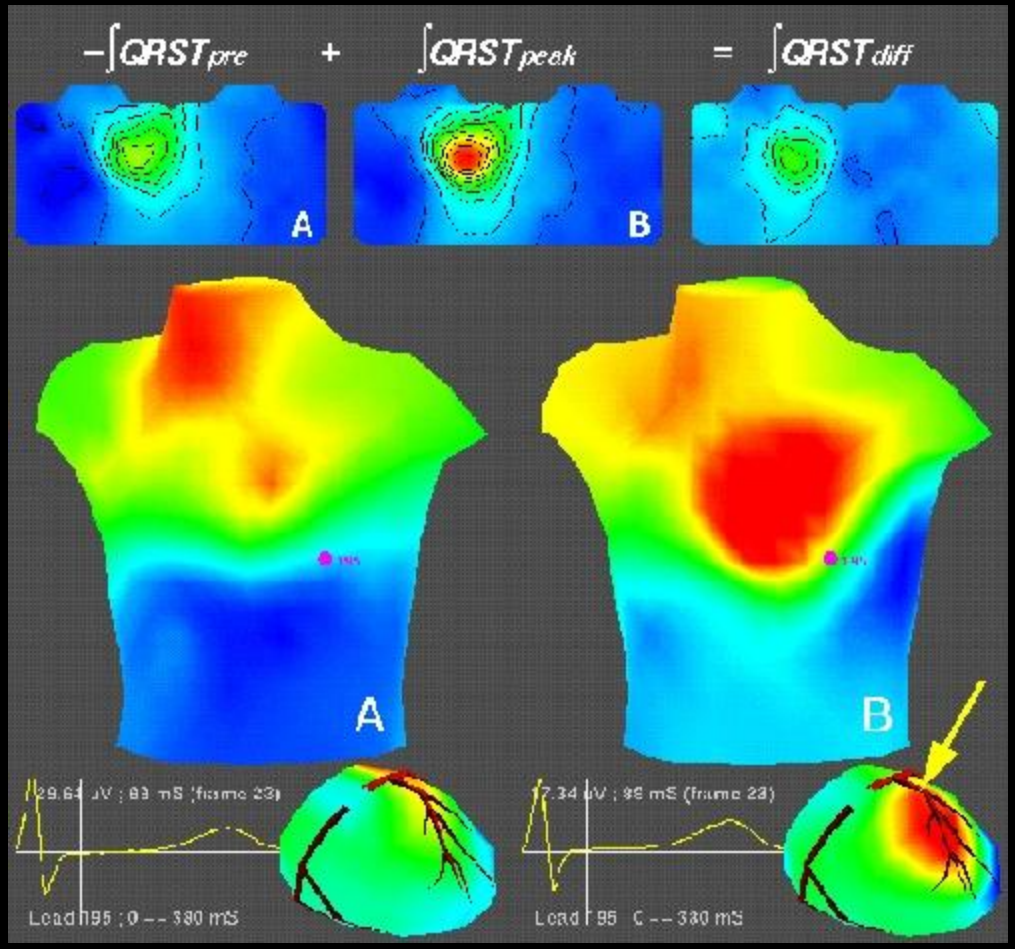
Main Problem!

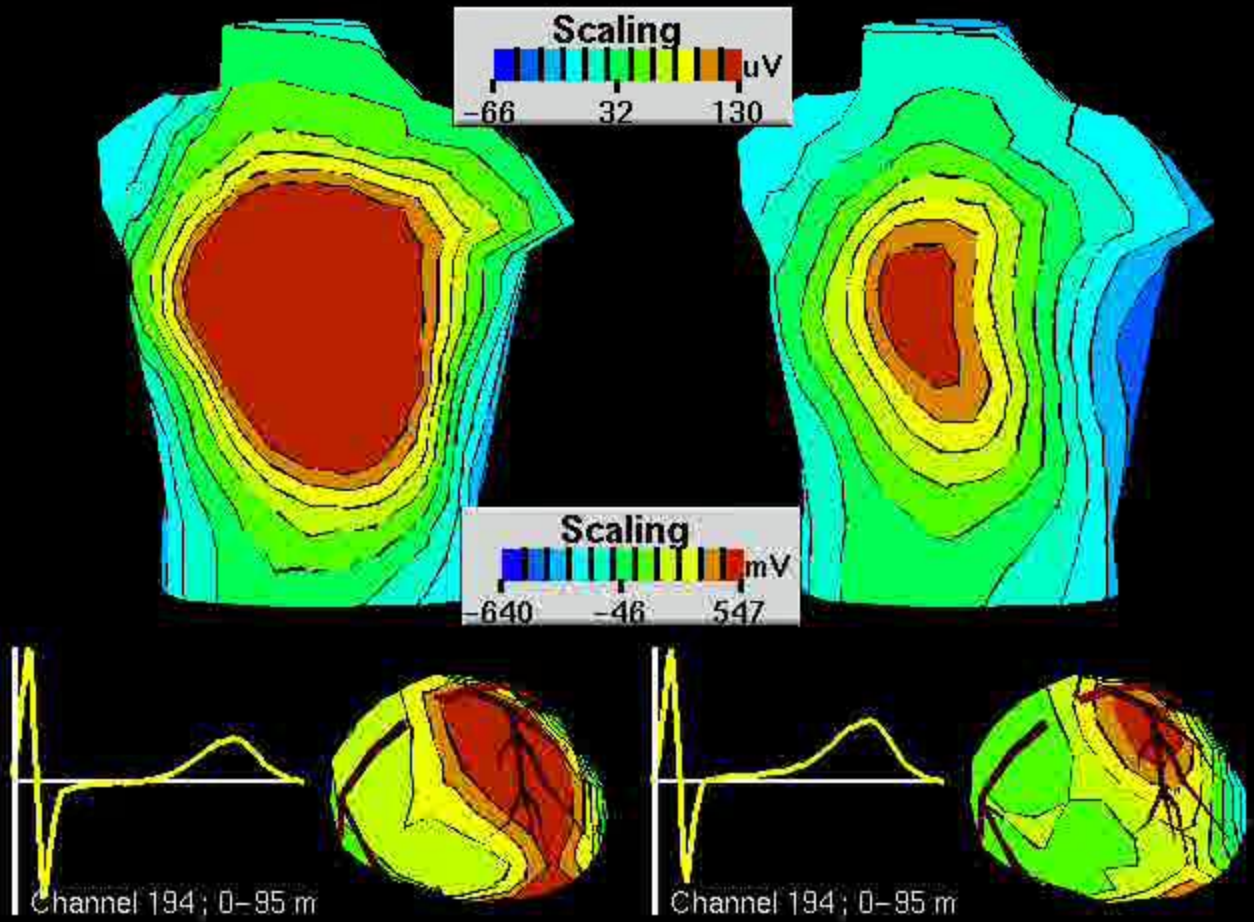
Can we improve the Diagnosis and Treatment of Disease, especially Heart Disease and Breast Cancer with Electromagnetic Fields?

Example of E&M for Diagnosis

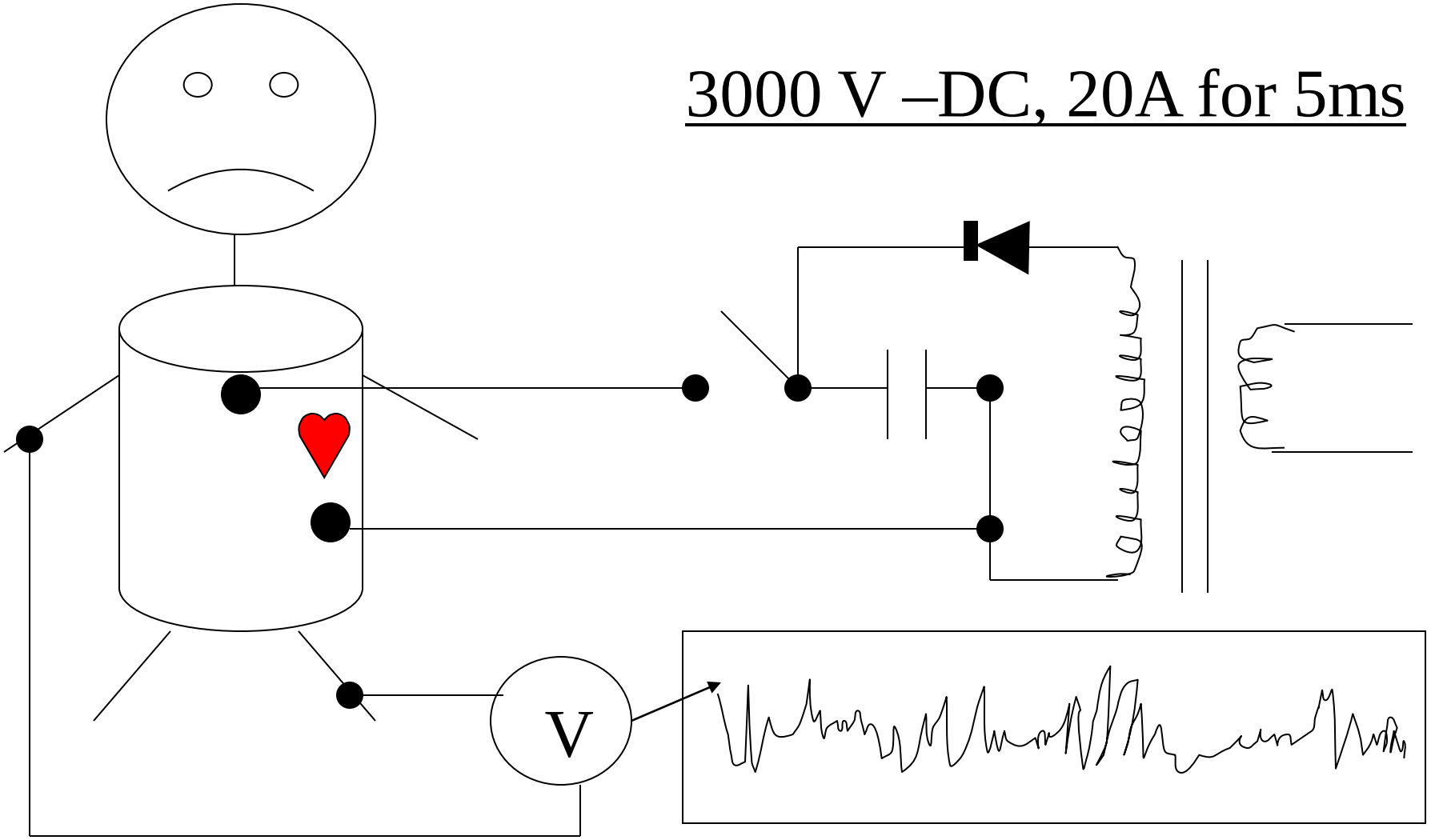
EKG




−∫QRST pre + ∫QRST peak = ∫QRST diff
A
B
A
B
29.64 µV ; 83 mS (frame 23)
Lead I 95 ; 0 -- 380 mS
7.34 µV ; 96 mS (frame 28)
Lead I 95 ; 0 -- 380 mS


Scaling
uV
-66
32
130
Scaling
mV
-640
-46
547
Channel 194 ; 0-95 m
Channel 194 ; 0-95 m

Example of E&M for Treatment- Defibrillation!



Impedance Imaging Problem;

How can one make clinically useful images of the electrical conductivity and permittivity inside a body from measurements on a body's surface?

Potential Applications

I. Continuous Real Time Monitoring of Function of:
   1. **Heart**
   2. **Lung**
   3. Brain
   4. Stomach
   5. Temperature

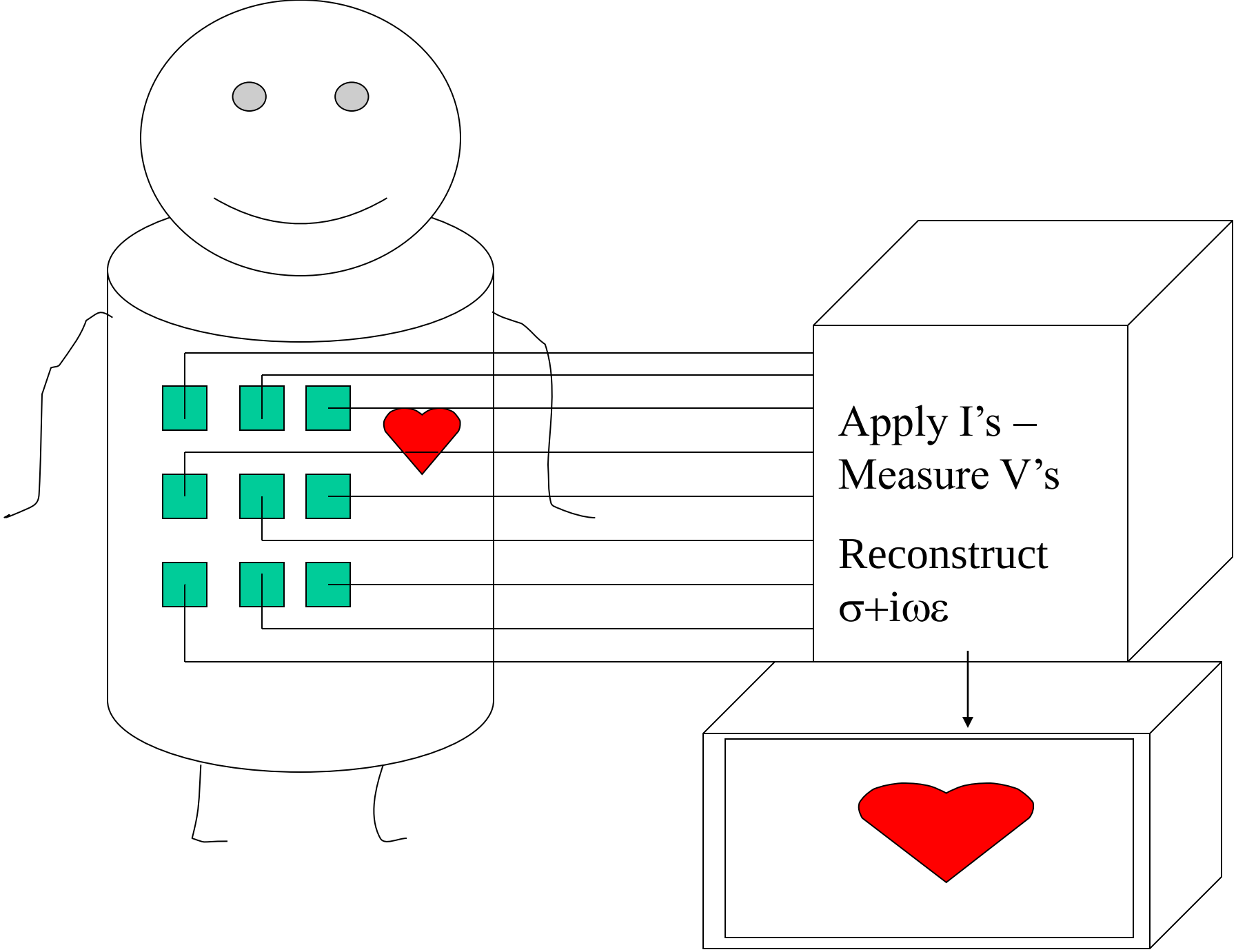
II. Screening:
   1. **Breast Cancer**
   2. Prostate Cancer

III. Electrophysiological Data for Inverse problems in:
   1. **EKG**
   2. EEG
   3. EMG

Reasons

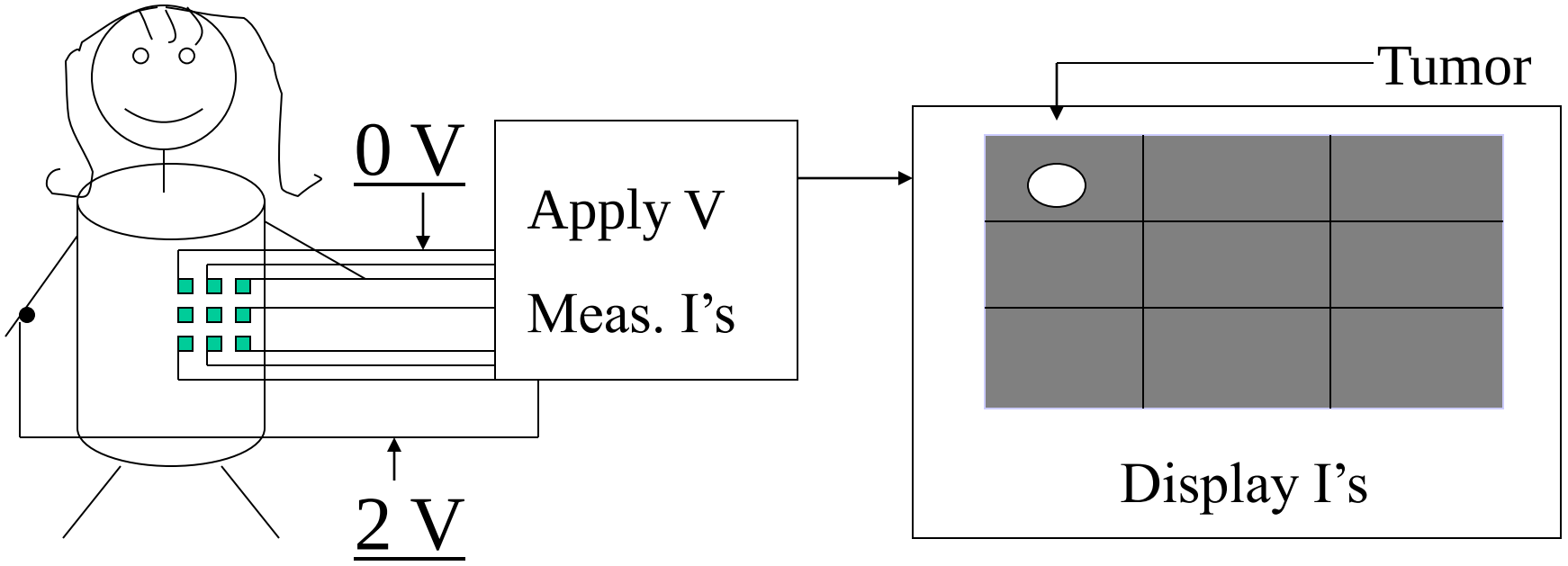
TISSUE	Conductivity S/M	Resistivity Ohm-Cm
Blood	.67	150
Cardiac Muscle	.2	500
Lung	.05	2000
Normal Breast	.03	3000
Breast Carcinoma	.2	500

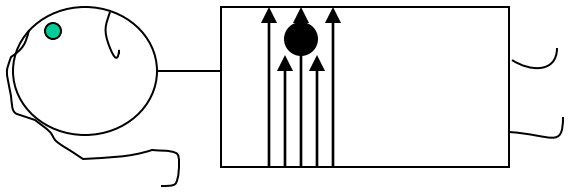
Procedure
For Imaging Heart and Lung Function in 3D
Electrical Impedance Tomography


Apply I's –
Measure V's
Reconstruct
σ+iωε

Procedure used by T-Scan for Electrical Impedance Mammography

T-Scan = Only Commercial System





V=0 volts

V=2 volts

Current I's in ma.

Is it useful?
Test by blinded Trials!

Sensitivity =

predicted to have cancer

Total # that have cancer

Specificity =

predicted NOT to have cancer

Total # that do NOT have cancer

X 100

Table 5: Results for Equivocal Mammograms (N=273)

	Mamm. alone	T-Scan Adjunctive	McNemar p-value (Mamm vs. djunctive)
Sensitivity (Biopsy pos.=50)	60%	82%	0.02
Specificity (Biopsy neg.=223)	41%	57%	0.0003

How can one increase the sensitivity and specificity?

Increase Resolution?

What determines “resolution”?

FIRST LIMIT IS THE NUMBER OF ELECTRODES

because

Degrees of freedom (voxels) reconstructed < L(L-1)/2

Where L=# of Electrodes

How to get Higher Resolution?

Let $L \rightarrow \infty$

Problem

Theorem

The ability to "distinguish" different conductivity distributions → 0 as L→∞ for fixed # of I gen's.

Solve the Problems:

1. Should we apply currents or voltages?
2. Can we distinguish σ from τ?
3. Which patterns of currents or voltages should we apply?
4. How many electrodes?
5. What size electrodes?
6. How can we reconstruct useful images?

How do we solve these problems?

Use **Mathematics**
and
Electromagnetic theory
to design system to reconstruct
and display conductivity inside
the body in 3D

What are the Equations?

Maxwell's

$$\nabla \wedge H = J + \partial D / \partial t$$

$$\nabla \wedge E = -\partial B / \partial t$$

$$\nabla \bullet D = \rho$$

$$\nabla \bullet B = 0$$

Assume

$$E(x,t) = E(x)e^{i\omega t}, H(x,t) = H(x)e^{i\omega t}$$

$$D(x,t) = D(x)e^{i\omega t}, B(x,t) = B(x)e^{i\omega t}$$

$$J(x,t) = J(x)e^{i\omega t}$$

Constitutive Relations

$$D = \varepsilon E$$

$$B = \mu H$$

$$J = \sigma E$$

Thus

$$\nabla \wedge H = (\sigma + i\omega\varepsilon)E$$

$$\nabla \wedge E = -i\omega\mu H$$

$$\Downarrow$$

$$\nabla \cdot \nabla \wedge H = \nabla \cdot (\sigma + i\omega\,\varepsilon) E = 0$$

$$\nabla \wedge E = -i\omega\,\mu\,H$$

Assume $\omega = 0$

$$\Downarrow$$

$$\nabla \cdot \sigma E = 0$$

$$\nabla \wedge E = 0$$

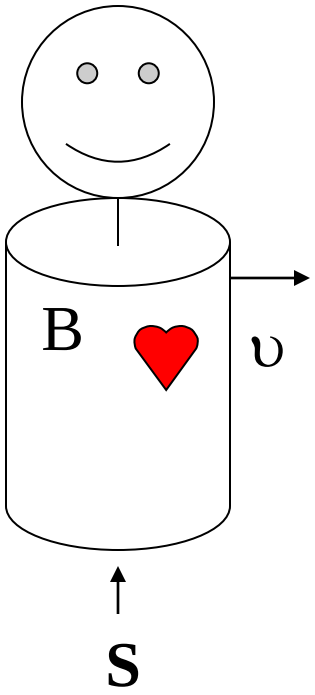
$$\nabla \wedge E = 0 \Rightarrow E = -\nabla U$$

Thus

$$\nabla \cdot \sigma \nabla U = 0$$

Main Equation

$$\nabla \cdot \sigma \nabla U = 0$$



$$\nabla \cdot \sigma \nabla U = 0 \quad \text{in B}$$

$$\sigma \partial U / \partial \nu = j \quad \text{on S}$$

Forward Problem:

Given conductivity σ and current density $\mathbf{j}$ find $v = U$ on S.

i.e.

Find the Neuman to Dirichlet map:

$$\mathbf{R(\sigma)j=v.}$$

Where

$$\mathbf{R(\sigma): H^{-1/2}(S) \rightarrow H^{+1/2}(S)}$$

Inverse Problem:
Given

R(σ)

Find

σ

Apply Currents or Voltages?

1. Apply currents measure voltages

since

$R(\sigma)$ is smoothing

but

$$\Lambda(\sigma) = R(\sigma)^{-1}$$

Is desmoothing!

$$\{\Lambda(\sigma) : H^{+1/2}(S) \rightarrow H^{-1/2}(S)\}$$

Properties of R

R has a complete orthonormal set of eigenfunctions in $L^2(S)$ and its eigenvalues are decreasing to 0.

See Board.

Can we distinguish different conductivities?

2.We can distinguish different conductivities when using infinite precision!

Calderon

Kohn and Vogelius

Sylvester and Uhlmann

Nachman

…

How to distinguish different conductivities when precision is finite?

3. Apply “the best” current patterns to distinguish conductivities;
These are eigenfunctions of N-D map.

Let

$$\langle f, g \rangle \equiv \int_S f(x) g(x) dS_x$$

$$\| f \|^2 = \langle f, f \rangle$$

The "distinguishability" of σ from τ by current density j is denoted by

$\delta(\sigma,\tau;j)$

Given by

$$\delta(\sigma,\tau;j) \equiv \left\| (R(\sigma) - R(\tau))j \right\| / \left\| j \right\|$$

We find the “best” Current density by finding the max over j of

$$\frac{\langle (R(\sigma)-R(\tau))j,\ (R(\sigma)-R(\tau))j\rangle}{\langle j,j\rangle}$$

From Rayleigh the max distinguishability is

$\delta(\sigma,\tau;\mathbf{j})$

where

$(R(\sigma)-R(\tau))\ \mathbf{j}=\rho\mathbf{j}$

ρ is the largest eigenvalue of the absolute value of

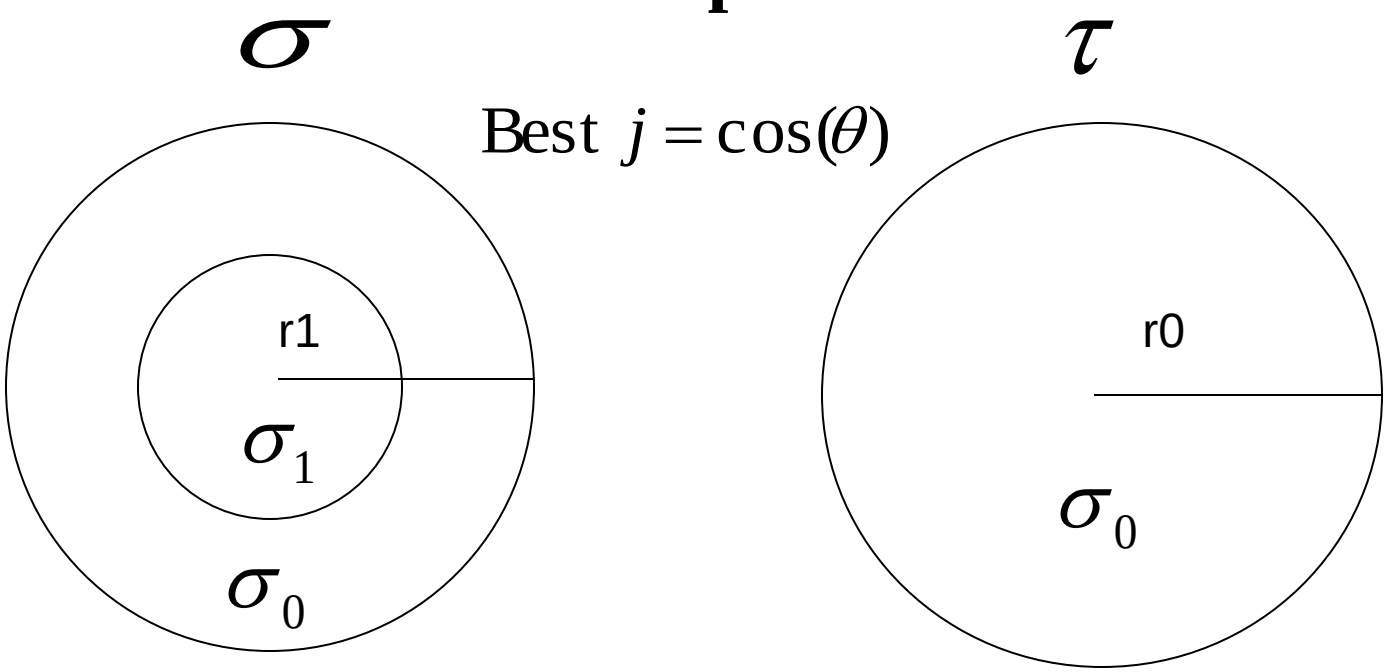
$R(\sigma)-R(\tau)$

Thus σ is distinguishable from τ by measurements of precision ε iff

$$\max \delta(\sigma,\tau;j)=\delta(\sigma,\tau;\mathbf{j})=\rho > \varepsilon$$

What is the size of the smallest inhomogeniety?

Example



$$\delta(\sigma, \tau; j) = (r0/\sigma_0)2\mu\Gamma^2/(1+\mu\Gamma^2).$$

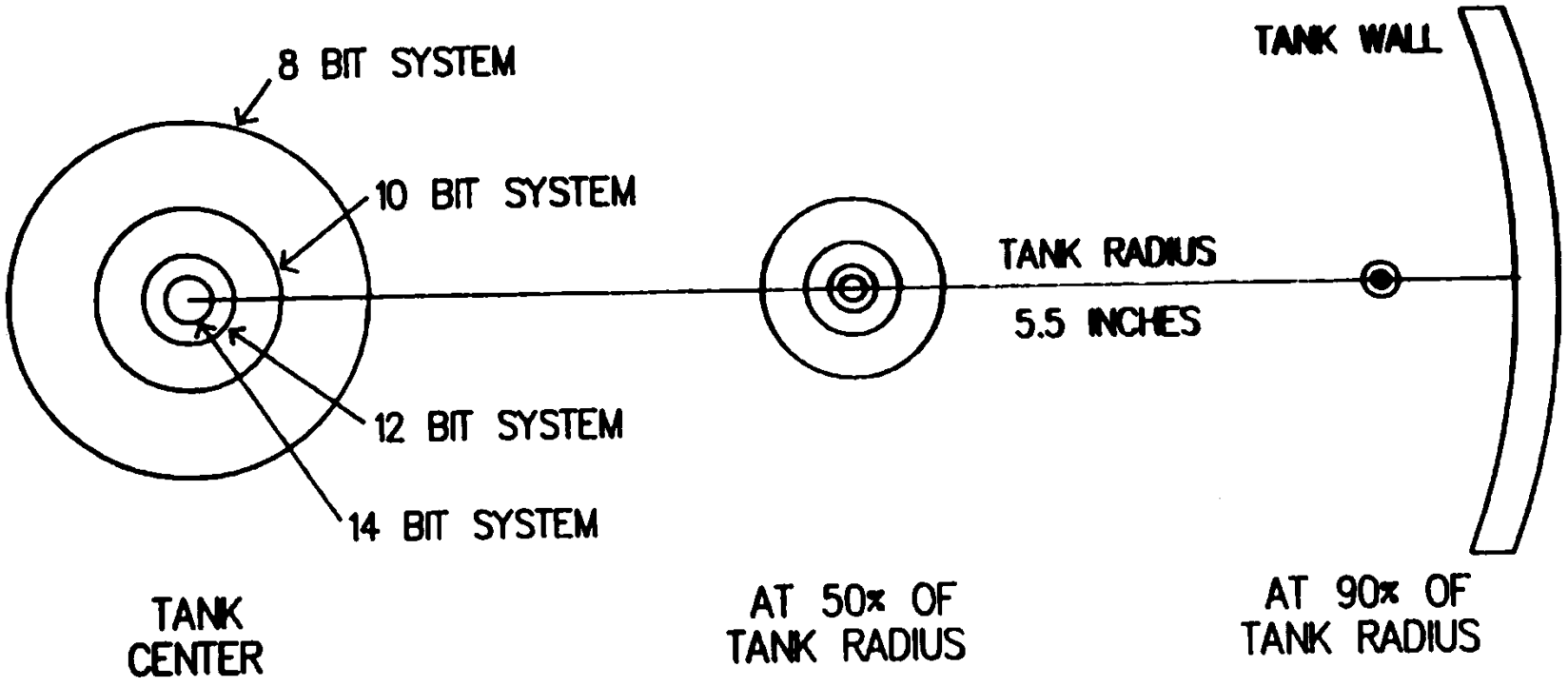
$$\Gamma \equiv r1/r0; \mu \equiv (\sigma_1 - \sigma_0)/(\sigma_1 - \sigma_0).$$

Distinguishable iff

$$\delta(\sigma, \tau; j) \geq \varepsilon. \Leftrightarrow \mu\Gamma^2 = O(\varepsilon).$$

ECCT

SMALLEST DETECTABLE DEFECT



How do we find “best”current patterns when we don’t know what is inside?

Secret Adaptive Process!

Adaptive method to find best current;

Guess - j_0

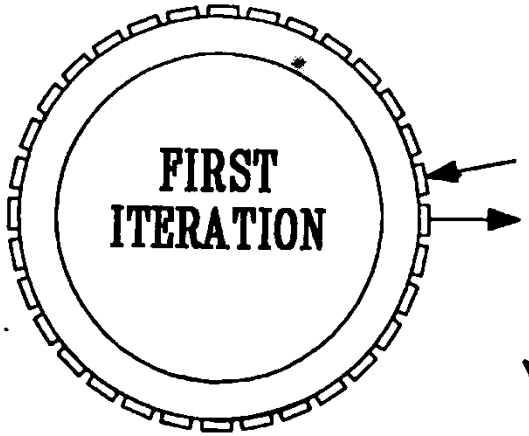
Measure (or compute) - $R(\sigma)j_0$, $R(\tau)j_0$

Let -

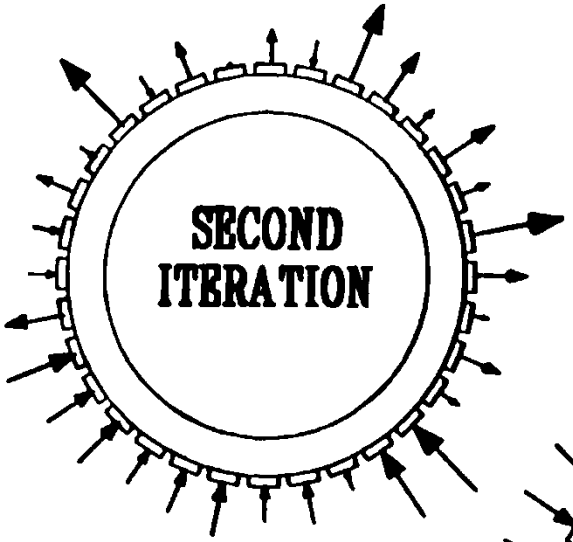
$$j_1 = (R(\sigma)j_0 - R(\tau)j_0) / \| R(\sigma)j_0 - R(\tau)j_0 \|$$

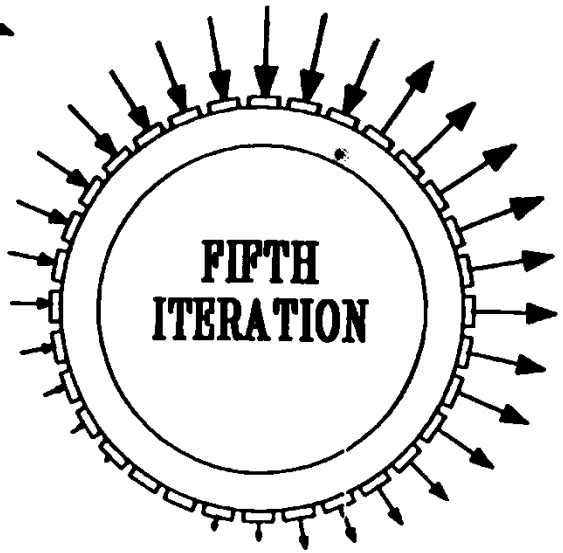
If $j_1 \neq j_0$ Let $j_0 \equiv j_1$ and try again!

BEST CURRENT ALGORITHM



DEVELOPED AT
RENSSELAER (RPI)
BY D. ISAACSON





BY THE FIFTH ITERATION,
THE SYSTEM HAS DETERMINED
THE "BEST" PATTERN OF CURRENT
FOR DETECTING THE UNKNOWN DEFECT!

How do we find ALL the Current patterns that are useful?

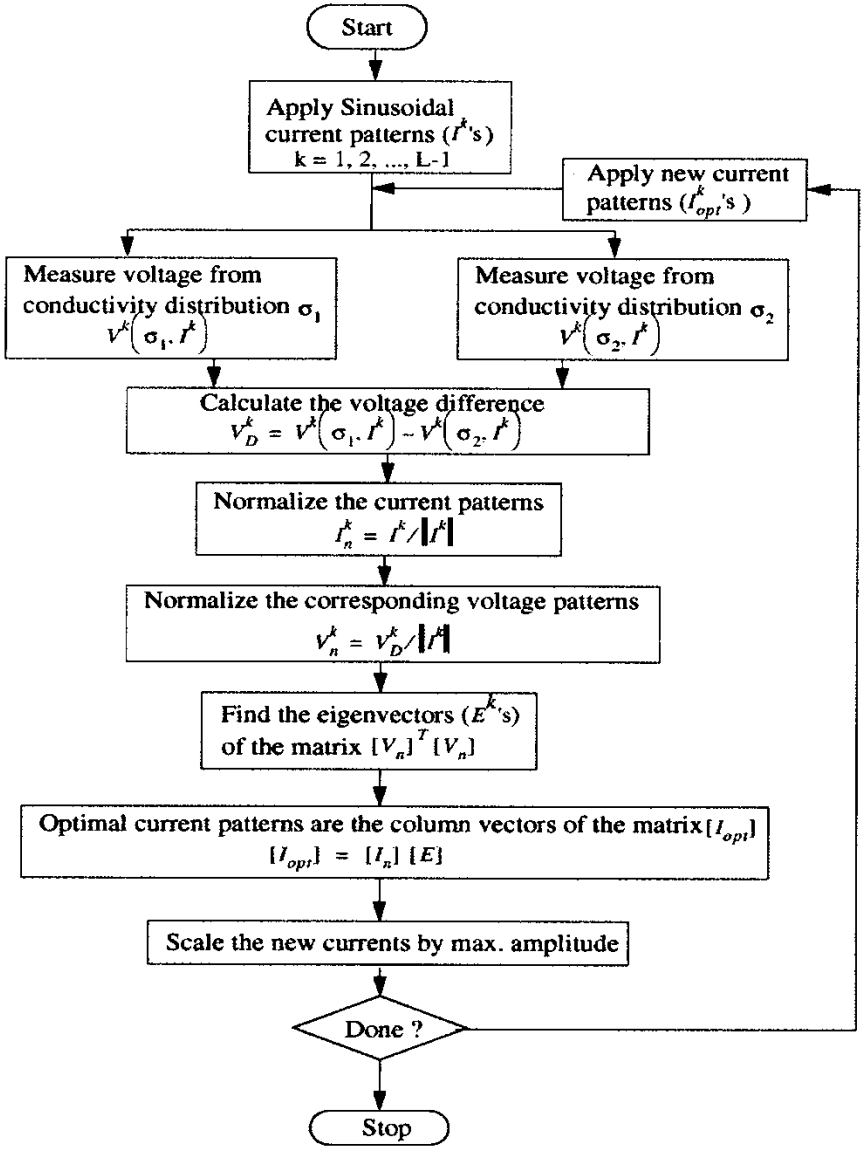


Figure 1. Flow chart for computing the optimal current patterns

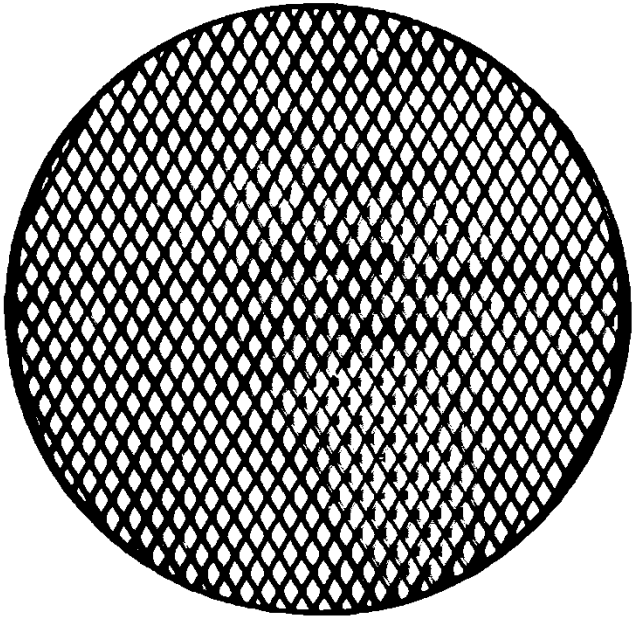
Does it Work?

Electric Current Computed Tomography

PHYSICAL METALLURGY LABORATORY
MATERIALS RESEARCH CENTER

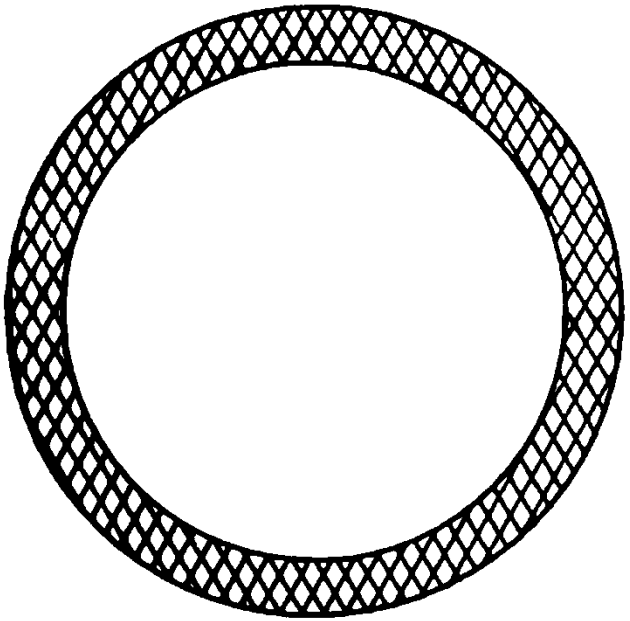
H.D. Solomon
M.R. Eggleston
R.J. Schwabe
L.F. Coffin
D. Isaacson

SOLID CYLINDER GEOMETRY



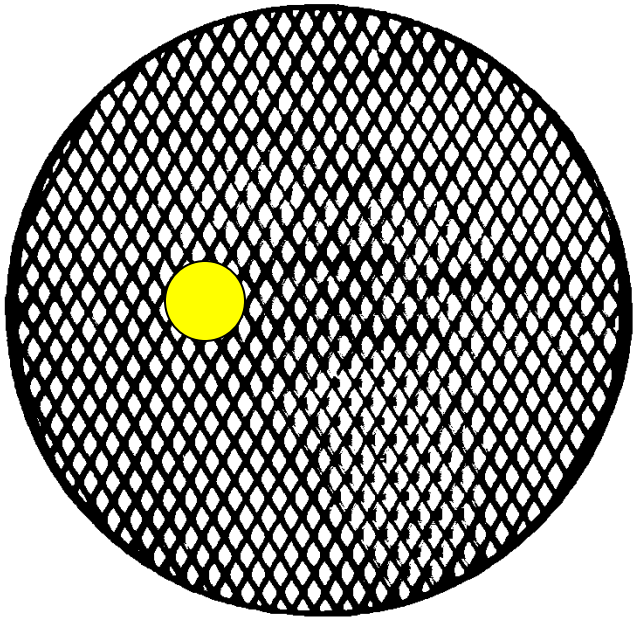
OUTER DIAMETER IS 5.5 INCHES

PIPE GEOMETRY



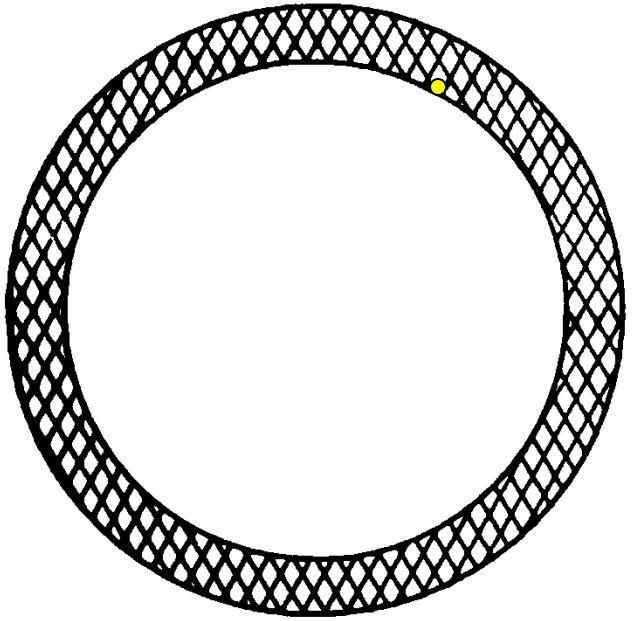
OUTER DIAMETER IS 5.5 INCHES
INNER DIAMETER IS 4.5 INCHES
WALL THICKNESS IS 0.5 INCHES

SOLID CYLINDER GEOMETRY

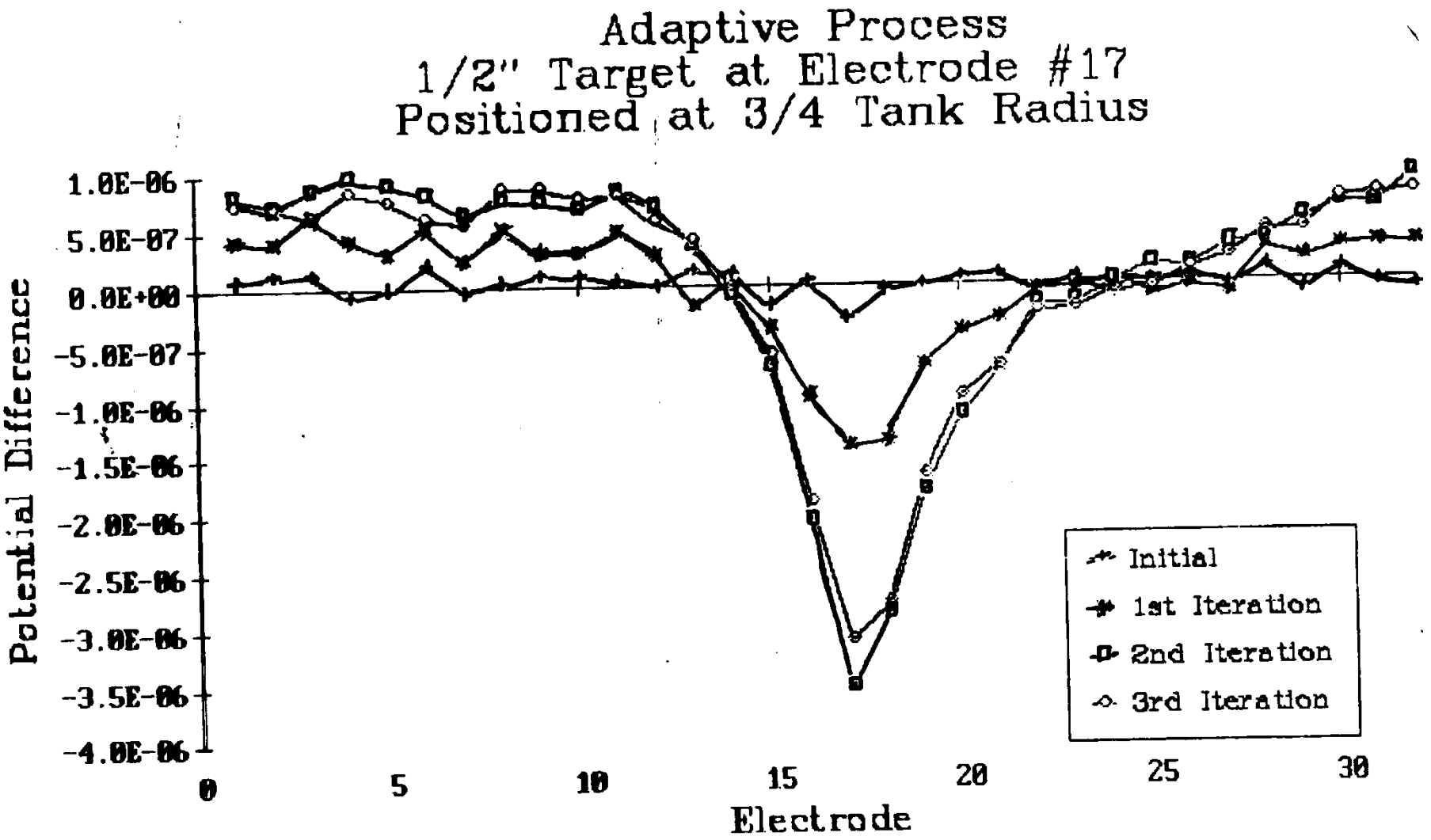


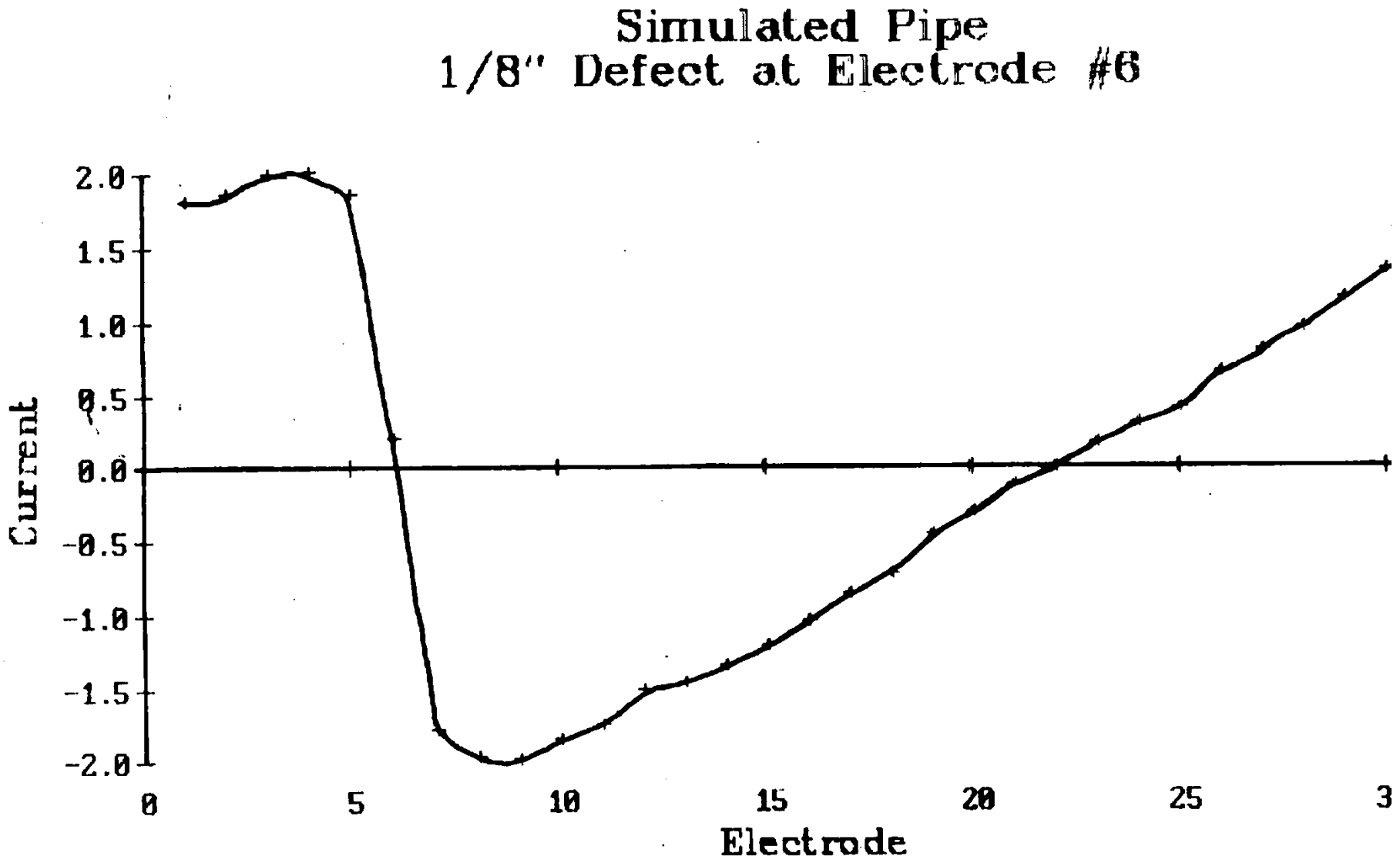
OUTER DIAMETER IS 5.5 INCHES

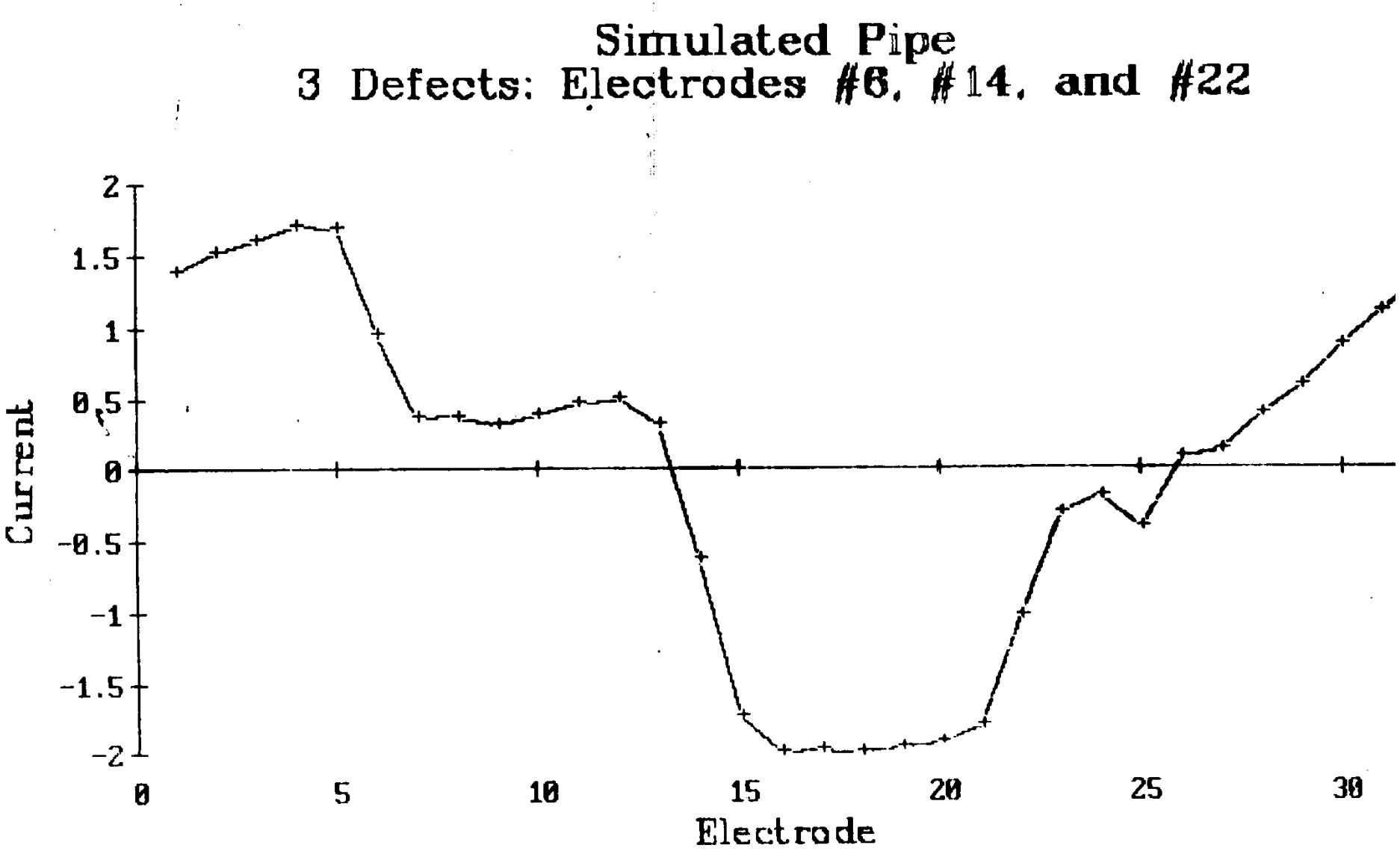
PIPE GEOMETRY

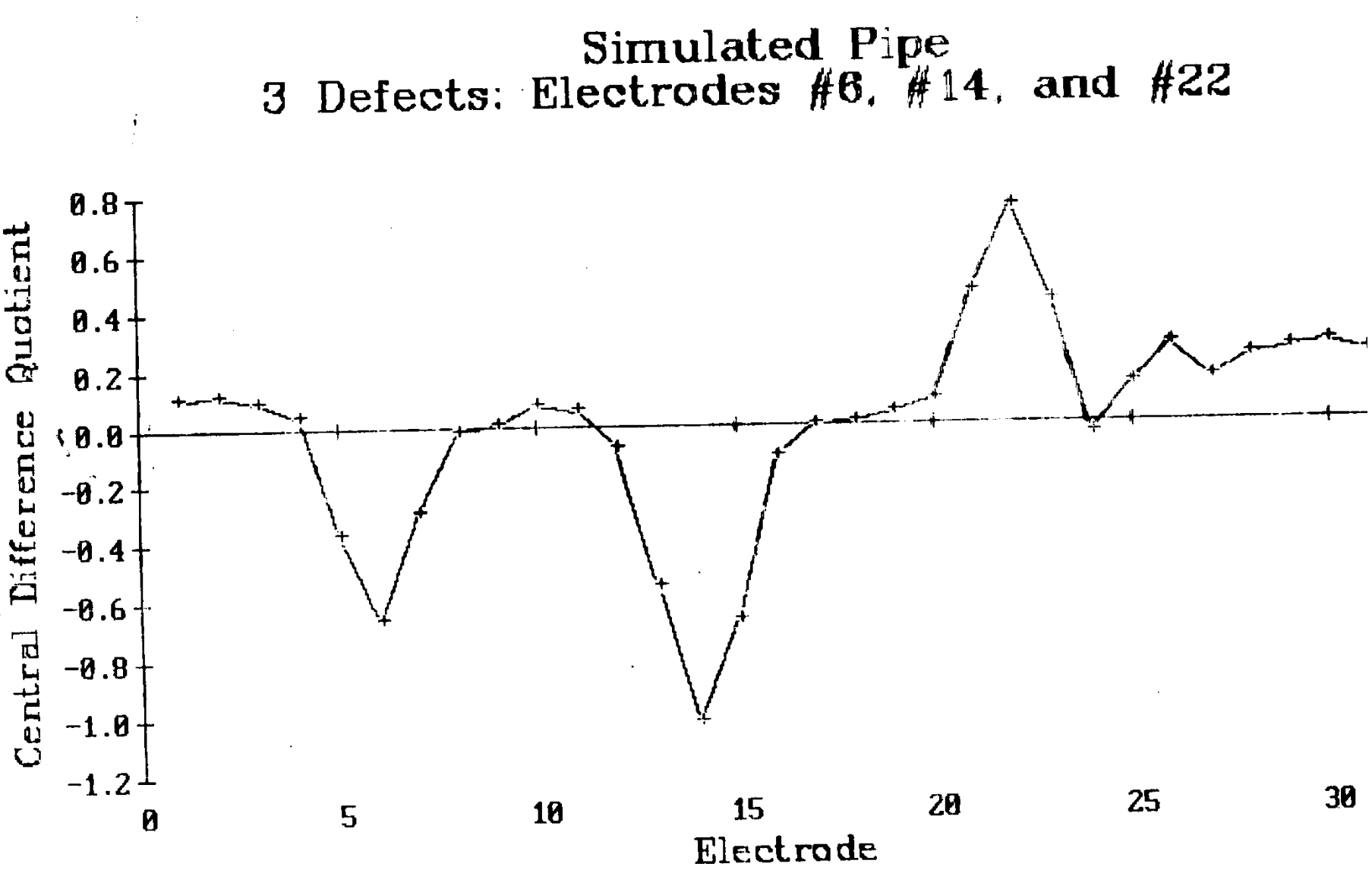


OUTER DIAMETER IS 5.5 INCHES
INNER DIAMETER IS 4.5 INCHES
WALL THICKNESS IS 0.5 INCHES


Adaptive Process
1/2" Target at Electrode #17
Positioned at 3/4 Tank Radius
Potential Difference
1.0E-06
5.0E-07
0.0E+00
-5.0E-07
-1.0E-06
-1.5E-06
-2.0E-06
-2.5E-06
-3.0E-06
-3.5E-06
-4.0E-06
0
5
10
15
20
25
30
Electrode
Initial
1st Iteration
2nd Iteration
3rd Iteration

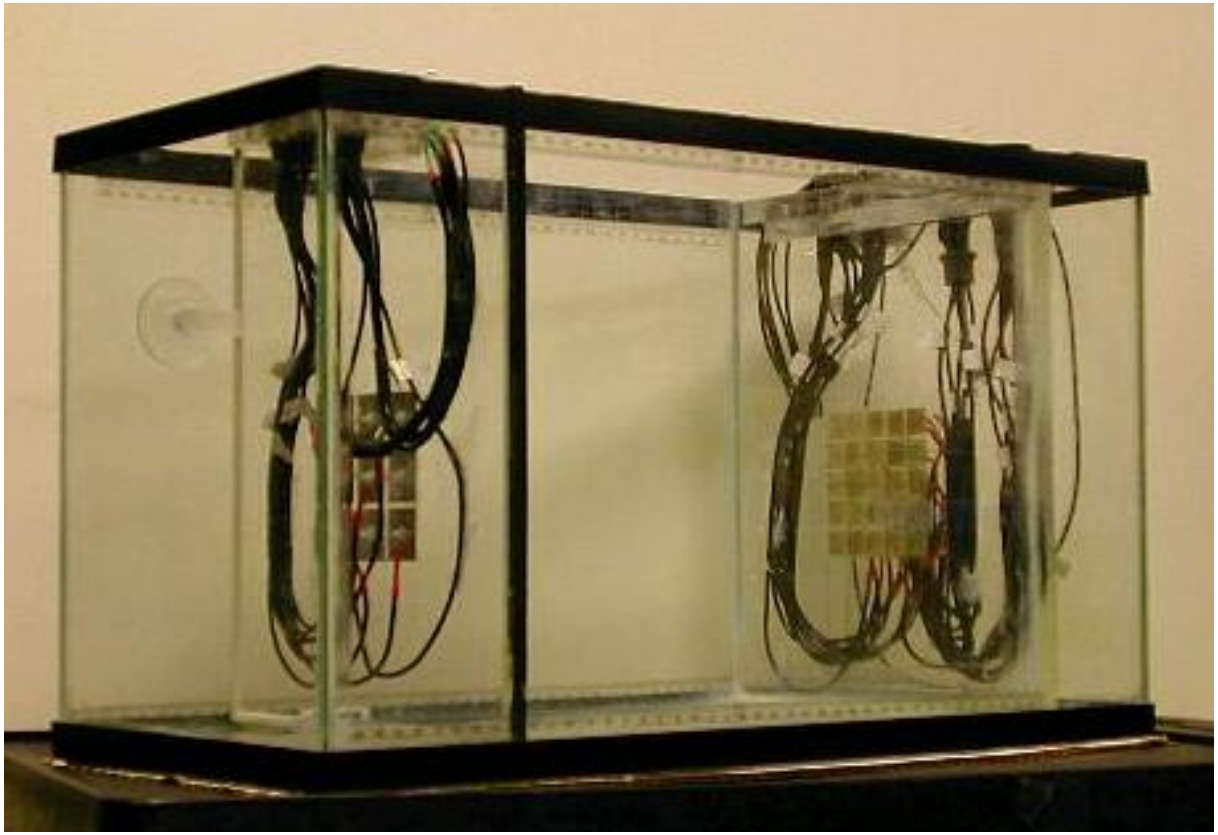

Simulated Pipe
1/8" Defect at Electrode #6
Current
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
5
10
15
20
25
3
Electrode


Simulated Pipe
3 Defects: Electrodes #6, #14, and #22
Current
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
Electrode


Simulated Pipe
3 Defects: Electrodes #6, #14, and #22
Central Difference Quotient
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
0
5
10
15
20
25
30
Electrode

Can optimal currents improve sensitivity and specificity in screening for breast cancer ?

5x5 Electrode Array Tank



Distinguishability Study Results

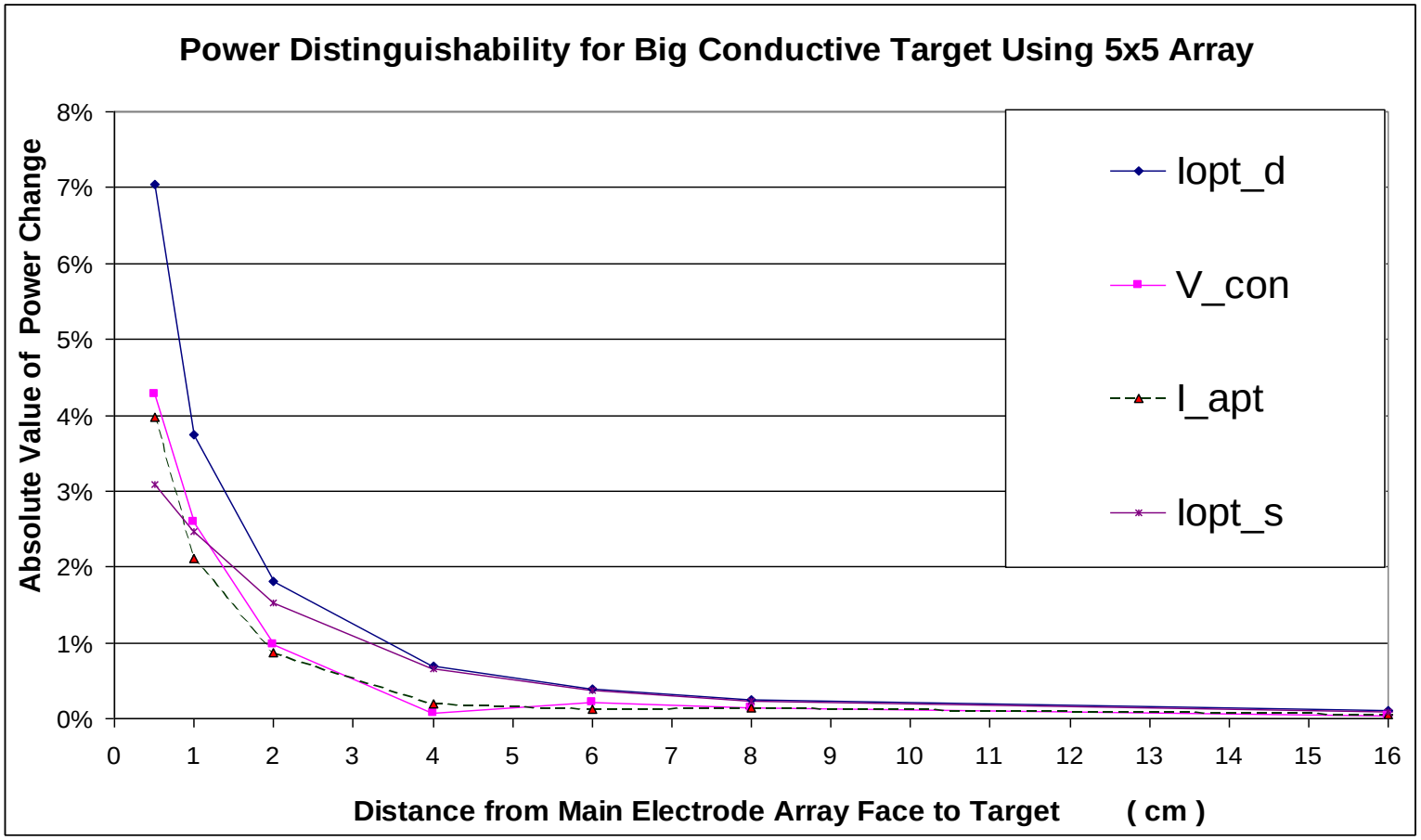
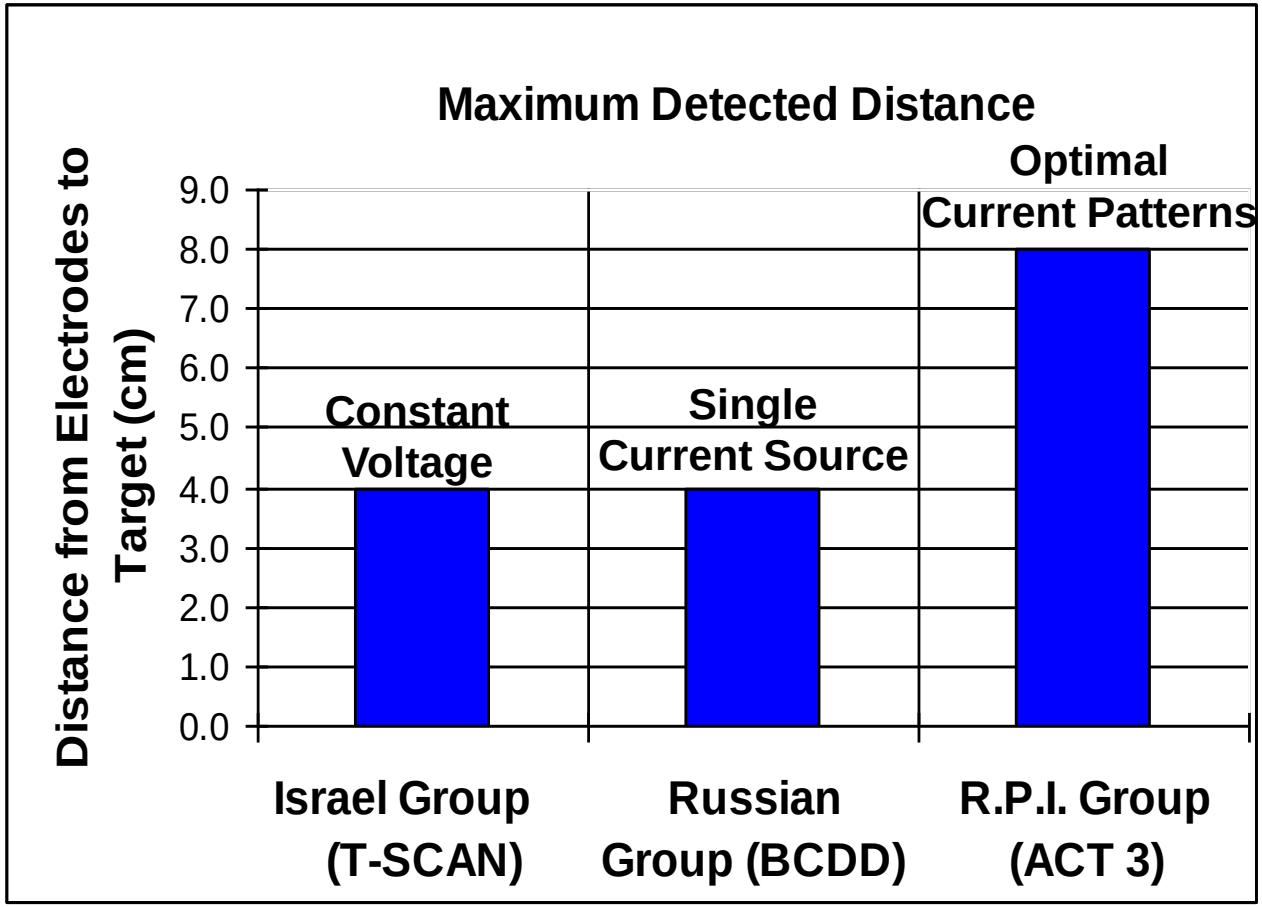


Figure 3. Optimal Current Pattern Iopt_d has better power distinguishability at all distances. For this experiment, the experimental noise level of the magnitude of the power change is 0.02%, above which targets may be distinguishable.

The depth below mammography electrodes at which an inhomogeneity can be detected by .4% accuracy



Electrode Array 5x5, Array Size: 8cm Square, Electrode Size: 14.8mm Square
Target Size: 24 mm Cube

From Poster by Tzu-Jen Kao

How many electrodes to use?

$$L \equiv \text{Number of electrodes}$$

$$\varepsilon \equiv \text{Measurement precision}$$

Then

$$L = O(\varepsilon^{-1/2}) \text{ in } 2D,\ O(\varepsilon^{-1/3}) \text{ in } 3D.$$

How many current sources to use?

As many as we have electrodes.

See Proof that as L $\rightarrow\infty$ distinguishability $\rightarrow$0 for a fixed number of current sources.

What size should we make the electrodes?

Space filling!

4. How can we reconstruct useful images?

1. Linearization (Noser 2-D ,Toddler 3-D);

   Fast, useful, not accurate for large contrast conductivities.

2. Optimization (Regularized Gauss-Newton);

   Slow, more accurate , iterative methods

3. Direct methods (Layer stripping, D-Bar);

   Solve full non-linear problem, no iteration!

End Part II

How do we make images?

Electrical Impedance Tomography

David Isaacson

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RPI

Part 2.
Electrical Impedance Imaging Algorithms.

Solve the Problems:

1. Should we apply currents or voltages?
2. Can we distinguish σ from τ?
3. Which patterns of currents or voltages should we apply?
4. How many electrodes?
5. What size electrodes?
6. How can we reconstruct useful images?

4. How can we reconstruct useful images?

1. Linearization (Noser 2-D ,Toddler 3-D);

   Fast, useful, not accurate for large contrast conductivities.

2. Optimization (Gauss Newton, Adaptive Kacmarcz);

   Slow, more accurate , iterative methods.

3. Direct methods (Layer stripping, CGO, dbar);

   Solve full non-linear problem, no iteration!

What can a linearization do?

Noser – a 2-D reconstruction

Toddler – a 3-D reconstruction

(both assume conductivity differs only a little from a constant.)

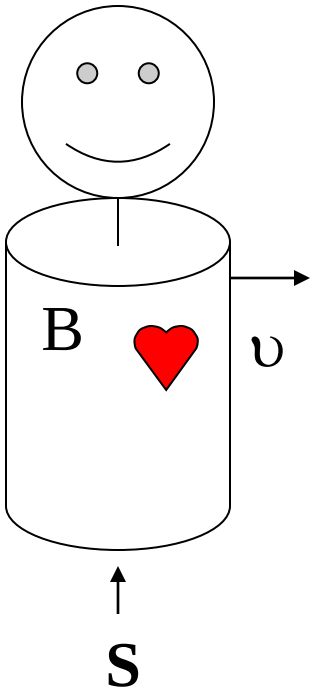
FNoser - Fast ,20 frames/sec

Real time imaging of Cardiac and Lung function shown in the following examples.

Linearizations
NOSER (S.Simske,…)
FNOSER(P.Edic,…)
TODDLER(R.Blue,…)

Main Equation

$$\nabla \cdot \sigma \nabla U = 0$$



$$\nabla \cdot \sigma \nabla U = 0 \quad \text{in B}$$

$$\sigma \partial U / \partial \nu = j \quad \text{on S}$$

Forward Problem:

Given conductivity σ and current density $\mathbf{j}$ find $v = U$ on S.

i.e.

Find the Neuman to Dirichlet map:

$$\mathbf{R(\sigma)j=v.}$$

Where

$$\mathbf{R(\sigma): H^{-1/2}(S) \rightarrow H^{+1/2}(S)}$$

Inverse Problem:
Given

R(σ)

Find

σ

$\nabla \cdot \sigma \nabla u^m = 0$	$\nabla \cdot \sigma_0 \nabla u_0^n = 0$
$\sigma \, \partial u^m / \partial \nu = j^m$	$\sigma_0 \, \partial u_0^n / \partial \nu = j_0^n$

$$u_0^n \nabla \cdot \sigma \nabla u^m = 0 \qquad u^m \nabla \cdot \sigma_0 \nabla u_0^n = 0$$

$$\int u_0^n \nabla \cdot \sigma \nabla u^m - u^m \nabla \cdot \sigma_0 \nabla u_0^n \, dx = 0$$

$$\Downarrow$$

$$\int_S u_0^n \sigma \partial_\nu u^m - u^m \sigma_0 \partial_\nu u_0^n \, dS = \int_B (\sigma - \sigma_0) \nabla u^m \cdot \nabla u_0^n \, dx$$

$$\int_S u_0^n \sigma \partial_\nu u^m - u^m \sigma_0 \partial_\nu u_0^n \, dS = \int_S u_0^n j^m - u^m j^n \, dS =$$

$$< j^m, (R(\sigma) - R(\sigma_0)) j^n > =$$

$$\text{Data(n,m)} =$$

$$\int_B (\sigma - \sigma_0) \nabla u^m \cdot \nabla u_0^n \, dx$$

$$\text{If } \delta\sigma \equiv \sigma - \sigma_0 << \sigma_0 \text{ then } u^m = u_0^m + O(\delta\sigma)$$

$$Data(n,m) = \int_B (\sigma - \sigma_0) \nabla u^m \cdot \nabla u_0^n \, dx$$

$$= \int_B \delta\sigma \nabla u_0^m \cdot \nabla u_0^n \, dx + O(\delta\sigma^2)$$

$$Data(n,m) \approx \int_B \delta\sigma \, \nabla u_0^m \cdot \nabla u_0^n \, dx$$

Choose BASIS, $\{\psi_k(x)\}$,

$$\delta\sigma(x) = \sum_k C_k \psi_k(x)$$

Thus only need to solve;

$$Data(m,n) = \sum_k C_k \int_B \psi_k(x) \, \nabla u_0^m \cdot \nabla u_0^n \, dx$$

$$Data(m,n) = \sum_k M^k_{m,n} C_k$$

What is the Basis?

SEE TRANSPARENCIES

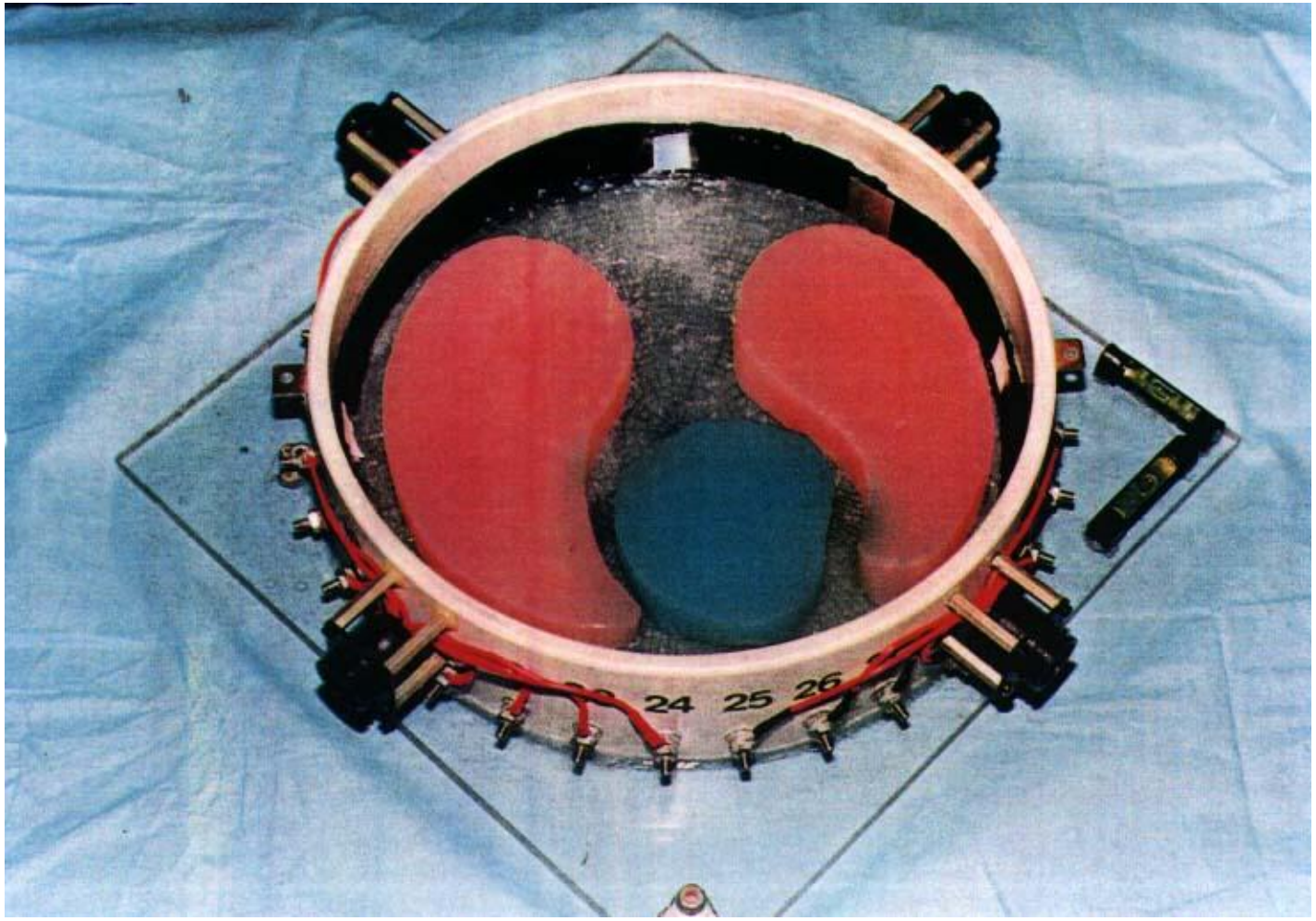
Does it work?

Test by experiment

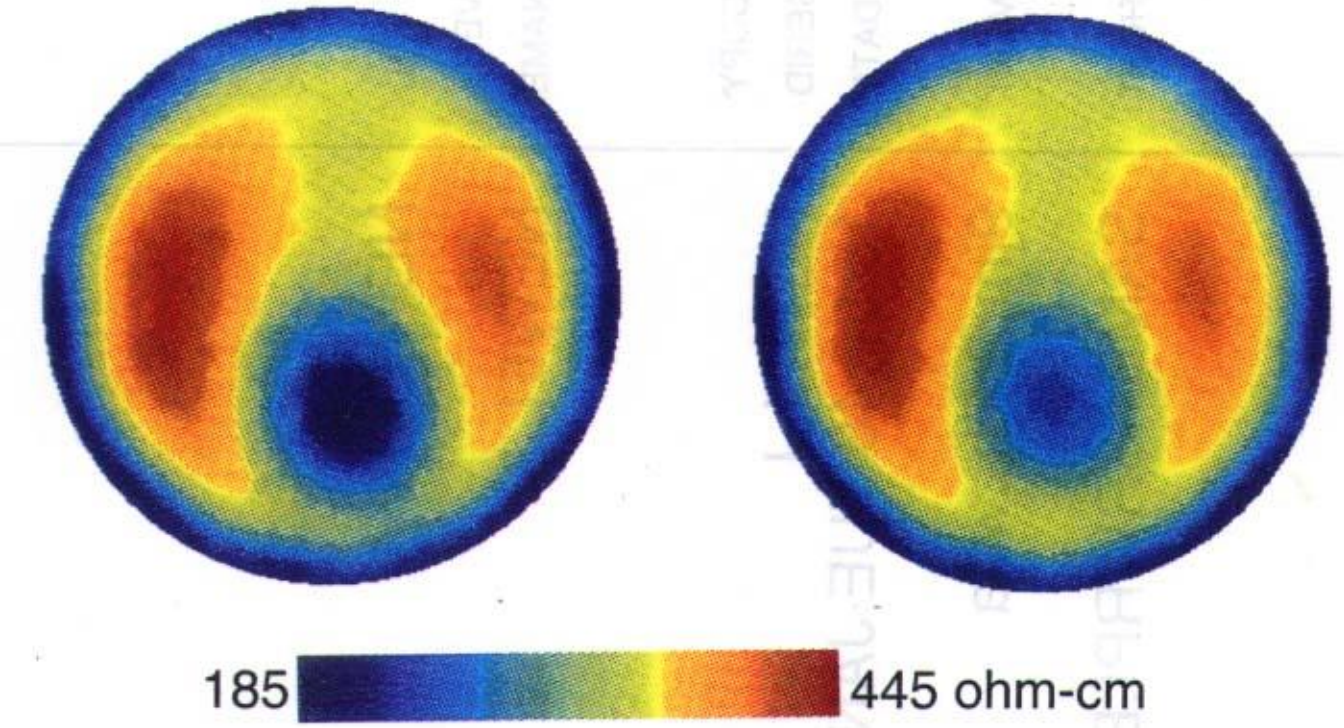
ACT 3

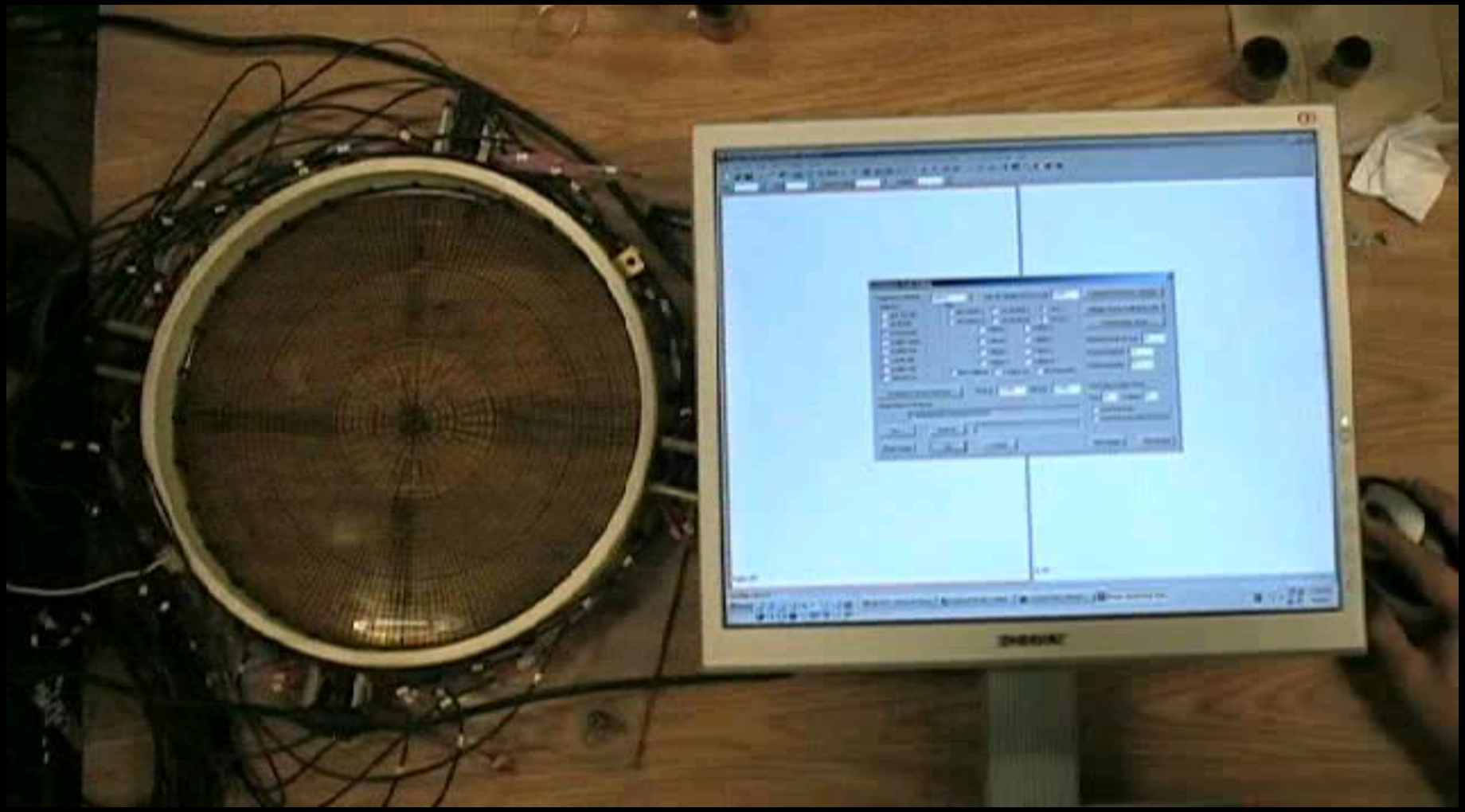
- 32 Current sources
- 32 Voltmeters
- 32 Electrodes
- 30 KHZ
- 20 Frames / Sec
- Accuracy > .01%

Phantom

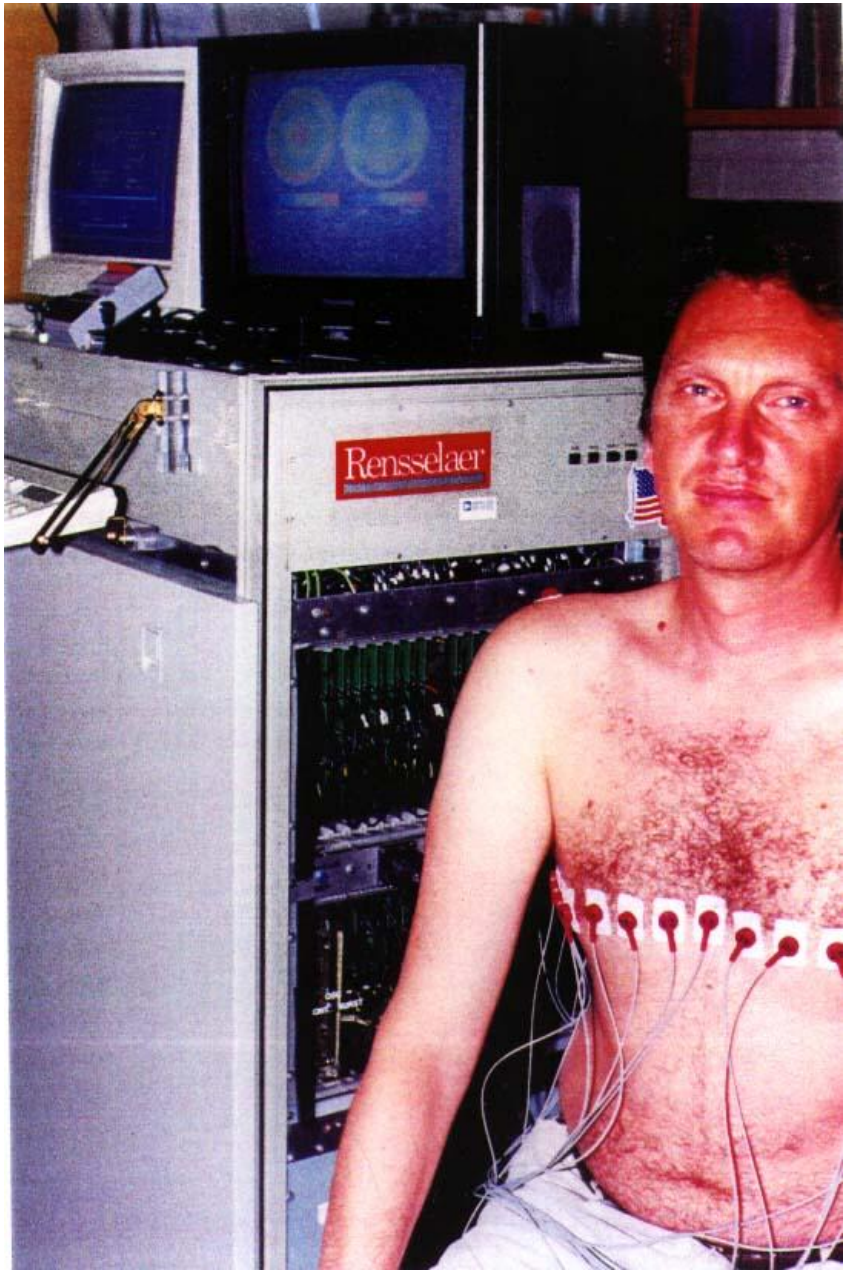


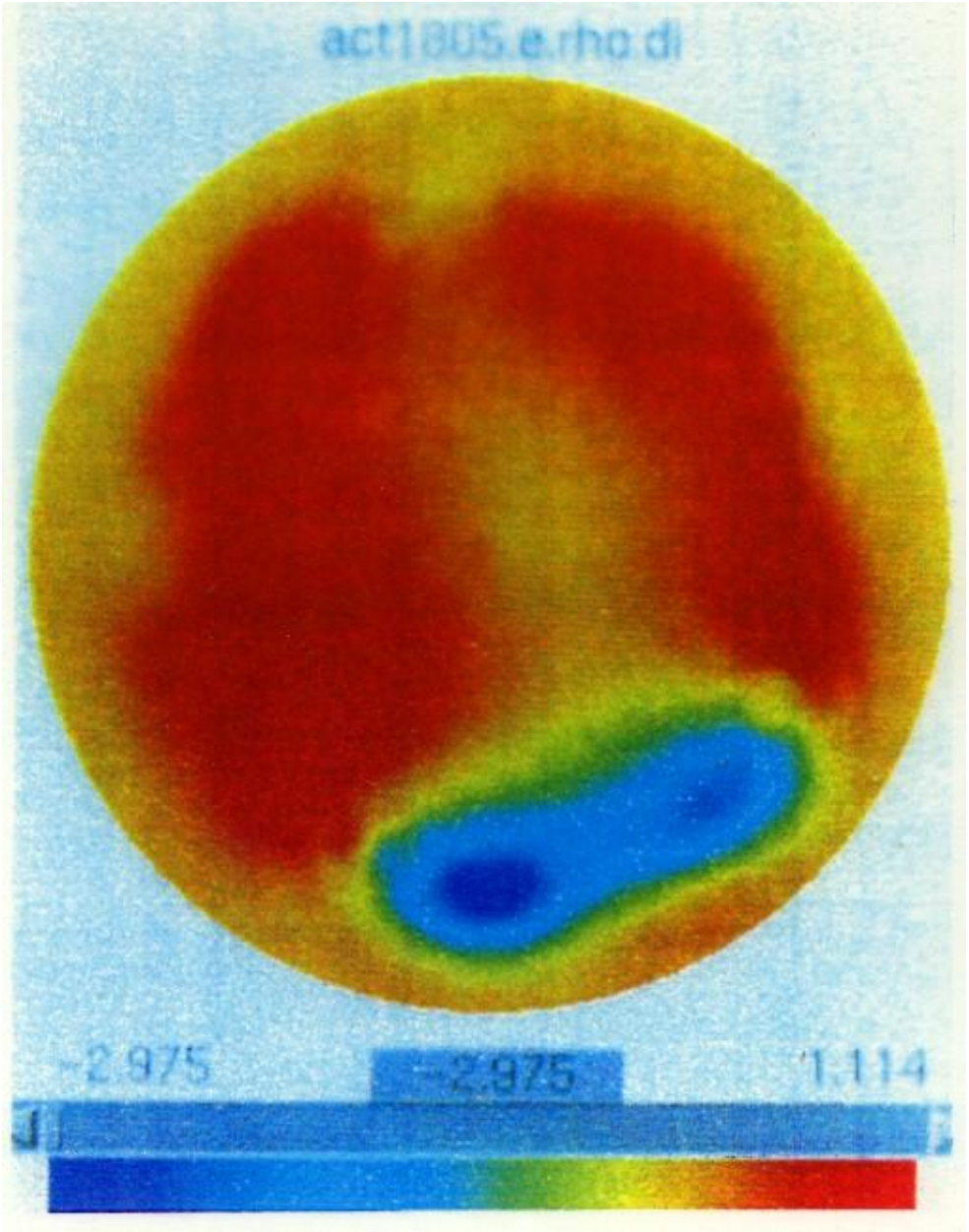
Reconstructions

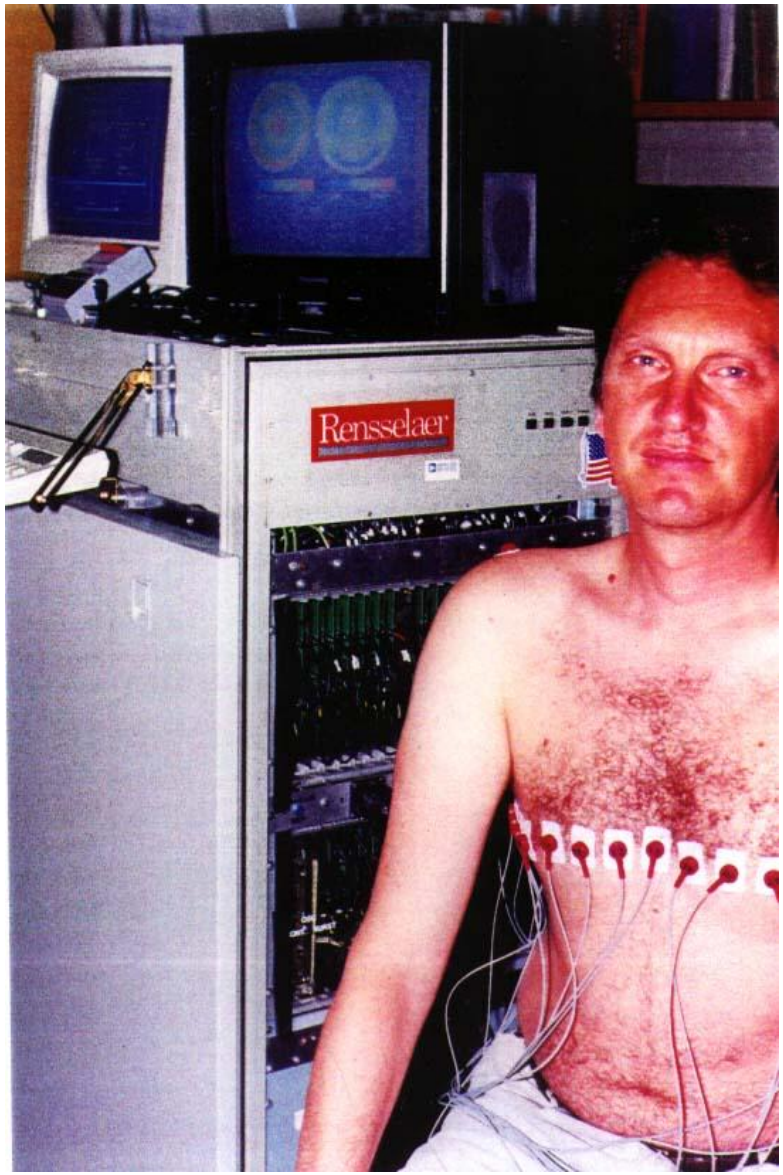


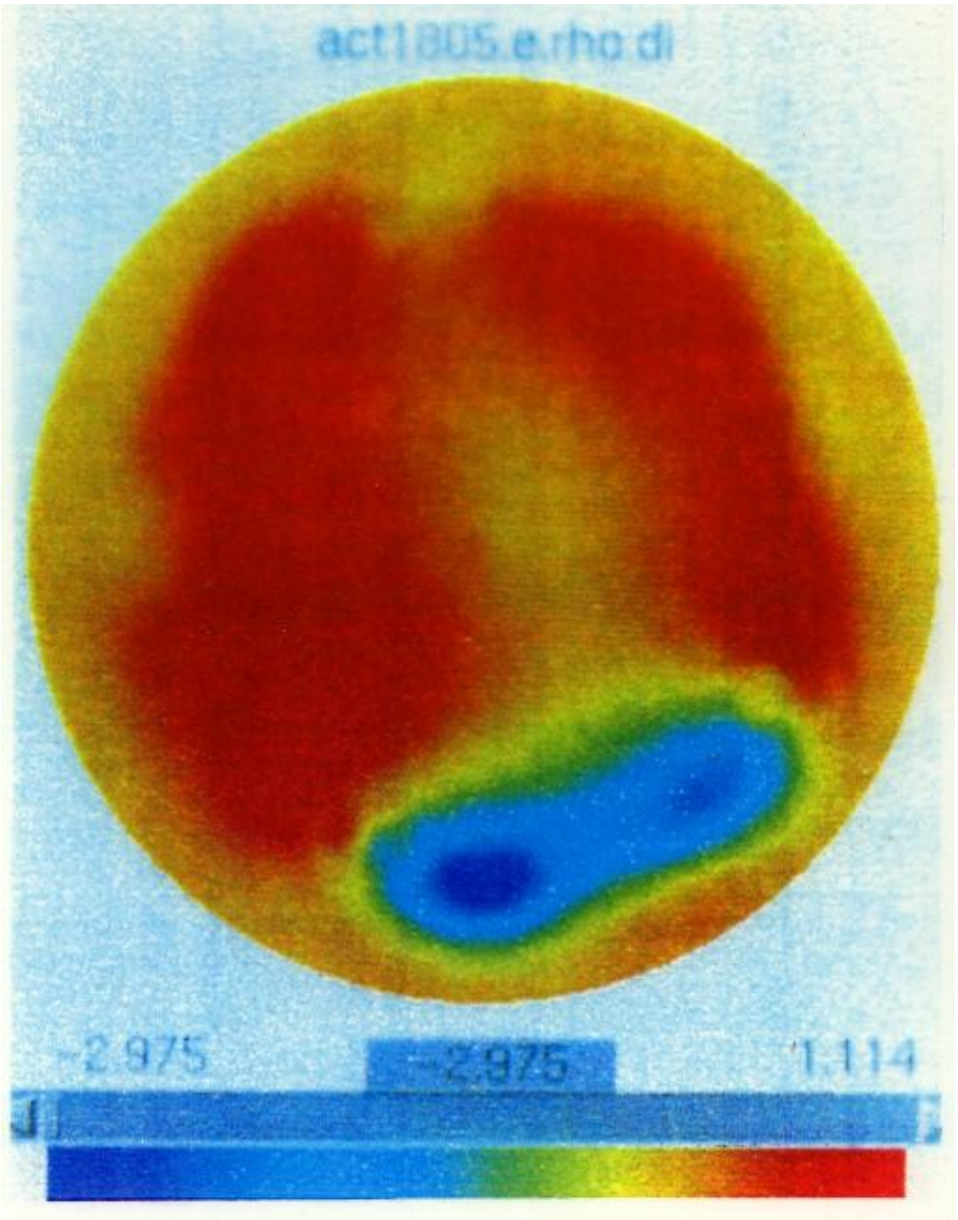


Can it image heart and lung function?


Rensselaer


act1805.e.rho.di
-2.975
-2.975
1.114

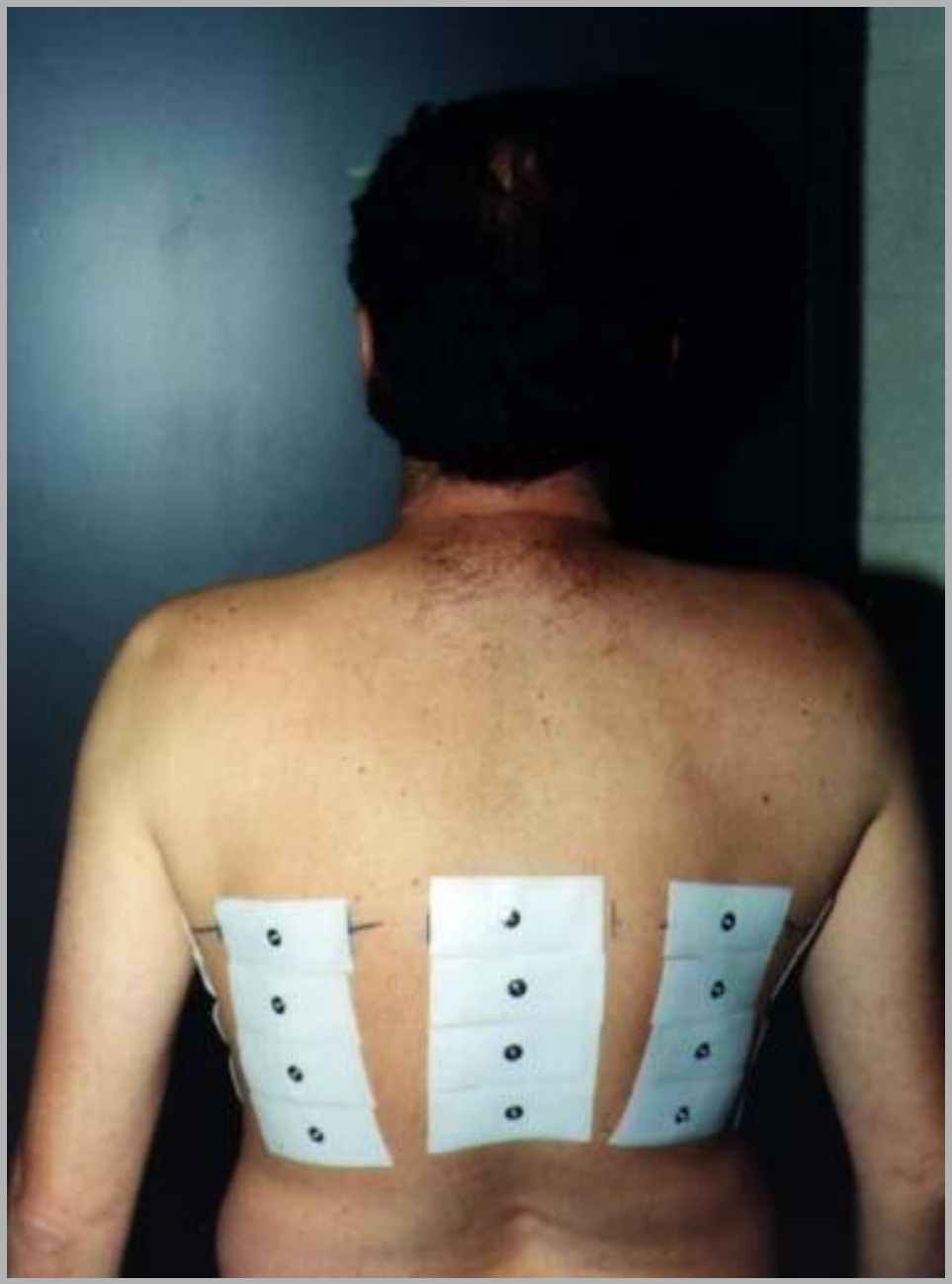


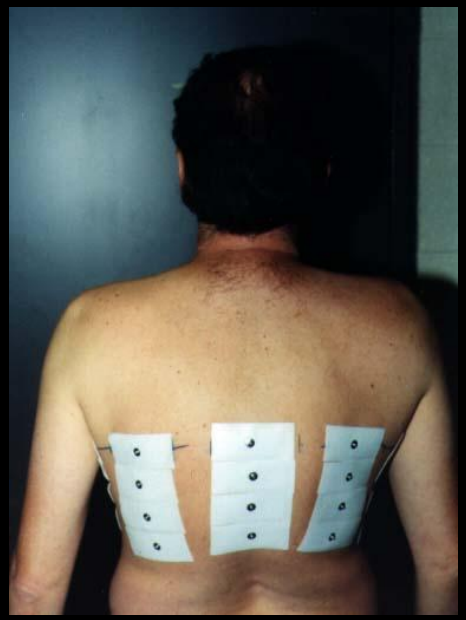


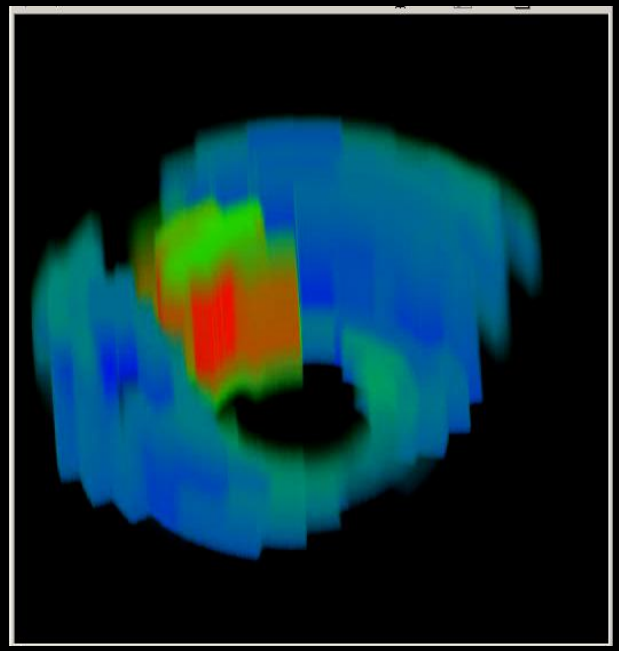
ACT 3 imaging blood as it leaves the heart (blue) and fills the lungs (red) during systole.

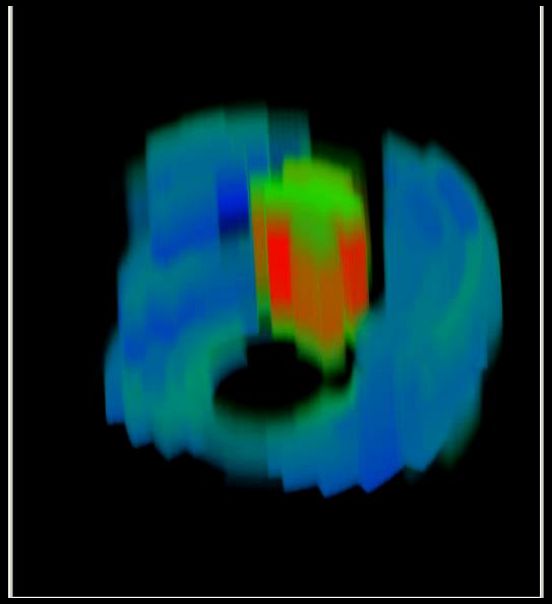
Show 2D Ventilation and Perfusion Movie

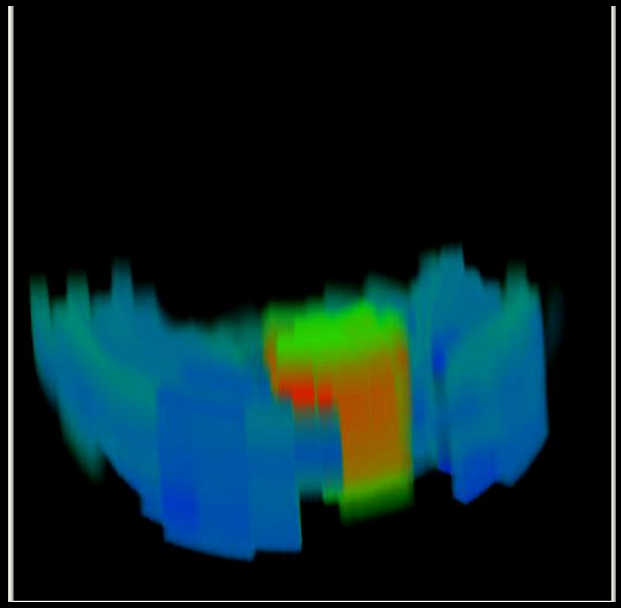
3D Electrode Placement



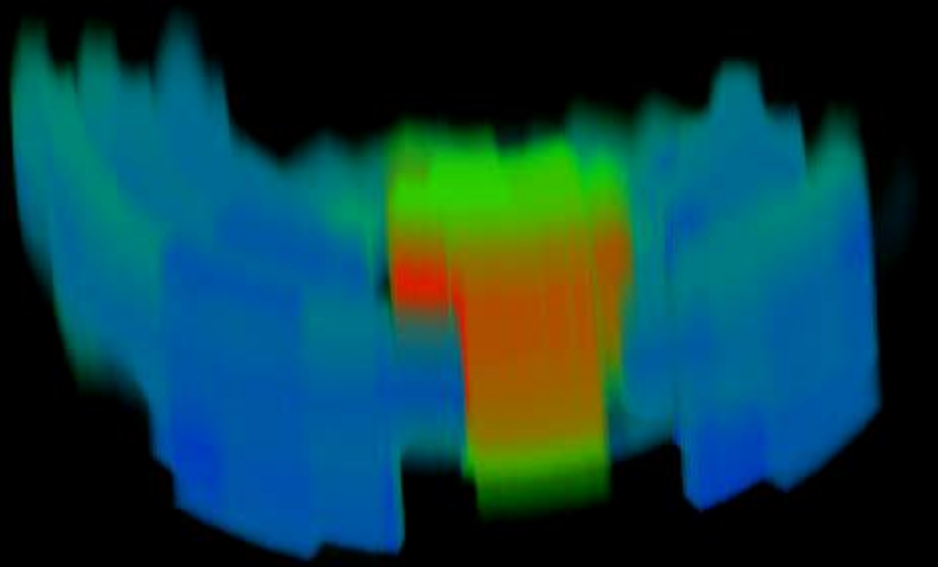






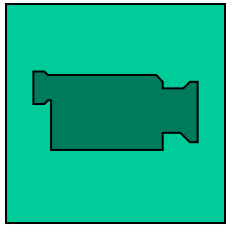


Heart Lung Static Image



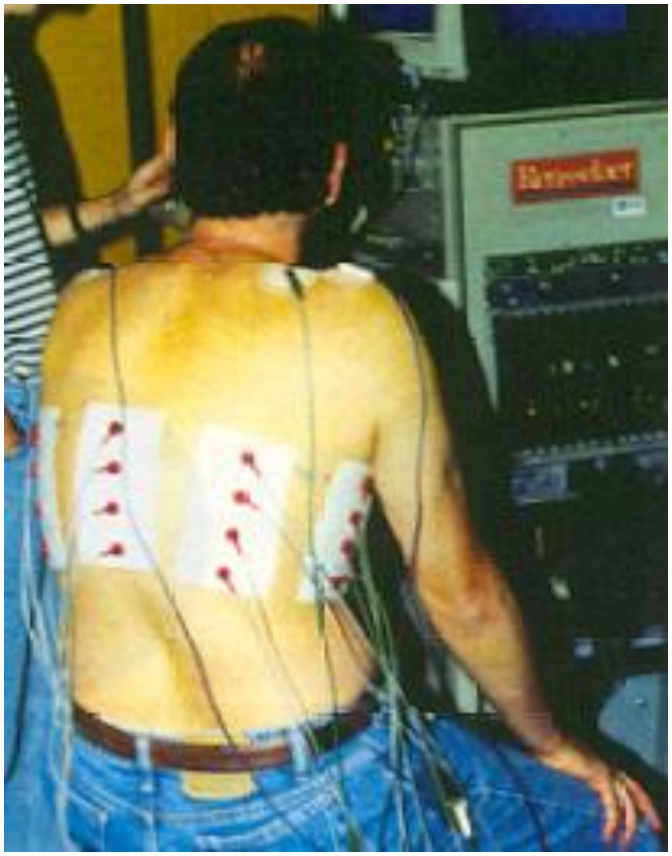
3D Heart lung

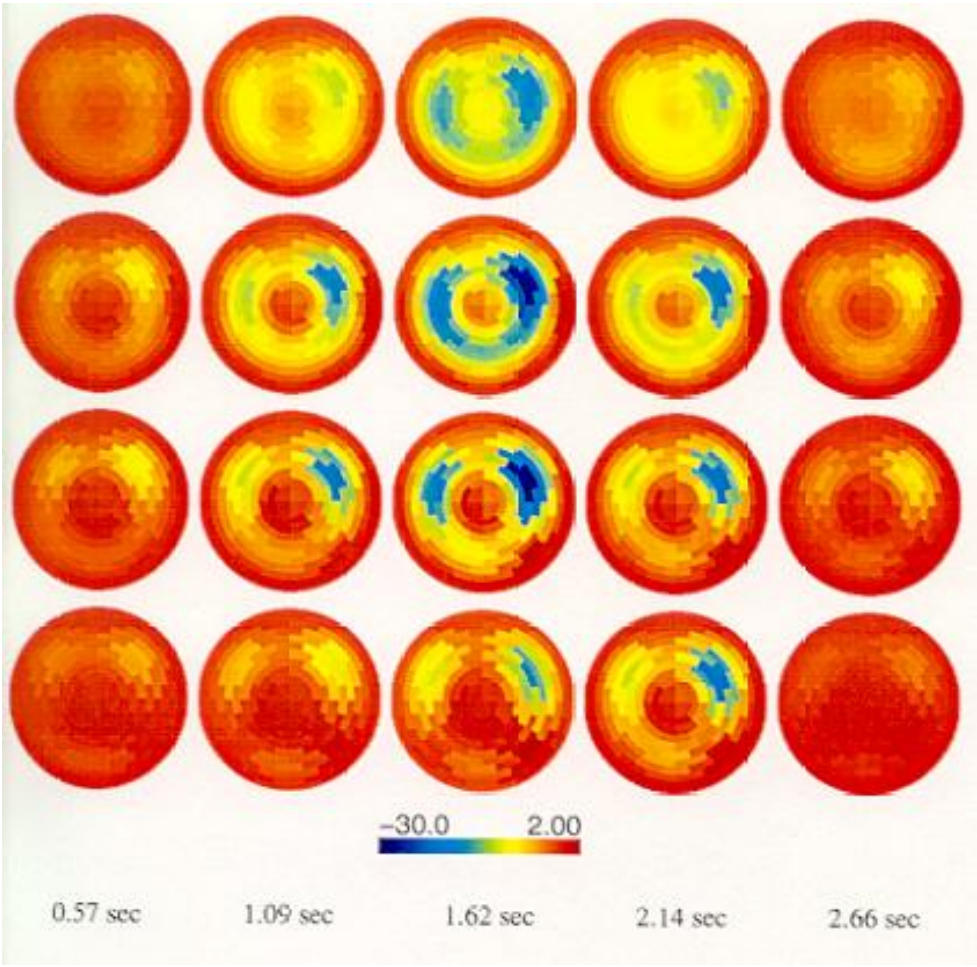
Show Heart Lung View from other source



Ventilation in 3D

3D Human Results





- Images showing conductivity changes with respiration

Cardiac in 3D

How can one get more accurate values of the conductivity, less artifact,and still be fast?

D-Bar method for EIT

J. Mueller , S.Siltanen, D.I.

Special thanks to A.Nachman

D-Bar Reconstruction method

- Convert inverse conductivity problem to an Unphysical Inverse Scattering Problem for the Schrodinger Equation.
- Use the measured D-N map to solve a boundary integral equation for the boundary values of the exponentially growing Faddeev solutions .
- Compute the unphysical Scattering transform in the complex k-plane from these boundary values.
- Solve the D-Bar integral equation in the whole complex k-plane for the Faddeev solutions in the region of interest.
- Take the limit as k goes to 0 of these solutions to recover and display the conductivity in the region of interest.

Problem: Find the Conductivity σ from the measured Dirichlet to Neumann map Λ_σ

Assume:

$$\nabla \cdot \sigma \nabla u = 0 \qquad \text{inside B.}$$

$$\mathrm{u} = \mathrm{V} \qquad \text{on } \partial\mathrm{B}.$$

$$\Lambda_\sigma \mathrm{V} = \sigma\, \partial\, \mathrm{u}/\partial \nu \qquad \text{on } \partial\mathrm{B}.$$

$\sigma = 1$ in a neighborhood of ∂B.

Let ;

$$\Psi = \Psi(p,\zeta) \equiv \sigma^{1/2}\, u,$$

$$q = q(p) \equiv \sigma^{-1/2}\, \Delta\, \sigma^{1/2}$$

Then

$$-\Delta \Psi + q \Psi = 0 \qquad \text{in } B$$

$$\Lambda_\sigma \Psi = \partial\Psi/\partial\nu \qquad \text{on } \partial B$$

and $q = 0$ in a neighborhood of ∂B.

Look for Solutions Ψ on all of R^n $(n \geq 2)$ with

$q = 0$ outside ∂B that satisfy

$\Psi \approx \exp(i\zeta \cdot p)$ as $|p| \to \infty$, where $\zeta \cdot \zeta = 0$.

In R^2 take $\zeta = k(1,i)$ where $k = k_1 + ik_2$

Let

$$\Psi = \Psi(p,\zeta) = \exp(i\zeta \cdot p)\, \mu(p,\zeta)$$

where $\mu \to 1$ as $|p| \to \infty$.

Observe that

$$(-\Delta - 2i\zeta \cdot \nabla)\mu + q\mu = 0$$

and $\mu \to 1$ as $|\mathrm{p}| \to \infty$.

We may recover σ from μ by the property that;

$$\sigma^{1/2}(p) = \mu(p,0) = \lim_{\zeta \to 0} \mu(p,\zeta).$$

Reason:

$$-\Delta\mu(\mathrm{p},0) + \mathrm{q}\mu(\mathrm{p},0) = 0$$

$$-\Delta\sigma^{1/2} + \mathrm{q}\sigma^{1/2} = 0$$

Since both $\sigma^{1/2}$ and $\mu \to 1$ at ∞ they are identical.

Main Problem: Given Λ_σ find μ?

1. First find Ψ and hence μ on ∂B by solving

$$[I + S(\Lambda_\sigma - \Lambda_1)]\,\Psi = \exp(i\zeta \cdot p) \text{ on } \partial B.$$

Here S denotes the operator

$$(Sw)(p) = \int_{\partial B} G(p - t)\, w(t)\, ds(t)$$

where G(p) is the Faddeev Greens function

$$-\Delta G = \delta, \quad G \approx \exp(i\zeta \cdot p) \text{ as } |p| \to \infty.$$

2. Compute the "unphysical" scattering transform

$$t(k) = \int_{\partial B} \exp(i\bar{\zeta} \cdot p)\,(\Lambda_\sigma - \Lambda_1)\,\Psi(p)\,ds(p)$$

3. Solve the $\bar{\partial}$ equation for $\mu(p,\zeta)$;

$$\partial\mu / \partial\bar{k} = \frac{1}{4\pi\bar{k}}\, t(k) \exp(i(\zeta + \bar{\zeta}) \cdot p)\,\bar{\mu}(p,k)$$

4. Take $\lim_{k \to 0} \mu(p,\zeta) = \sigma^{1/2}(p)$

5. Display σ.

Does it Work?

Numerical Simulation

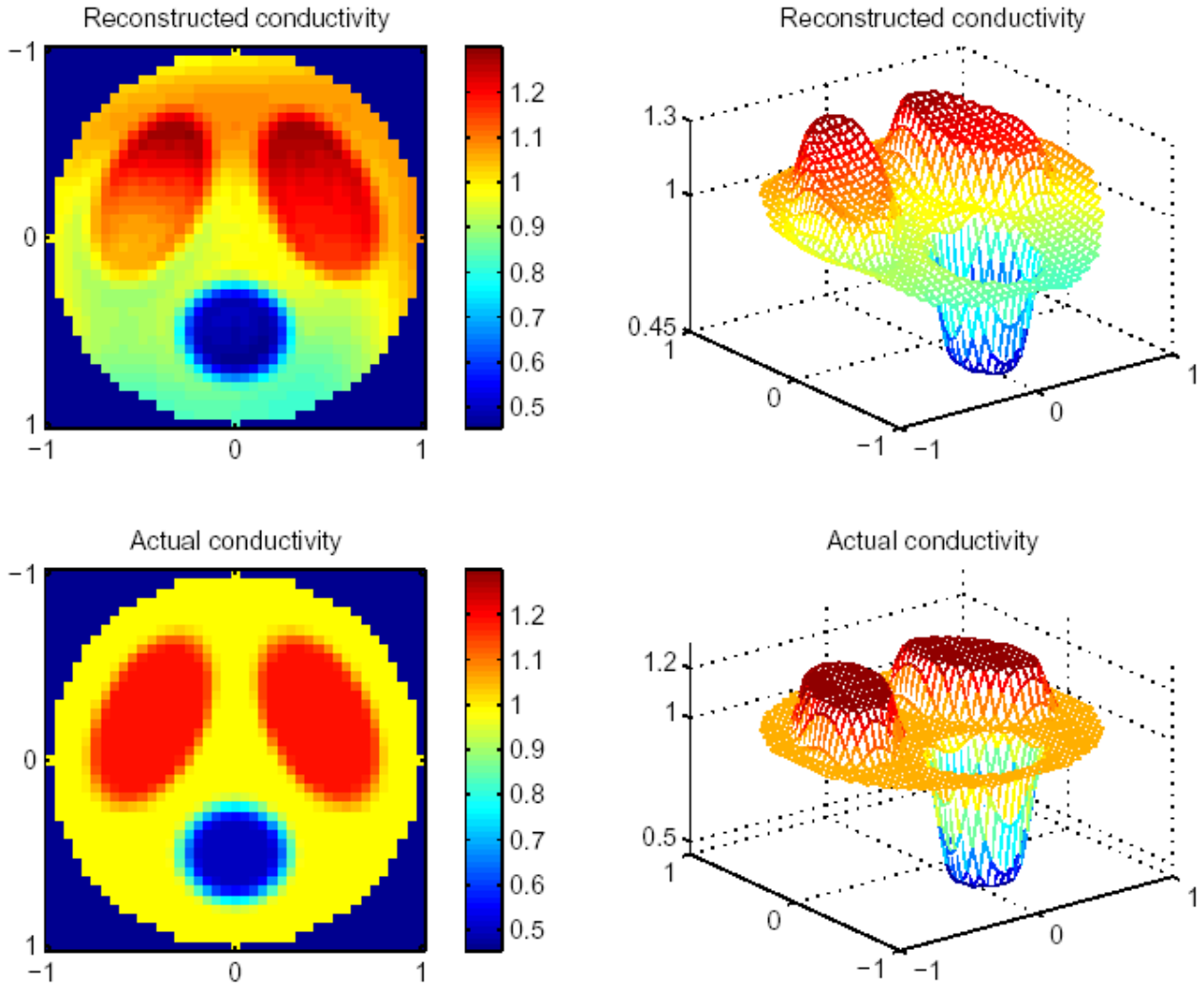
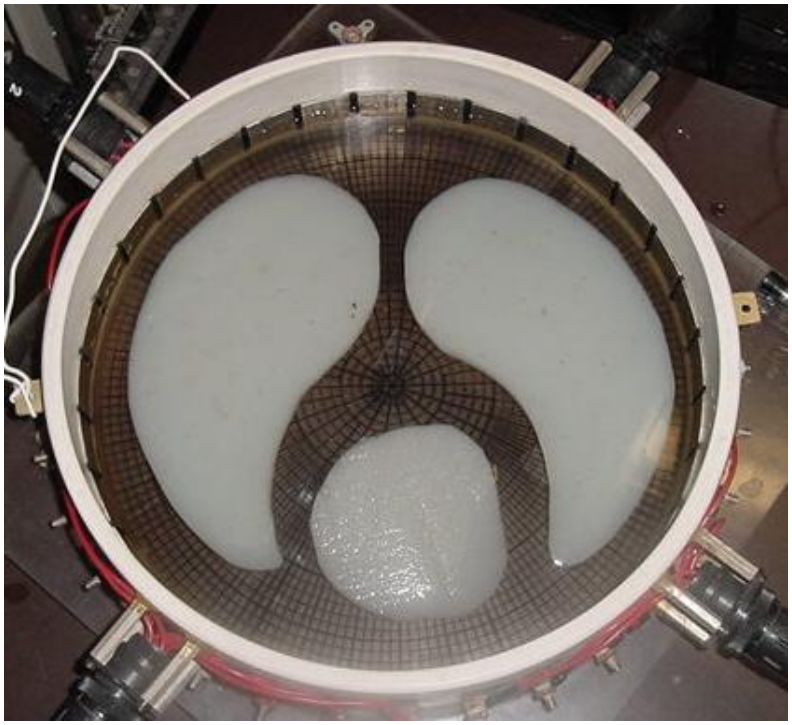
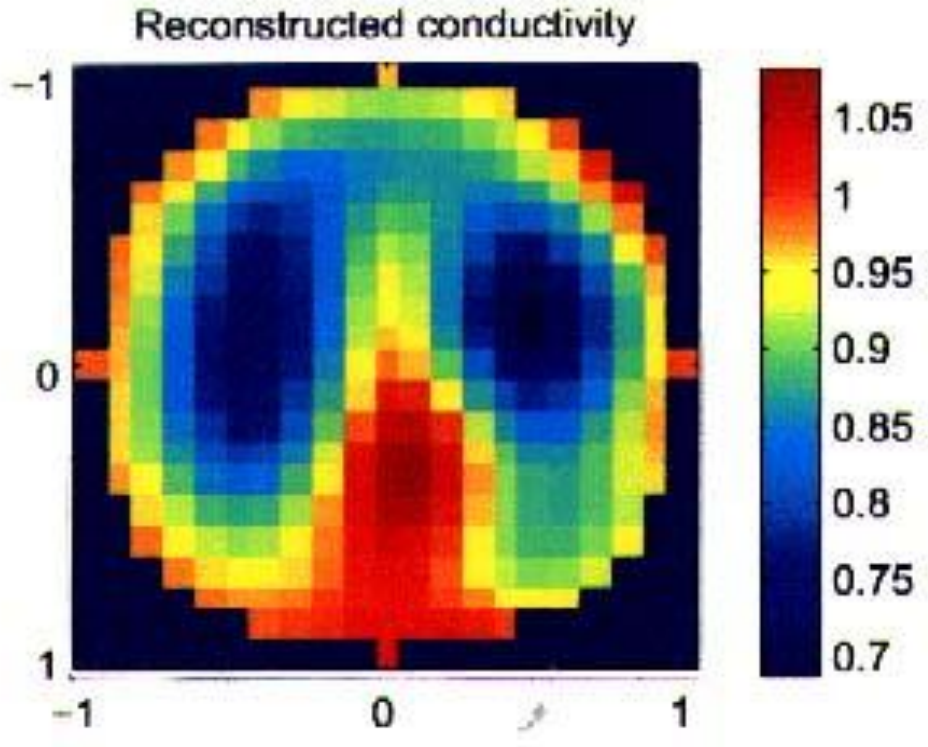


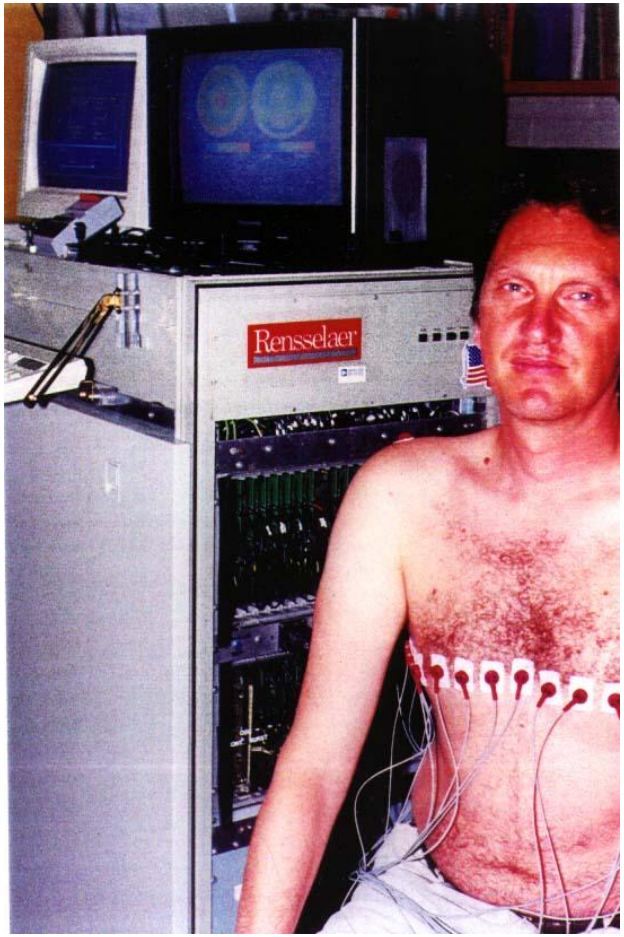
FIG. 5.2. *Plots of the actual and reconstructed conductivities for the virtual phantom chest.*

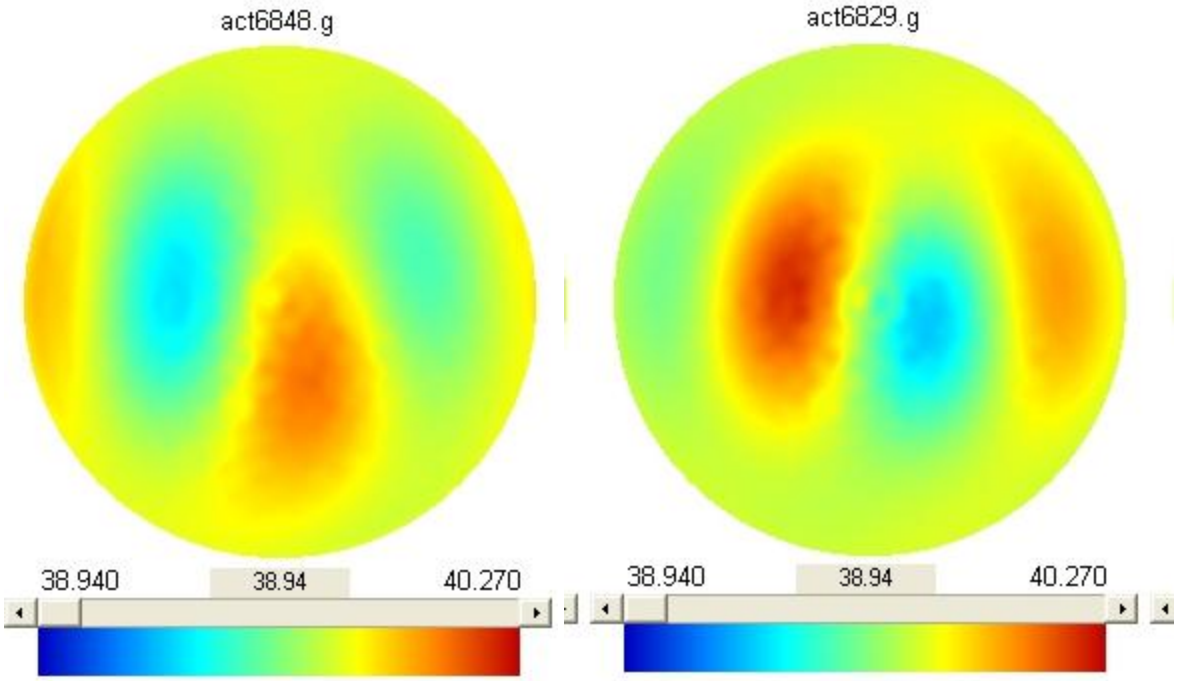
First D-Bar Reconstruction Results from Experimental Data





First D-Bar Cardiac Images

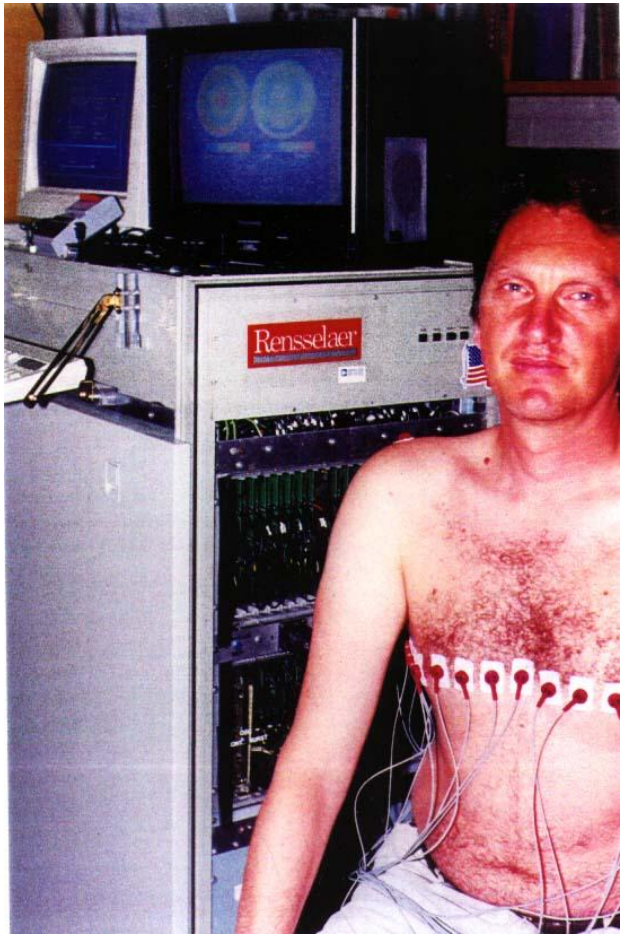


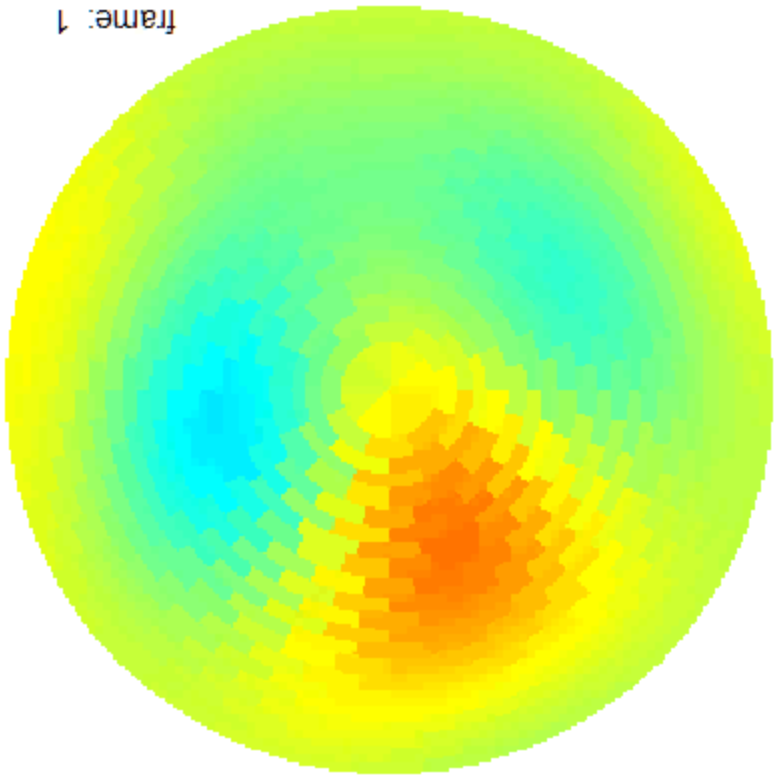


Changes in conductivity as heart expands (diastole) and contracts (systole) from one fixed moment in cardiac cycle.

First blood fills enlarging heart (red) while leaving lungs (blue) . Then blood leaves contracting heart (blue) to fill lungs (red).

Reconstruction by D-bar. Data by ACT3.





Click on the image at right to see a movie of changes in the conductivity inside a chest during the cardiac cycle. Difference's shown in the movie are all from one moment in the cycle. The movie starts with the heart filling and the lungs emptying.

Reconstruction by D-Bar. Data from ACT3.

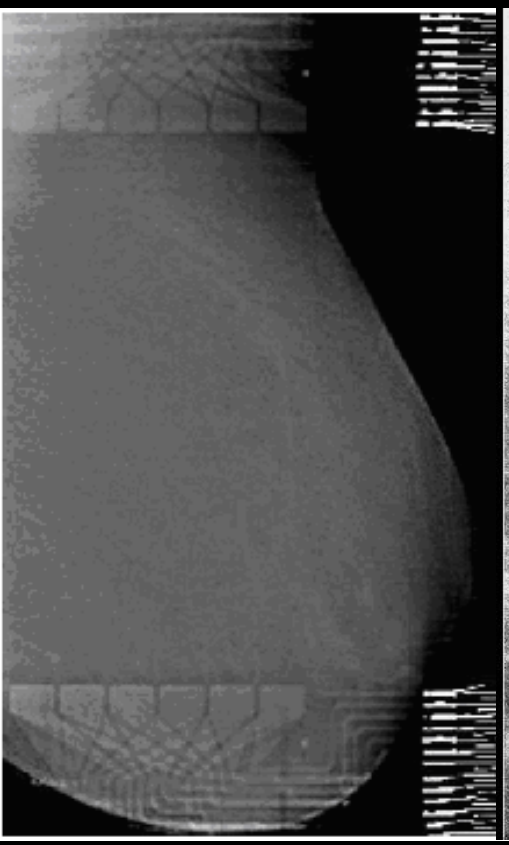
Problems:

- How to make D-bar method work better with experimental data?
- How to make it work in 3-D?
- How to make D-bar work with Optical,Acoustic, and Microwave Data?

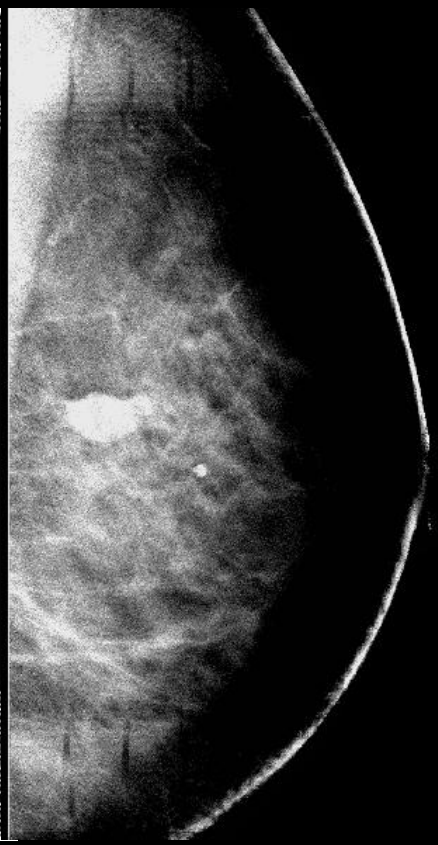
Can EIT Improve Sensitivity and Specificity in screening for Breast Cancer
?

Breast Cancer Problem

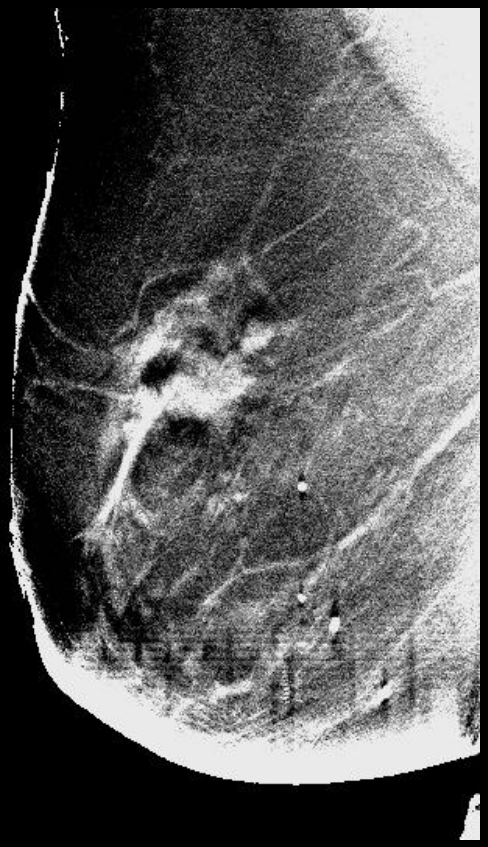
Which ones have cancer ?



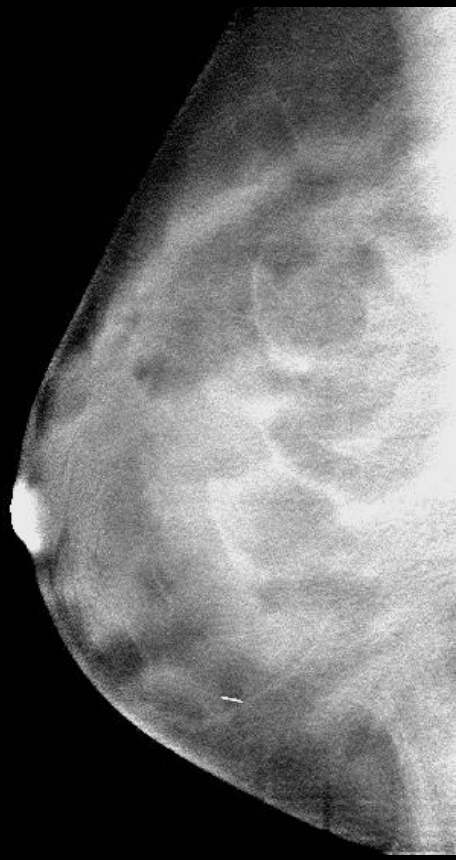
HS14R



HS21R



HS25L



HS10L

Electrical Impedance Tomography with Tomosynthesis for Breast Cancer Detection

Jonathan Newell

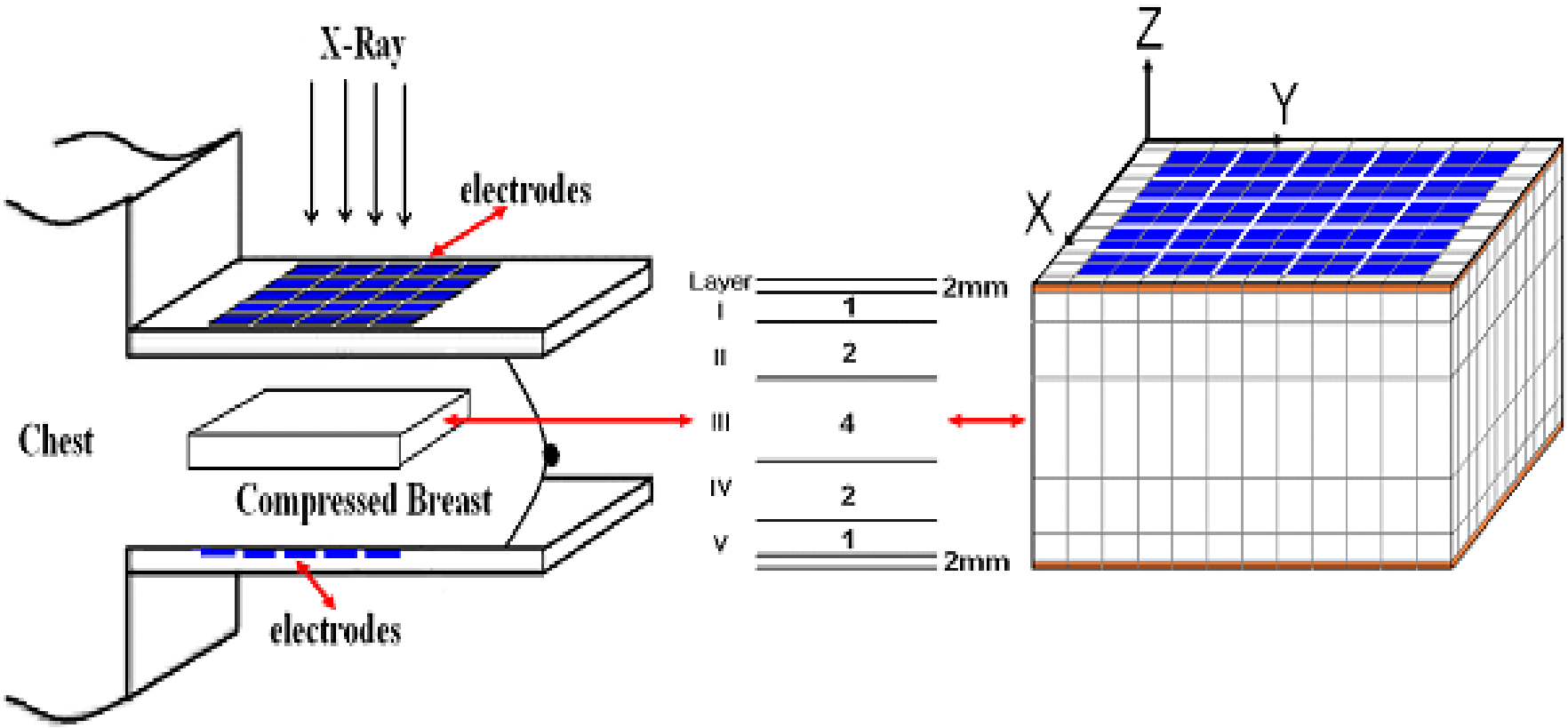
With:

David Isaacson
Tzu-Jen Kao
Richard Moore*
Gary J. Saulnier
Greg Boverman
Daniel Kopans*

And: Rujuta Kulkarni
Dave Ardrey
Chandana Tamma
Neha Pol

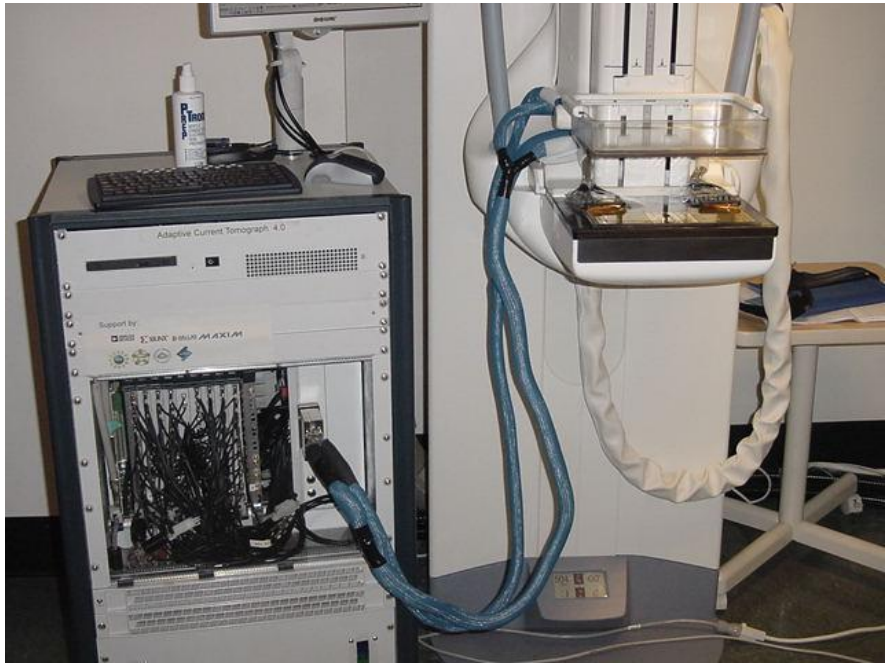
Rensselaer Polytechnic Institute
*Massachusetts General Hospital

EIT electrodes added to mammography machine.

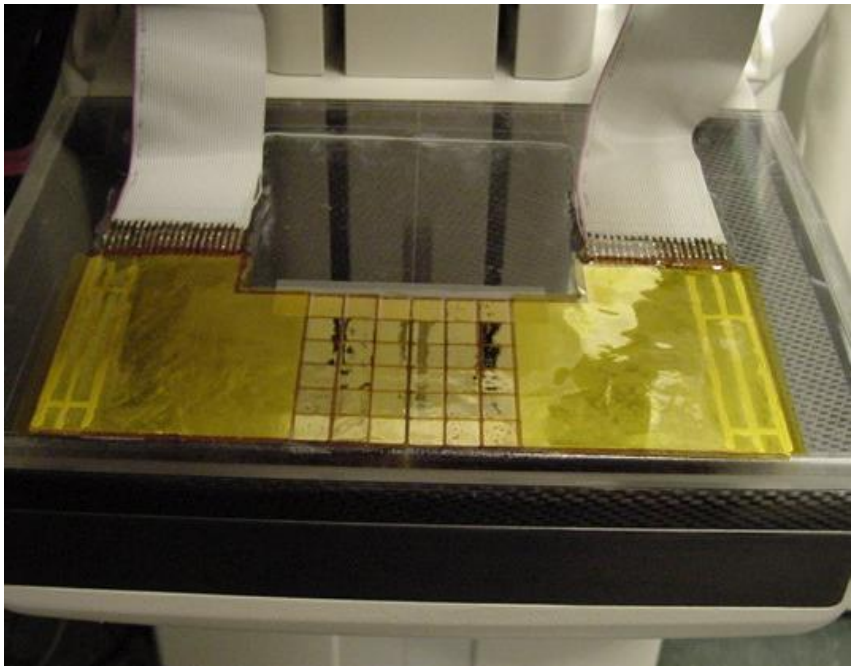


- 1 : 2 : 4 : 2 : 1 is the ratio of the mesh thicknesses.
- Only the center layer, III, is displayed in the results.

EIT Instrumentation

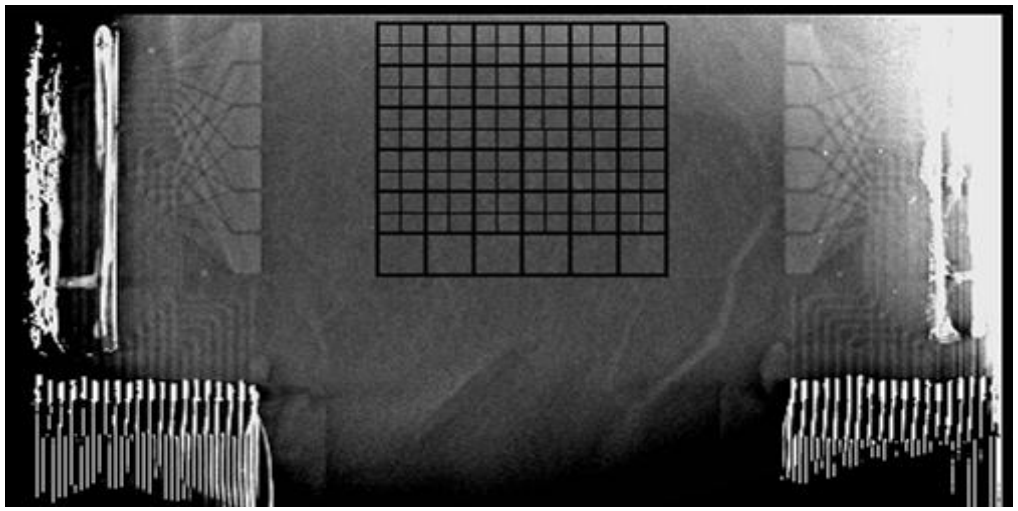


ACT 4 with Tomosynthesis unit



Radiolucent electrode array

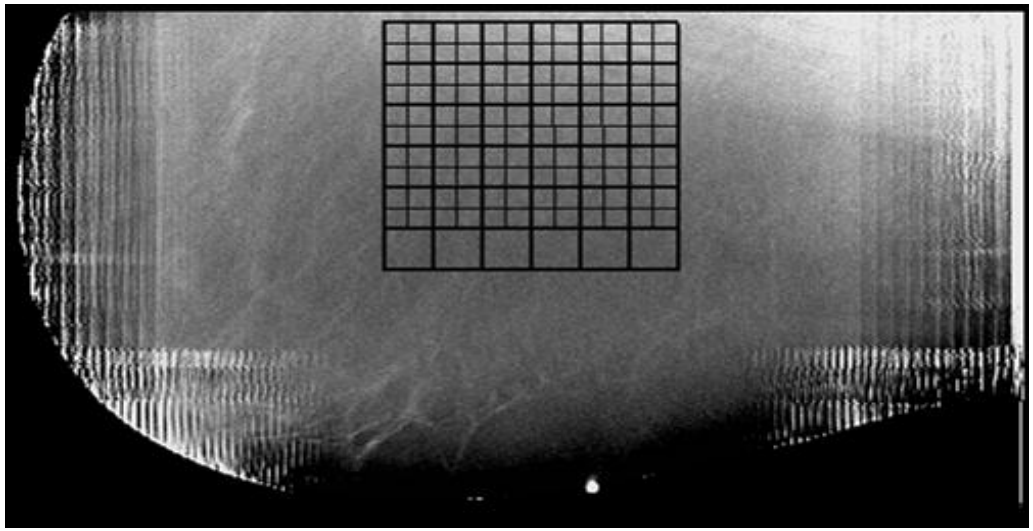
Co-registration of EIT and Tomo Images



To find the electrode position, display the slice containing the electrodes. Superimpose the mesh grid with correct scale.

Slice 15 of 91

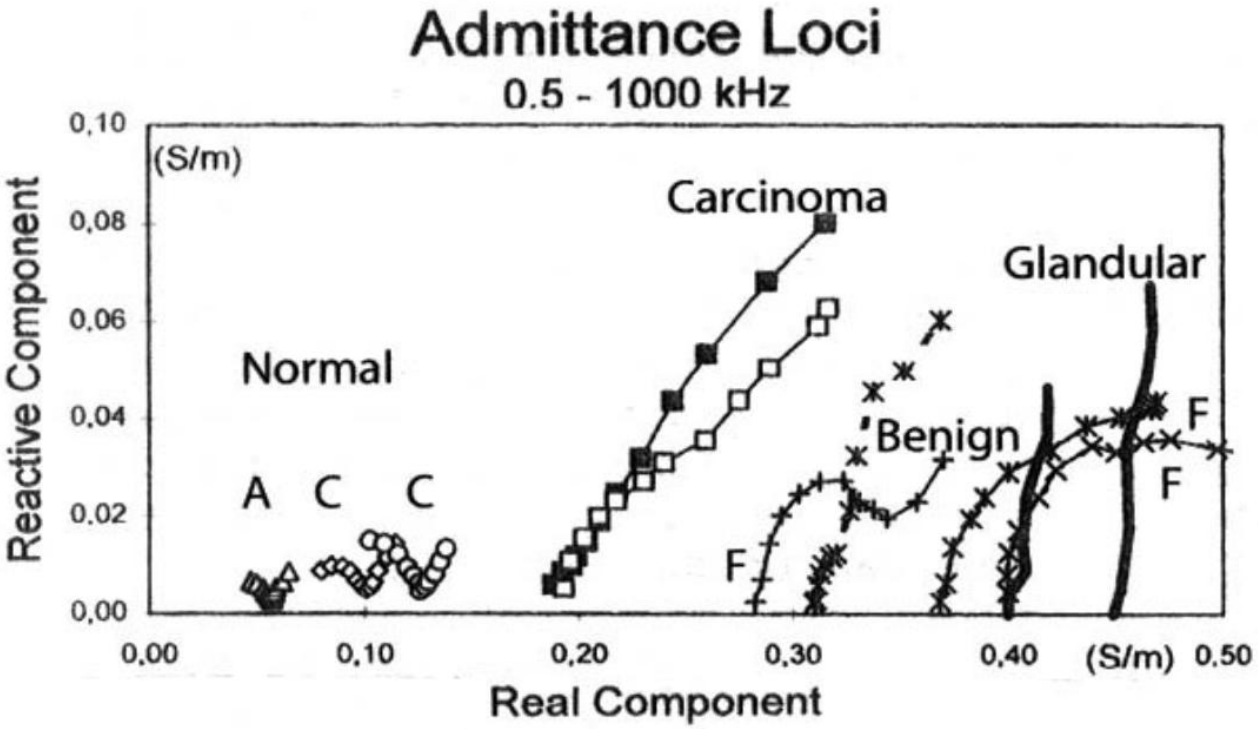
HS_14R
Normal



Then select the desired tomosynthesis layer.

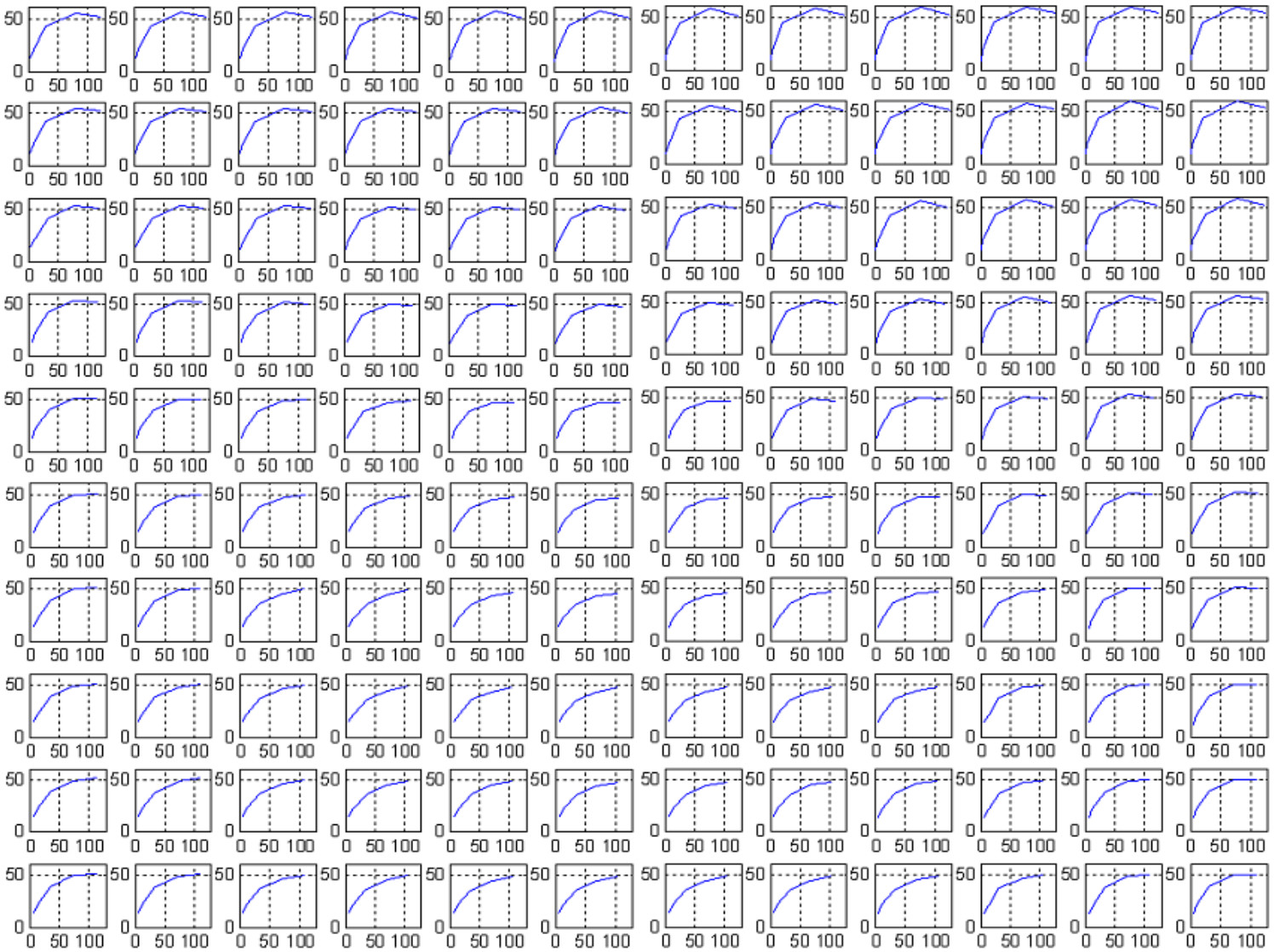
Slice 50 of 91

Admittance Loci: format for summaries of EIS data

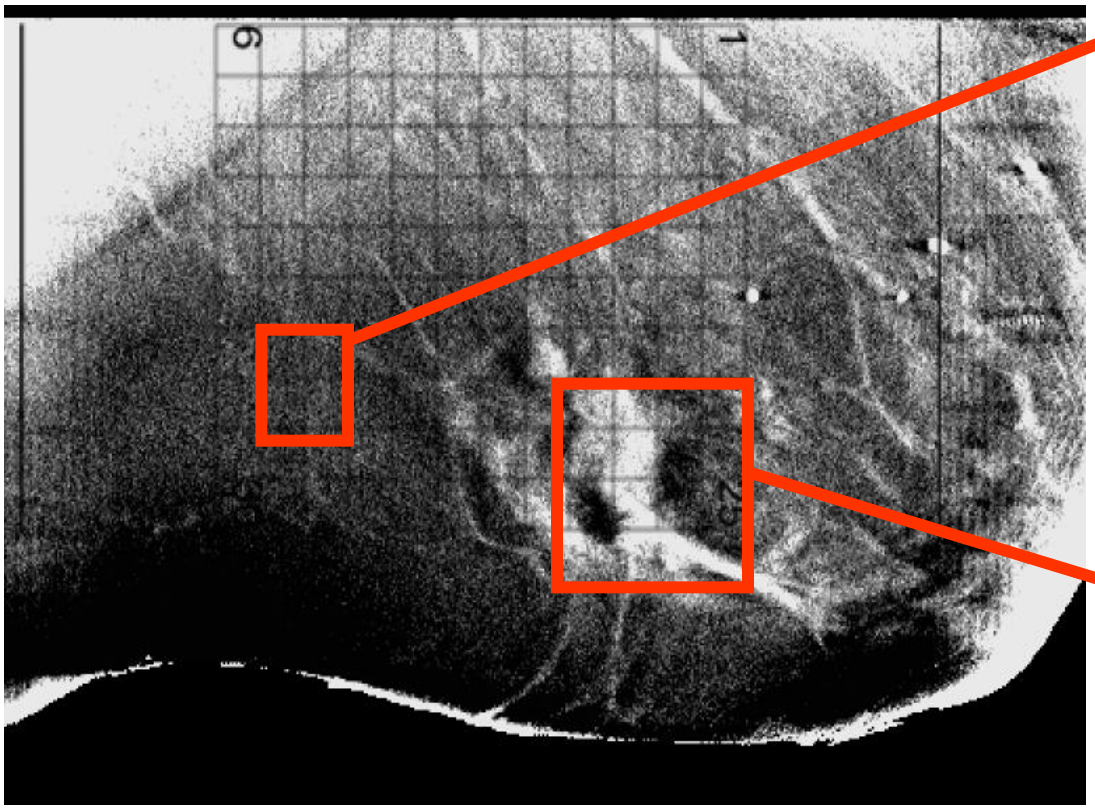


Results of in-vitro studies of excised breast tissue. *Jossinet & Schmitt 1999*

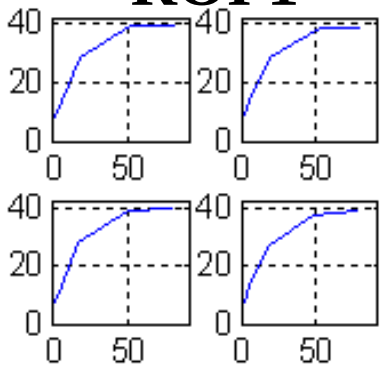
120 EIS plots for a normal breast (HS14_Right)



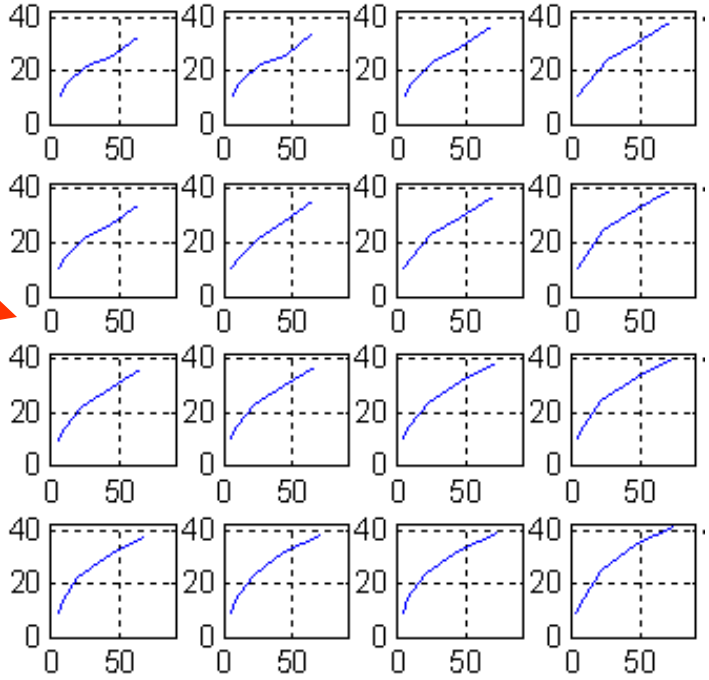
HS25_L: Invasive Ductal Carcinoma



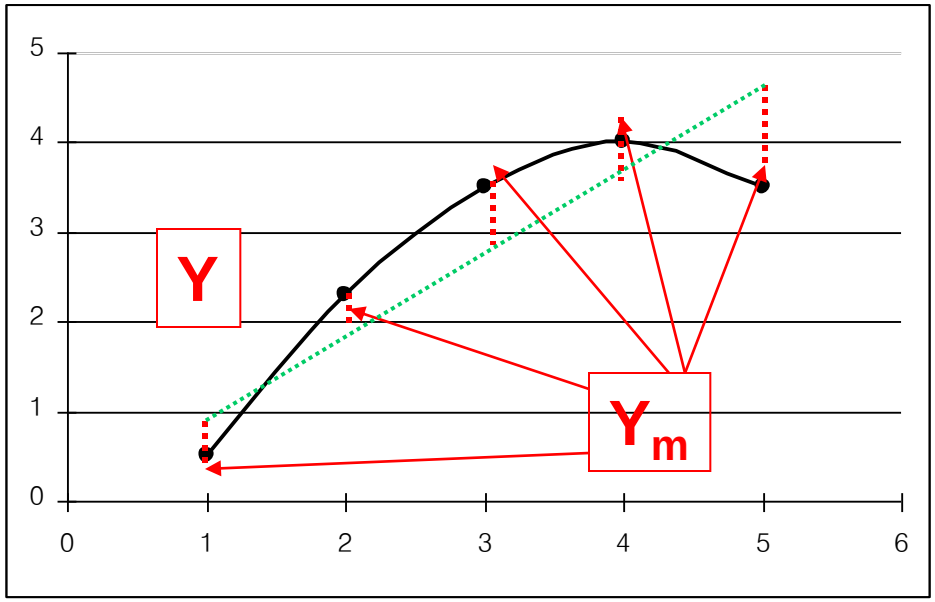
ROI 1



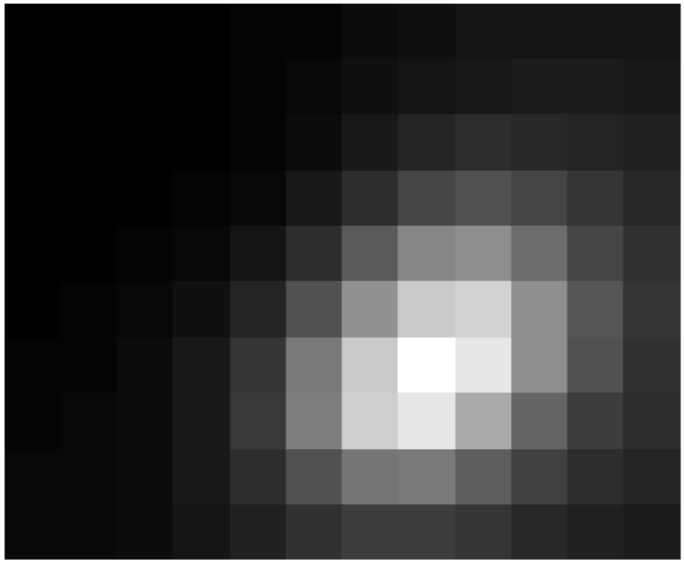
ROI 2

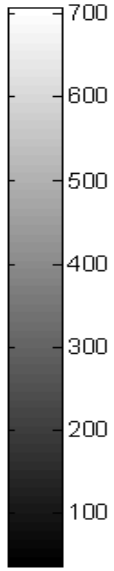


Linear Correlation Measure –LCM



LCM Image





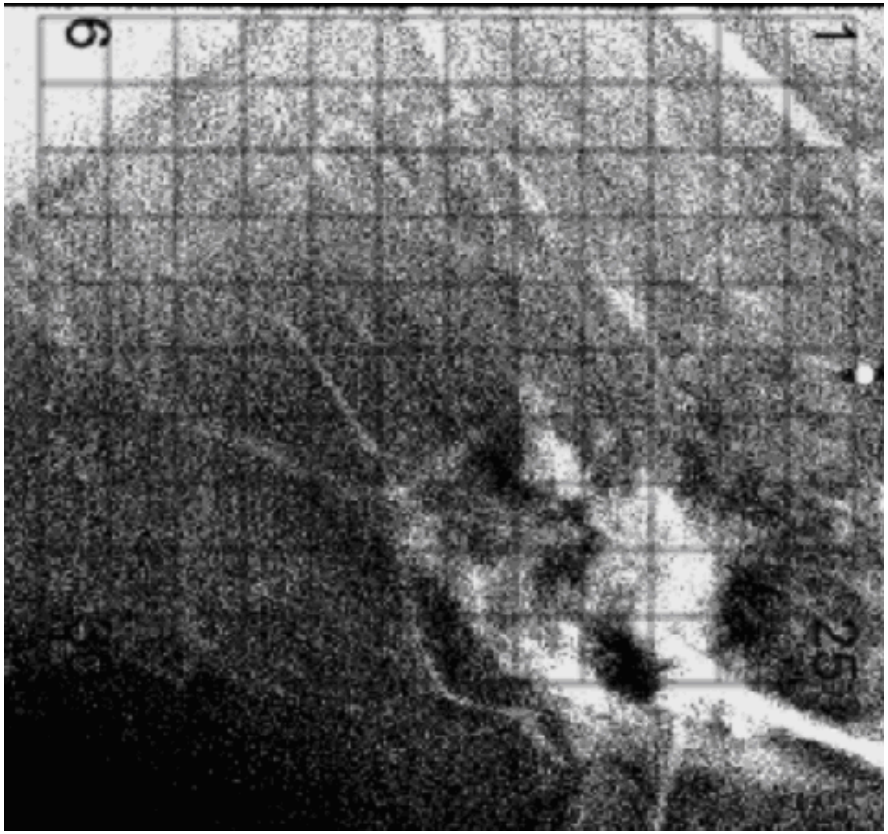
700

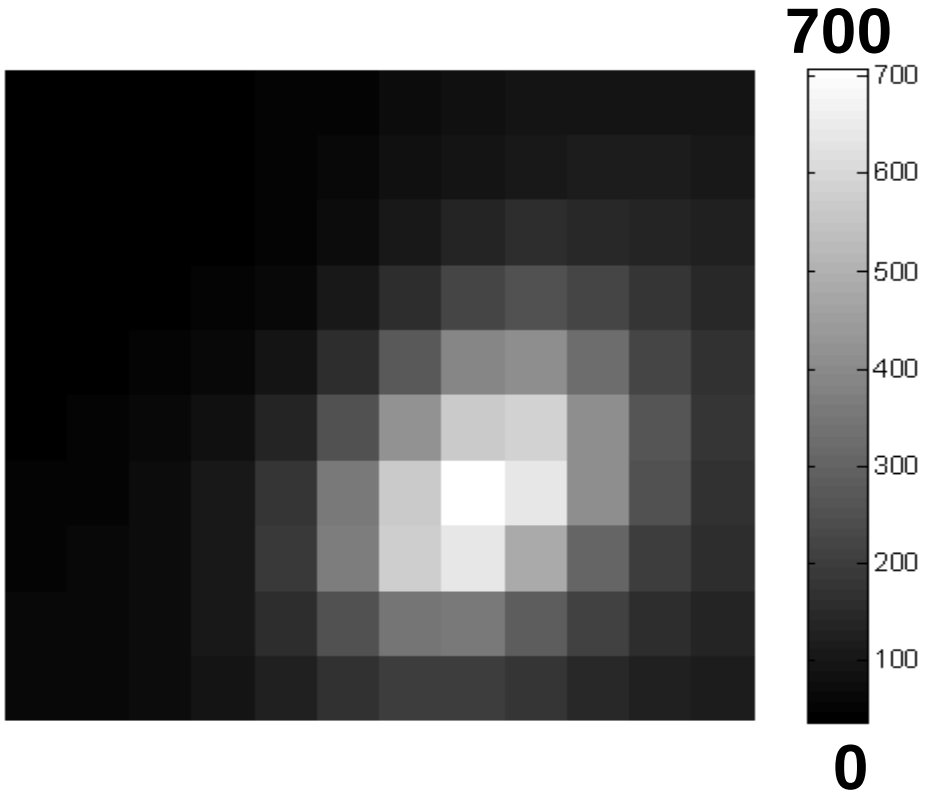
0

$$LCM = \frac{1}{1 - \frac{\left|\langle Y, Y_m \rangle\right|}{\|Y\|\|Y_m\|}}$$

compute for each voxel

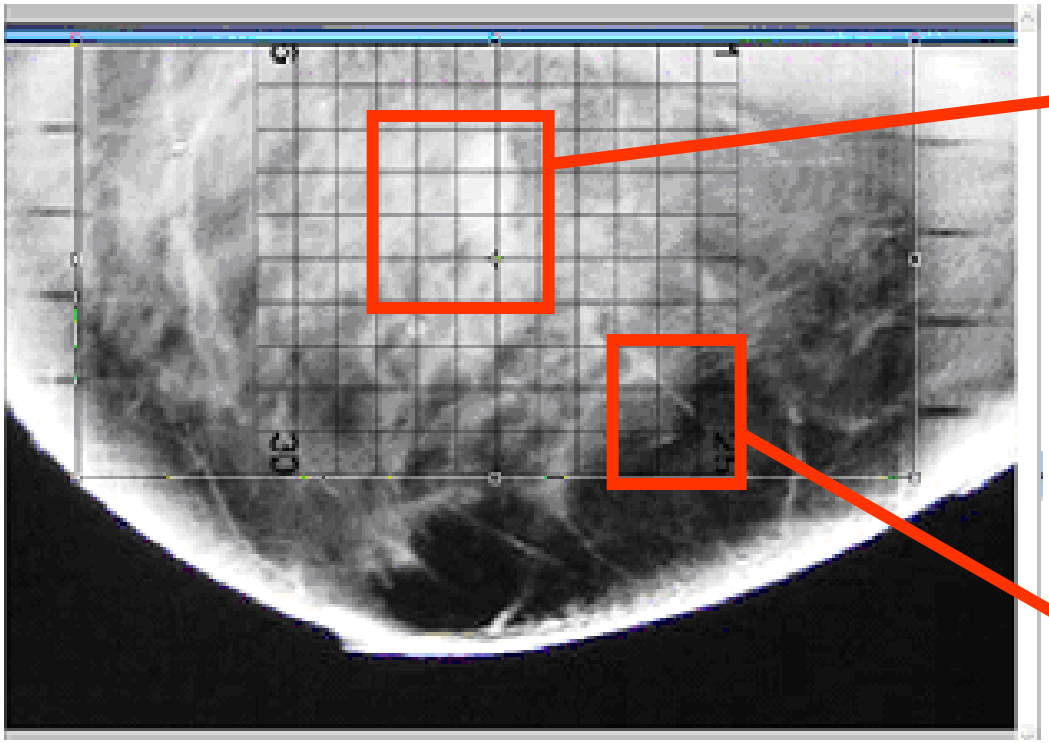
LCM Image of invasive ductal CA (HS25_L)



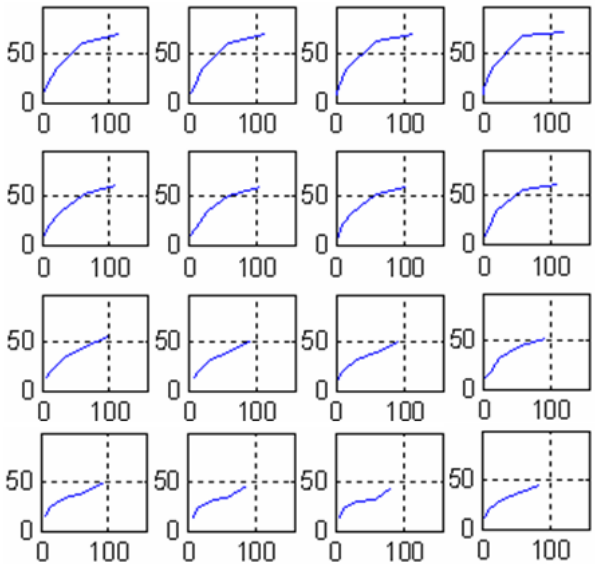


Gray scale image of LCM

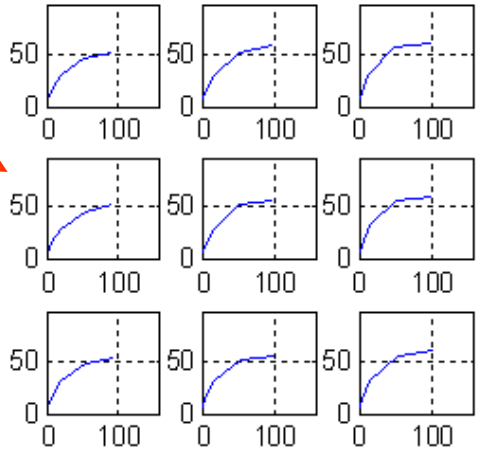
HS21_R: Fibroadenoma in the upper box



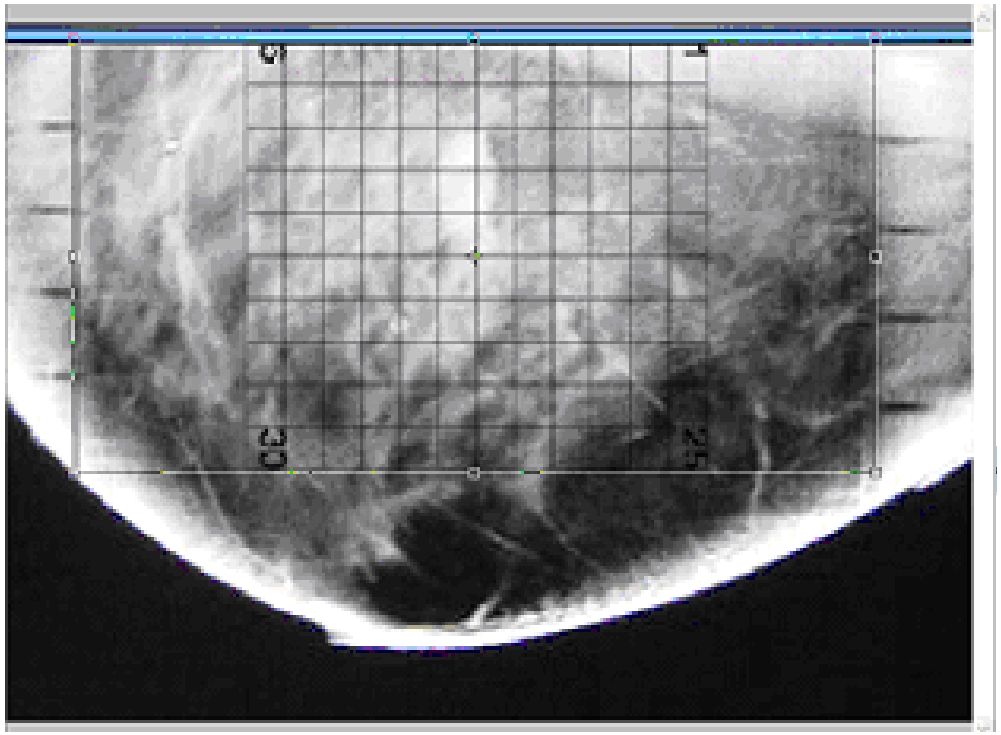
ROI 1

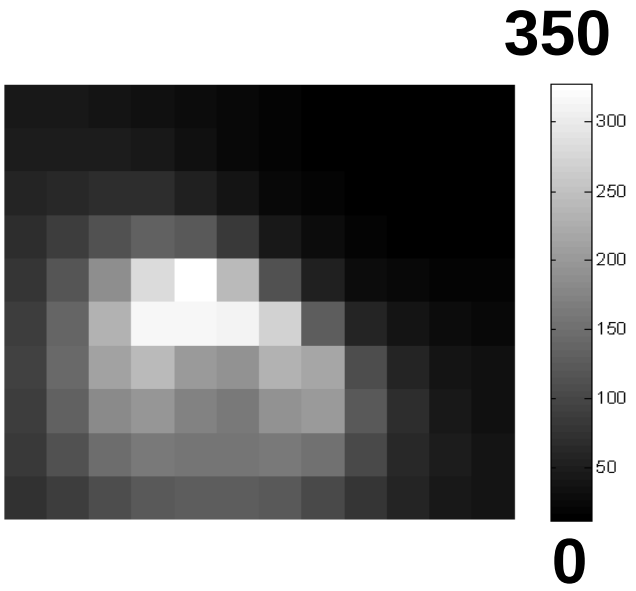


ROI 2



LCM Image of fibroadenoma (HS21_R)

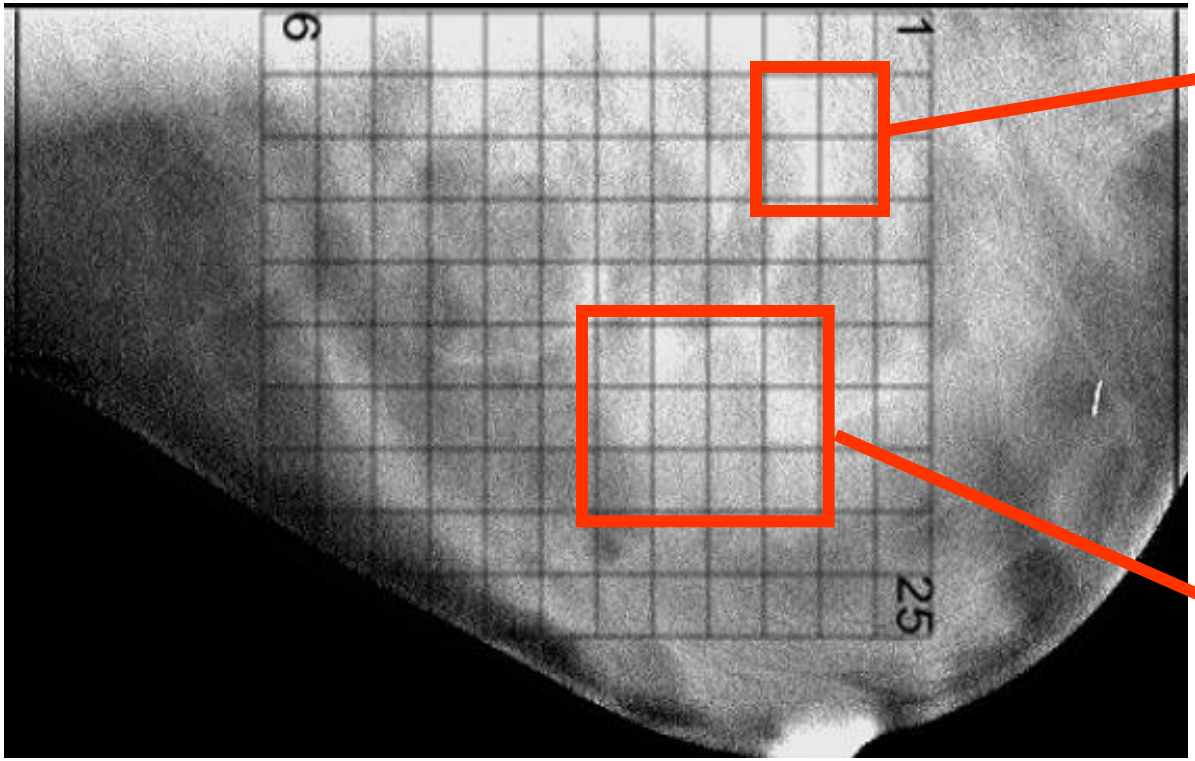




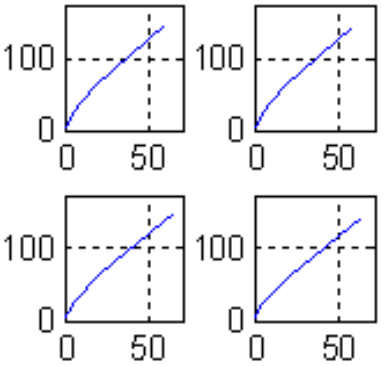
Gray scale image of LCM

HS10_L: Invasive Ductal CA

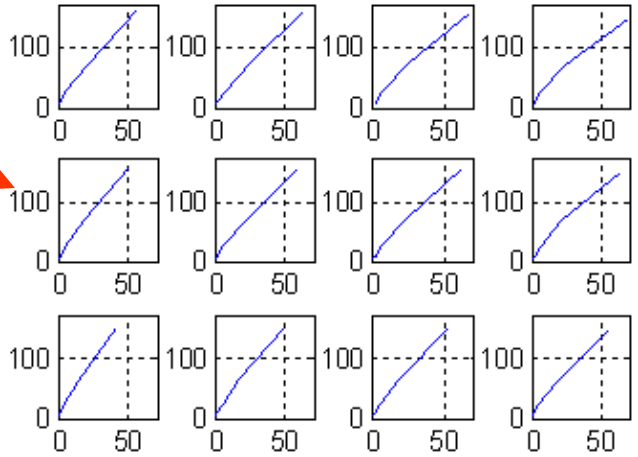
"Proliferation is worrisome"



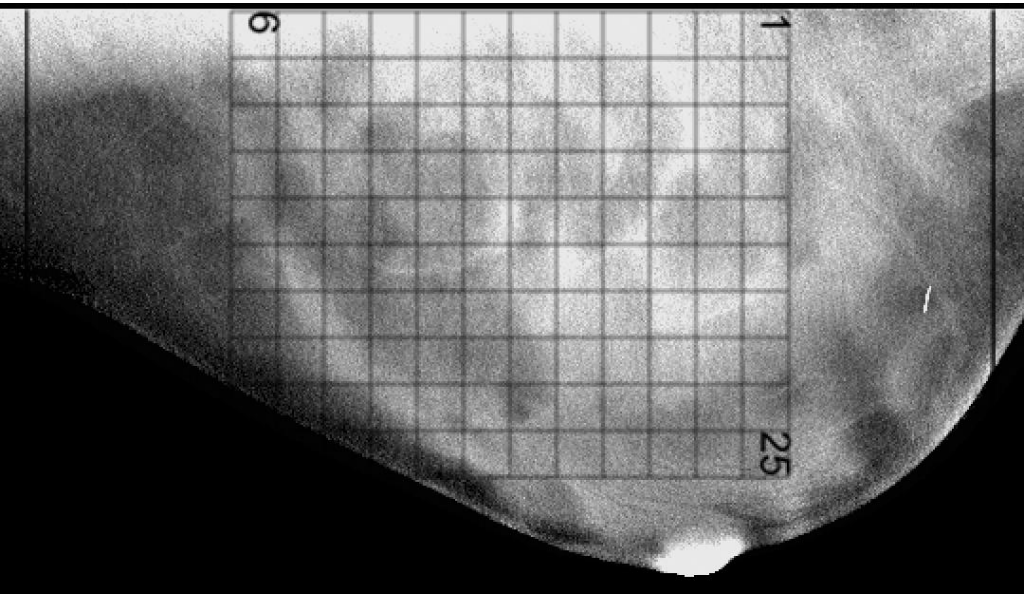
ROI 1

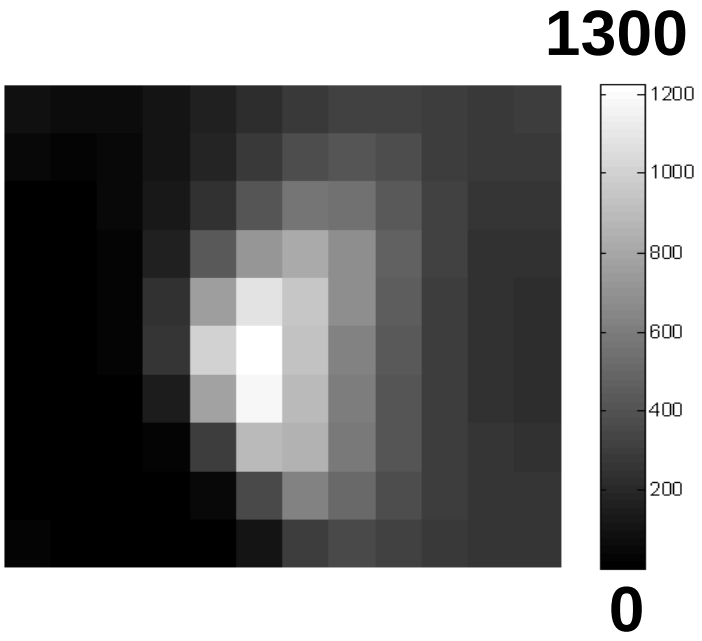


ROI 2



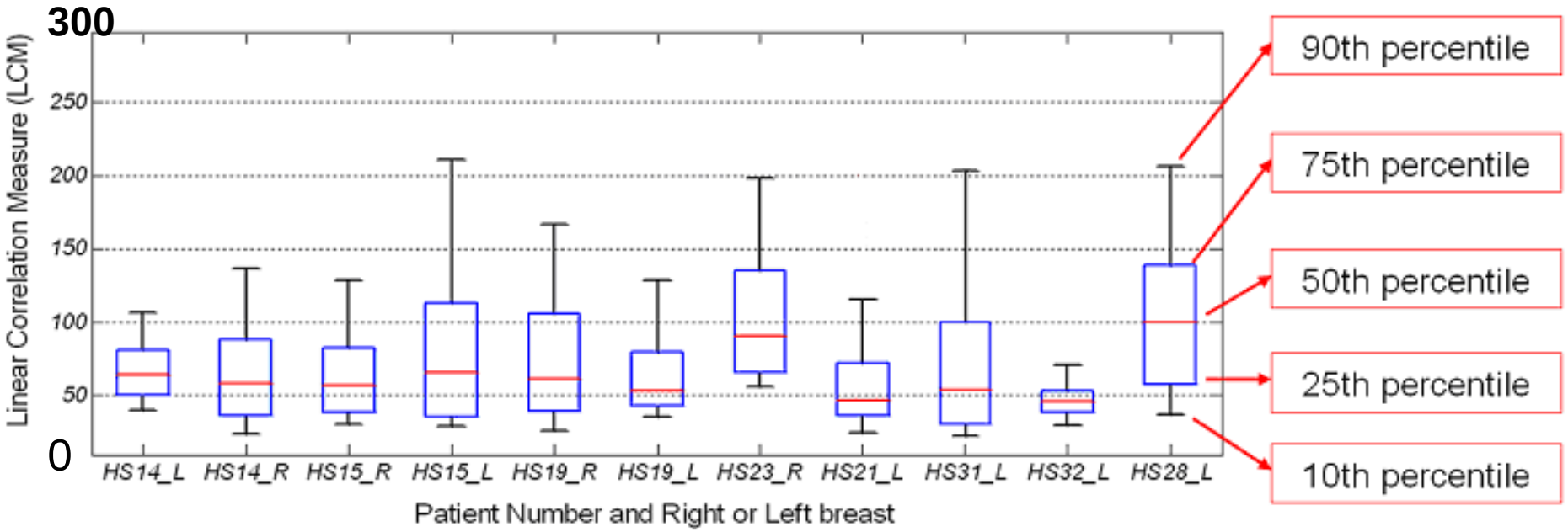
LCM Image of invasive ductal CA (HS10_L)





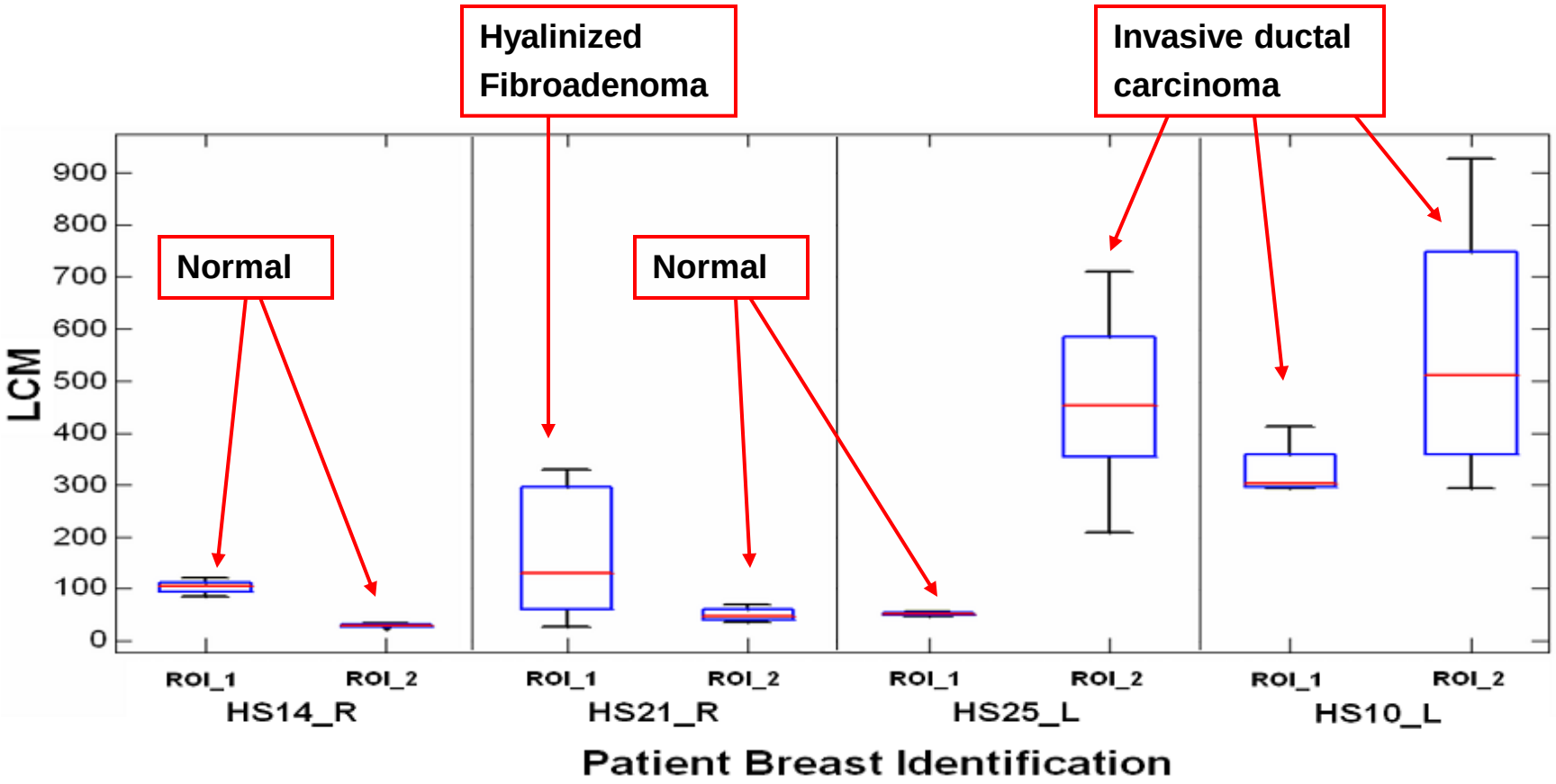
Gray scale image of LCM

LCM for 11 normal breasts



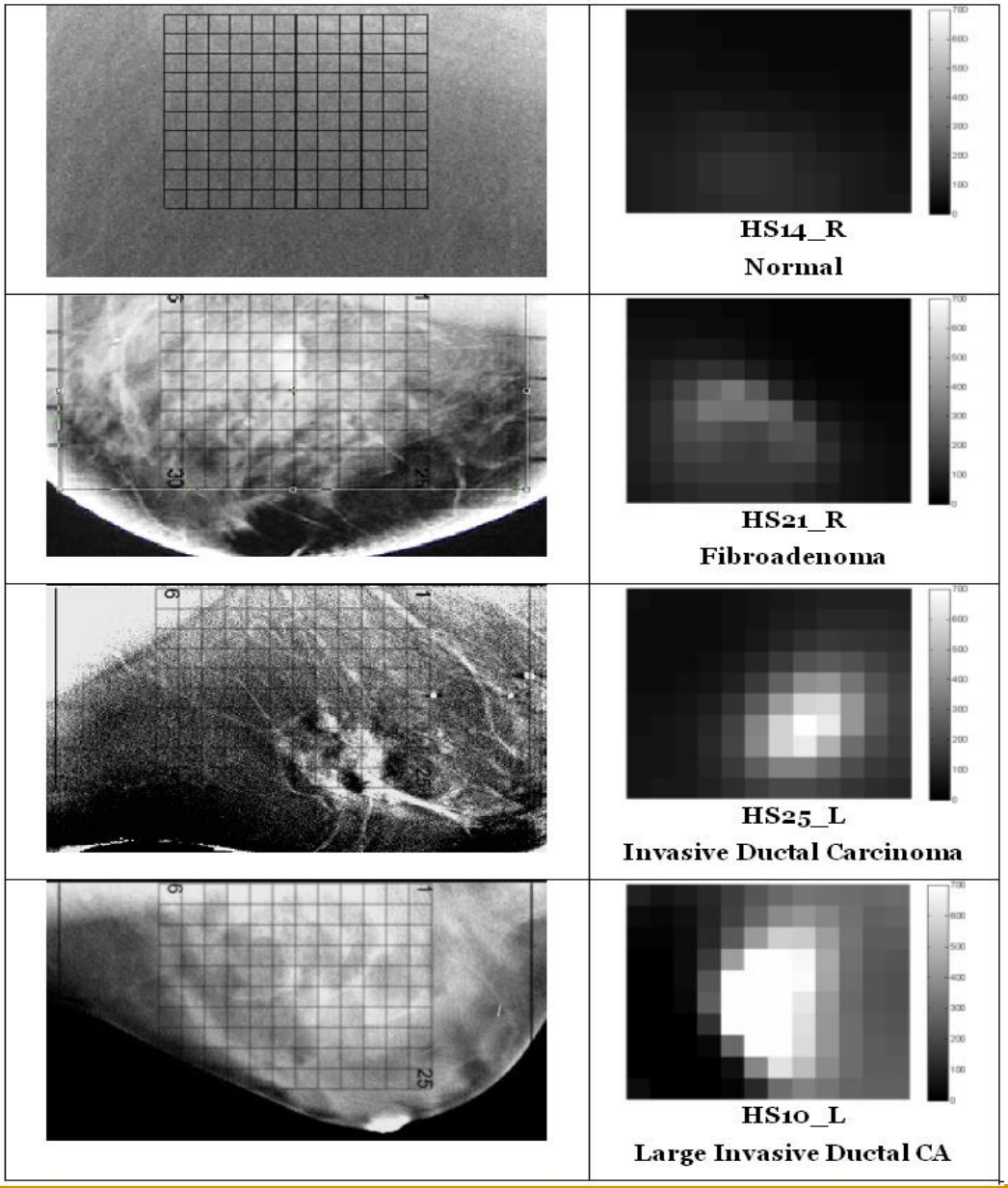
There are 120 EIS plots for layer 3 in each patient. The distribution of the LCM parameter in these plots is shown.

LCM for the regions of interest in 4 patients



The distributions of the LCM for the regions of interest identified. Note the LCM values are much larger for voxels associated with the malignant lesions.

LCM on the same scale



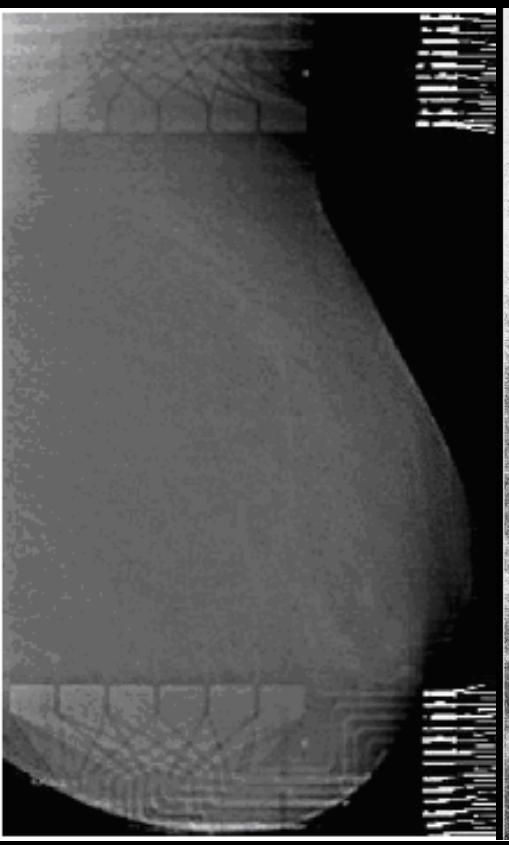
Normal Breast

Fibroadenoma

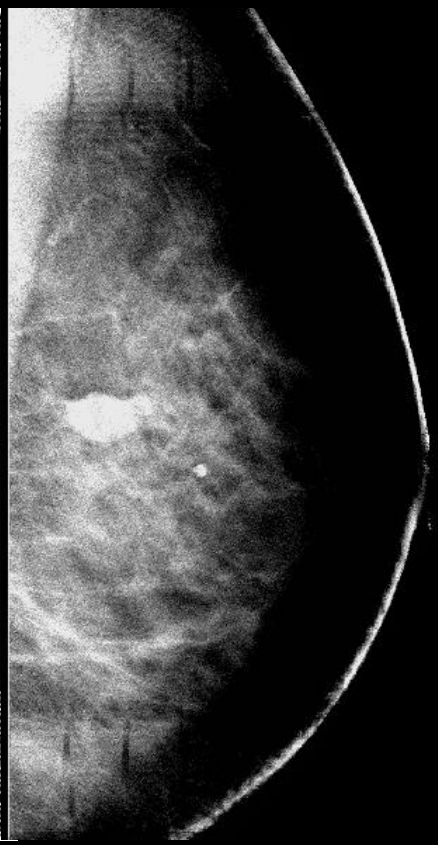
Invasive Ductal Carcinoma

Invasive Ductal Carcinoma

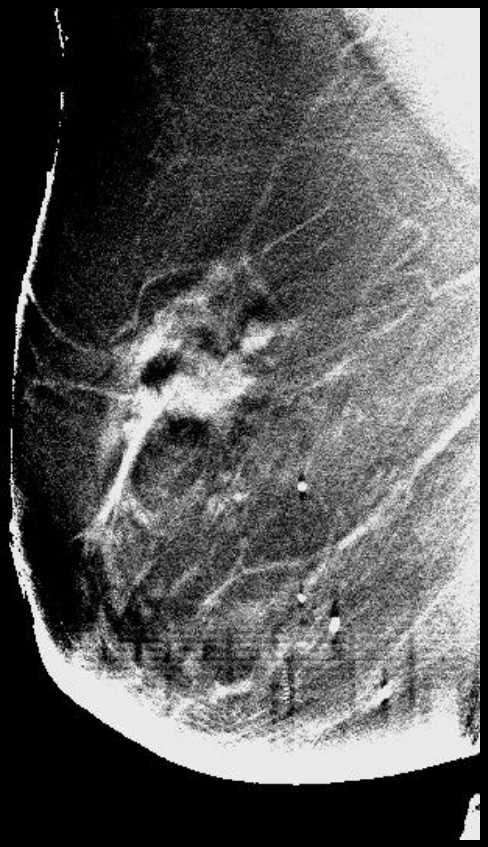
Which ones have cancer ?



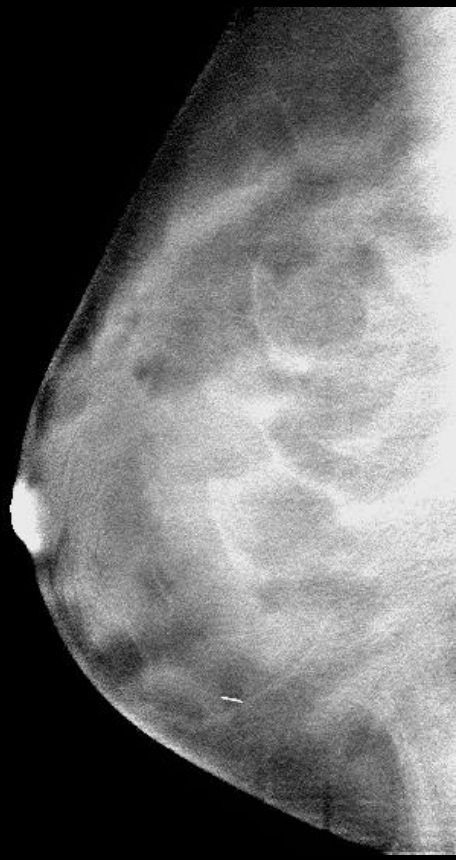
HS14R



HS21R

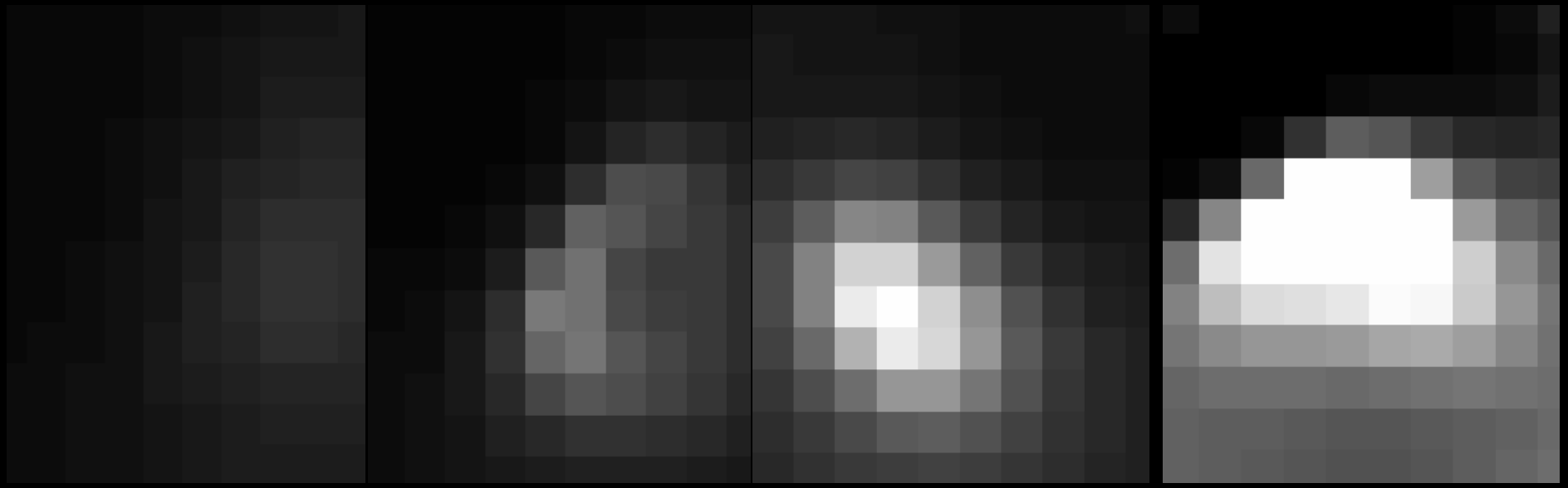


HS25L



HS10L

Which ones have cancer ?



HS14L

LCM=137

HS21L

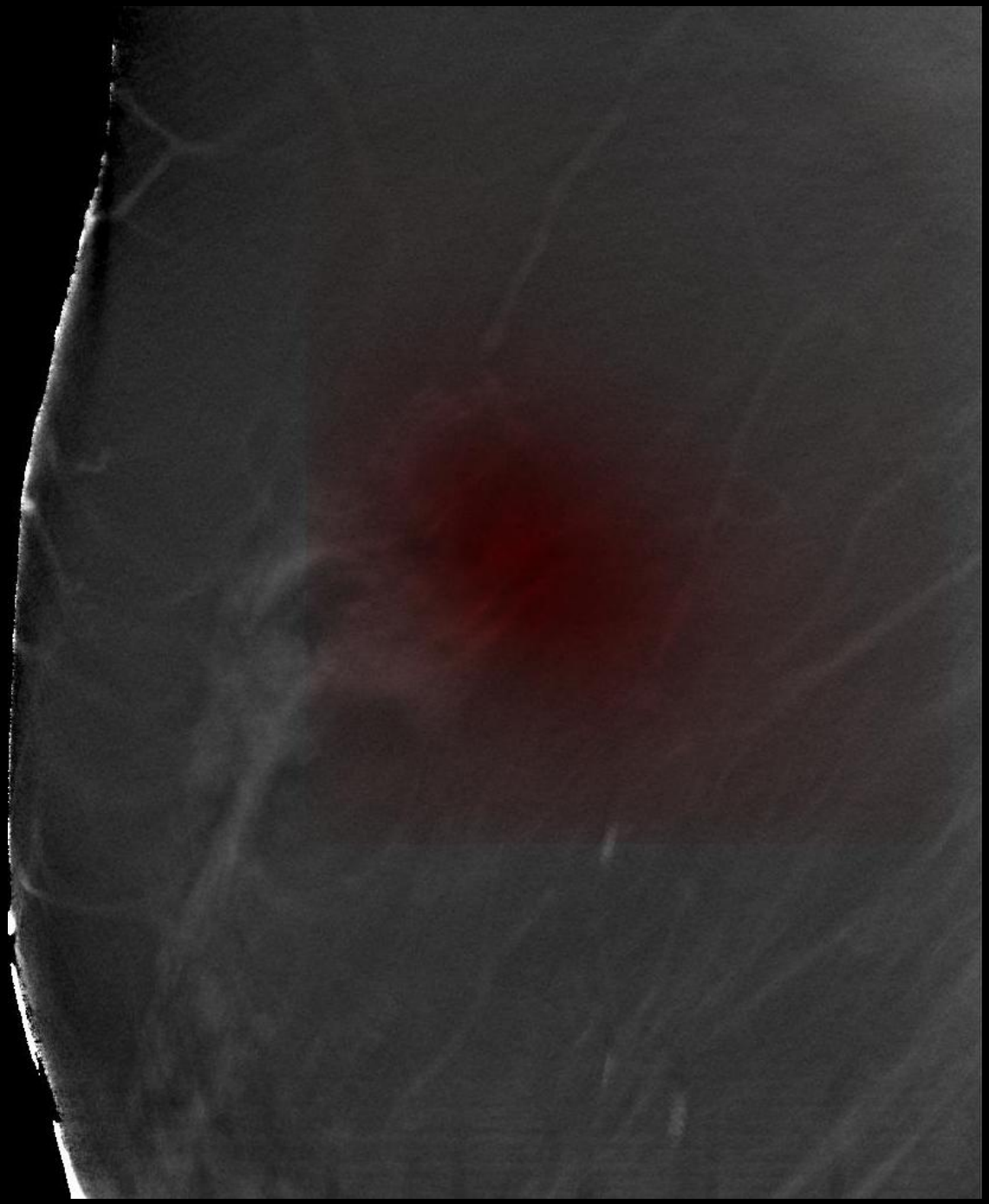
LCM=328

HS25R

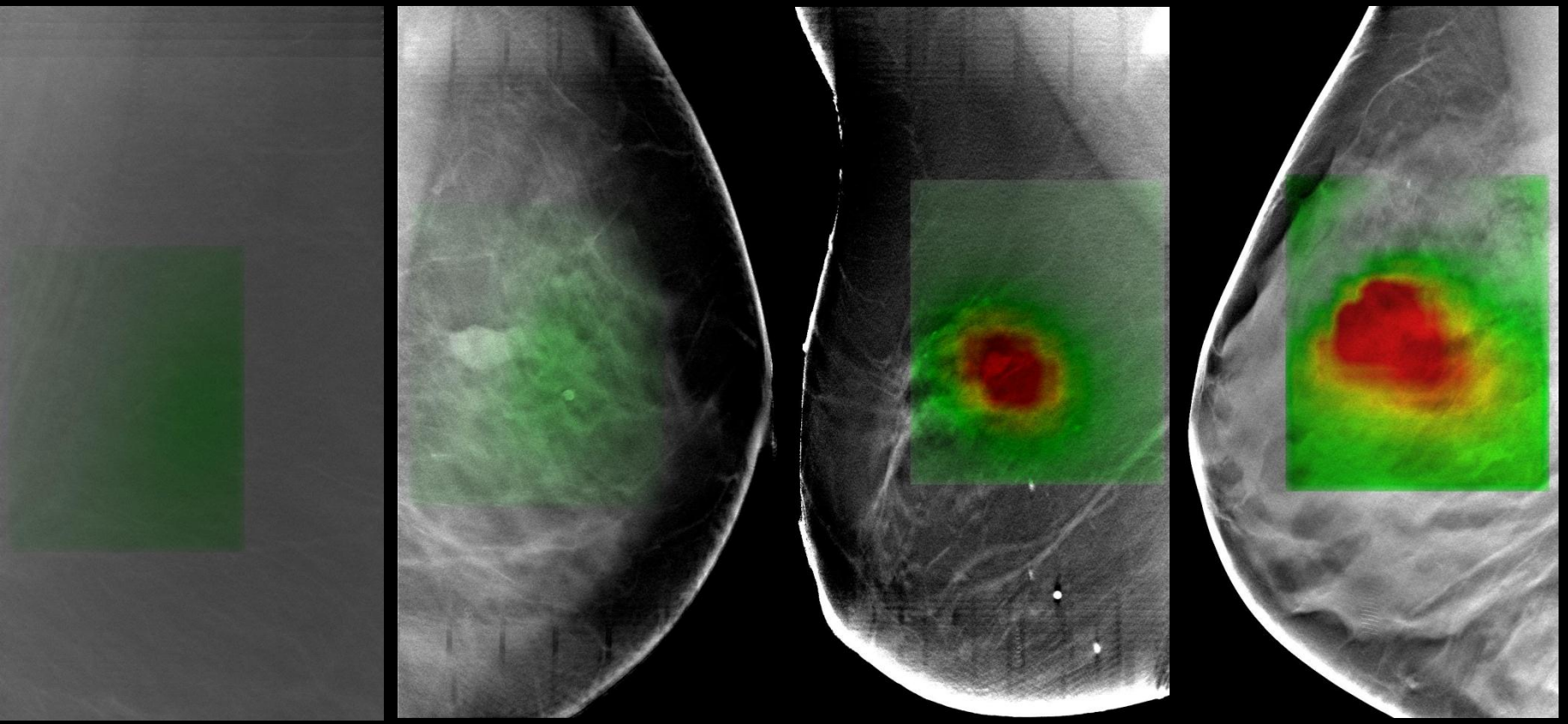
LCM=709

HS10R

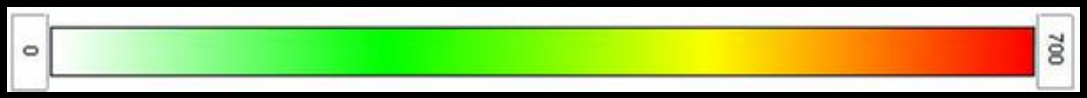
LCM=1230



Which ones have cancer?



HS14R HS21R HS25L HS10L



Can EIT Improve Sensitivity and Specificity in screening for Breast Cancer
?

Questions and Suggestions Happily Received by

isaacd@rpi.edu

Thank you,
especially

J.M., M.C., P.M.