30 Years of Computers in Medical Imaging

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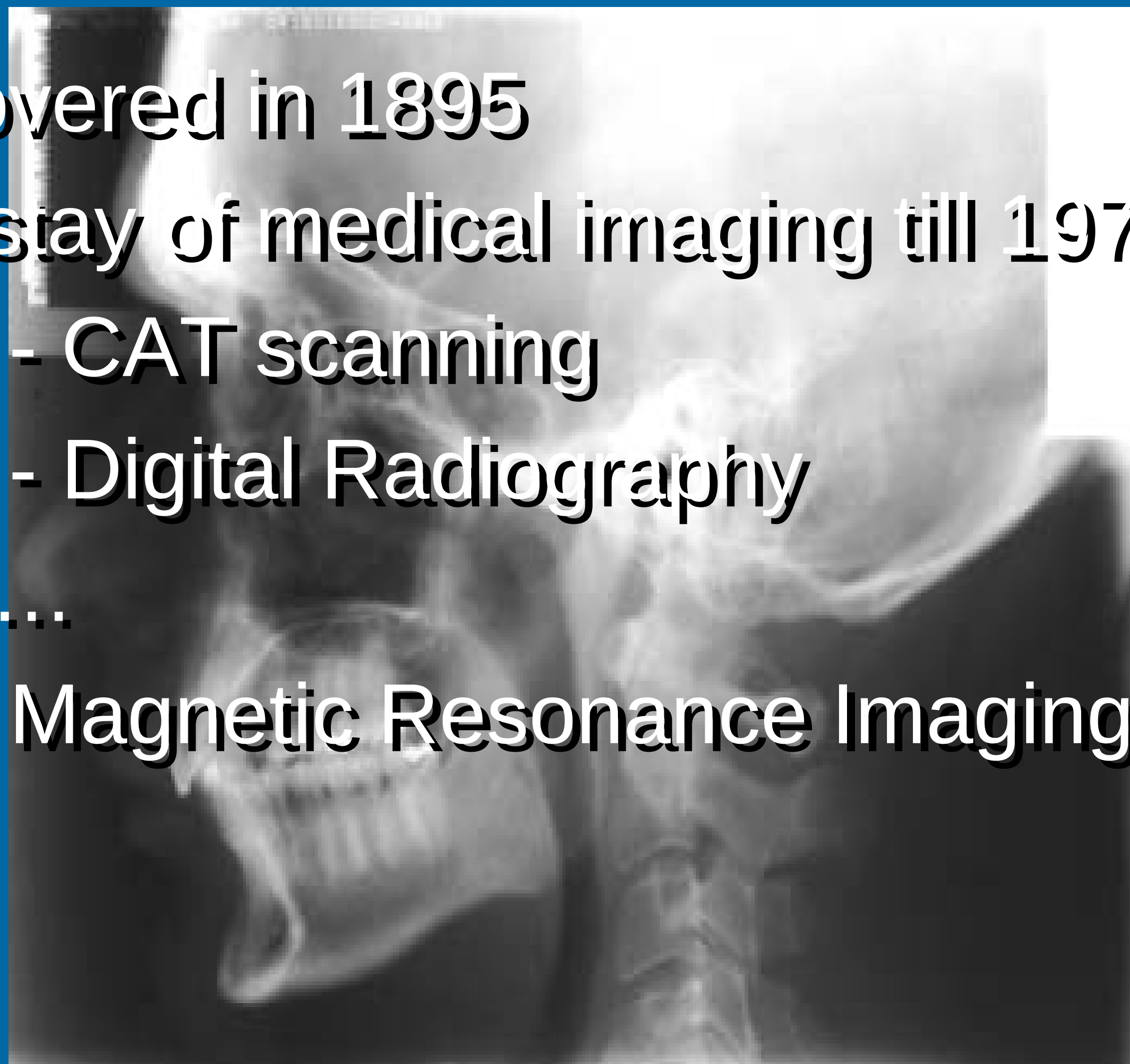
In the beginning…..X-rays



- Discovered in 1895
- Mainstay of medical imaging till 1970's
- 1971 - CAT scanning
- 1978 - Digital Radiography

……….

- 1980 Magnetic Resonance Imaging

Advent of the Digital Computer

- Late 1960's: Computers used to perform complex mathematics to reconstruct and process images
- Systems developed to display images
  - Early images presented by over-printing characters on line-printer!
- Directly responsible for enabling development of CT

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The Beginnings of CT

- J Radon 1917 “The Radon Transform”
  - Mathematical underpinnings of CT
- Ronald Bracewell (Stanford) 1956
  - Radio Astronomy
  - Reconstruction of radio sources from radio-telescope signals
  - Mathematics similar to CT reconstruction
  - Reconstructed images using mechanical calculator! (3 instructions/min?!)

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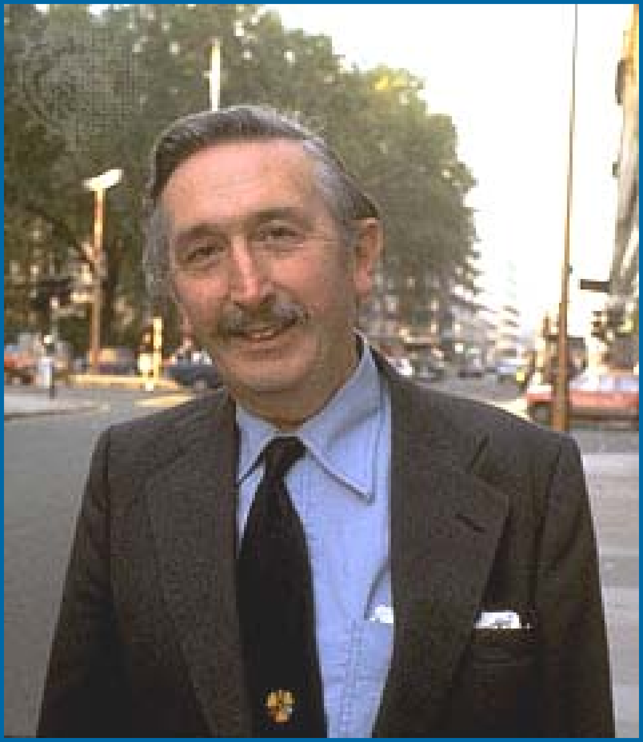
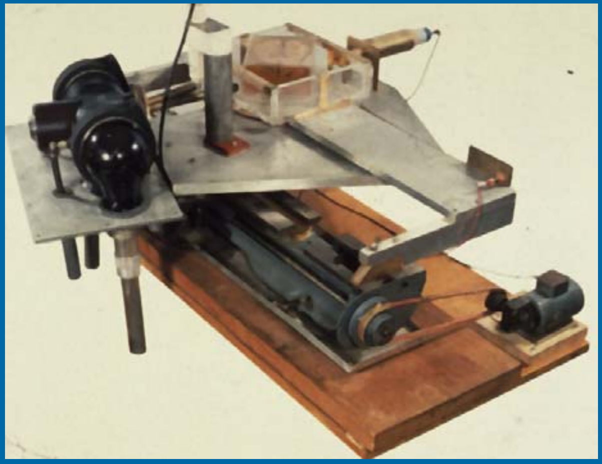
Sir Godfrey Hounsfield

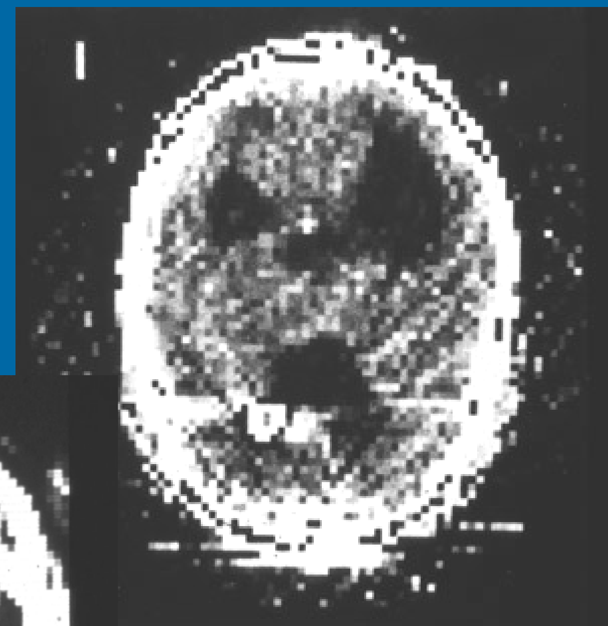
- Engineer for EMI PLC
- Nobel Prize 1979 (with Alan Cormack)
- Knighted 1981

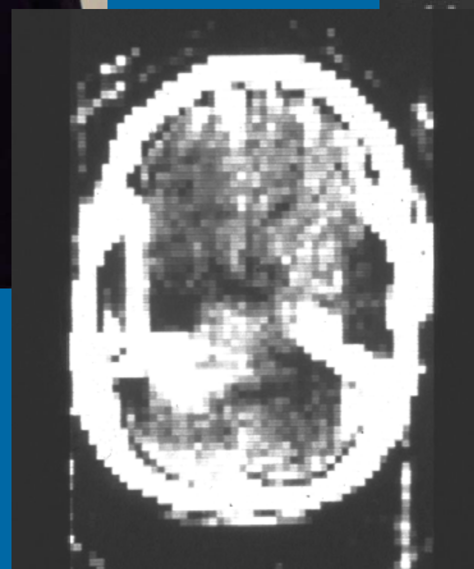




Early CT

The EMI-Scanner

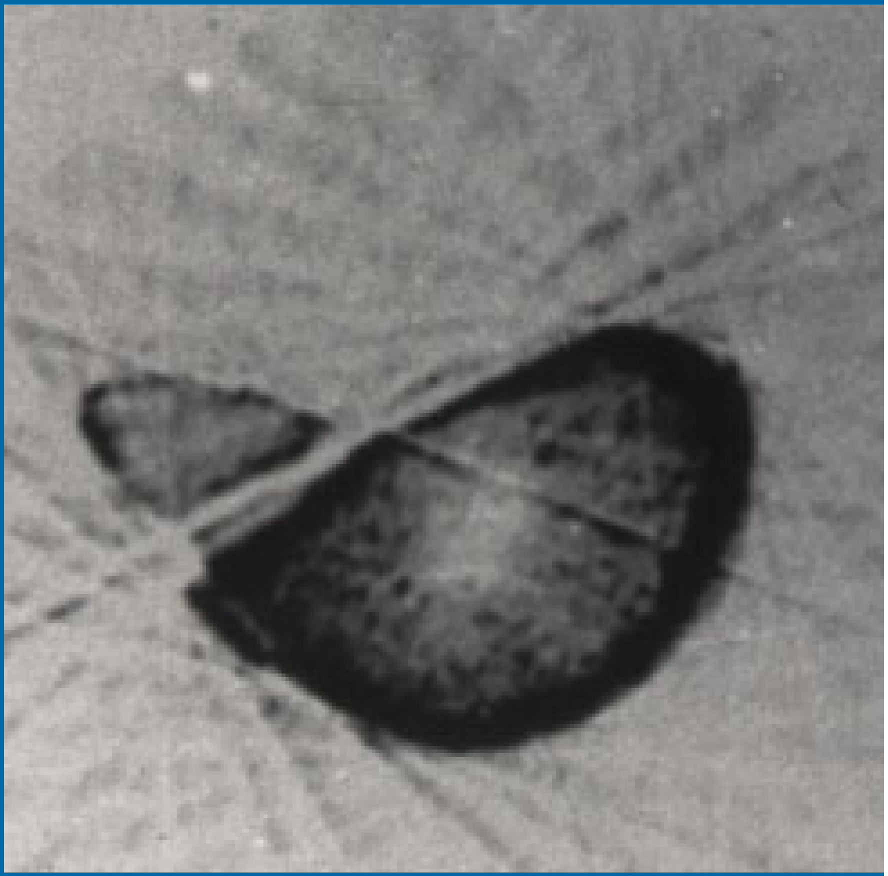




"Maybe potential world market for 6 CT machines" – EMI 1972

Clinical Acceptance of CT!?

- Dr James Ambrose 1972
  - Radiologist, Atkinson - Morley's Hospital London
  - Recognised potential of EMI-scanner
- "Pretty pictures, but they will never replace radiographs" – Neuroradiologist 1972



First NZ CT scan (1971)

Then (1974)……………..and Now

- 80 x 80 image
- 3 mm pixels
- 13 mm thick slices
- Two simultaneous slices!!!
- 80 sec scan time per slice
- 80 sec recon time

- 512 x 512 or 1024 x 1024 image
- <1mm slice thickness
- <0.5mm pixels
- <0.5 sec rotation
- <0.5 sec recon per slice
- Isotropic resolution
- Spiral scanning - up to 16 slices simultaneously

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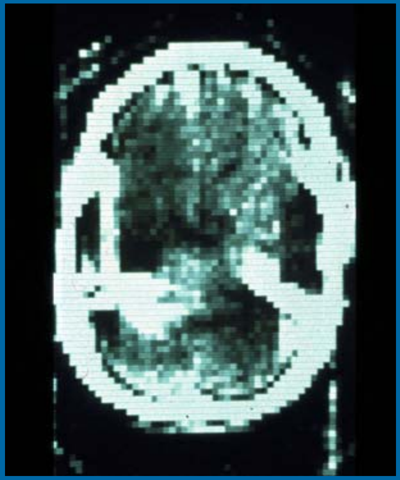
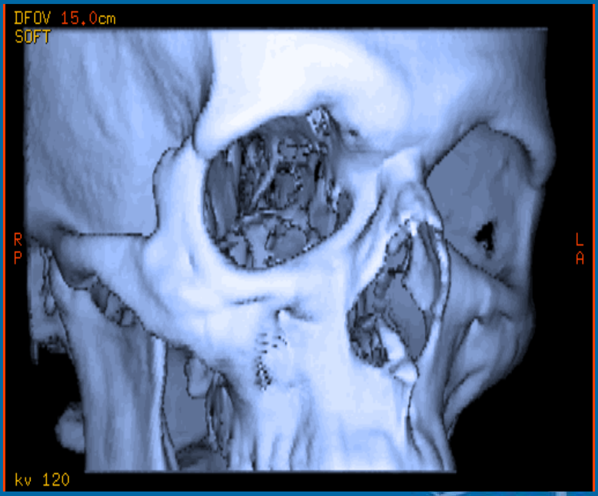
30 Years of CT





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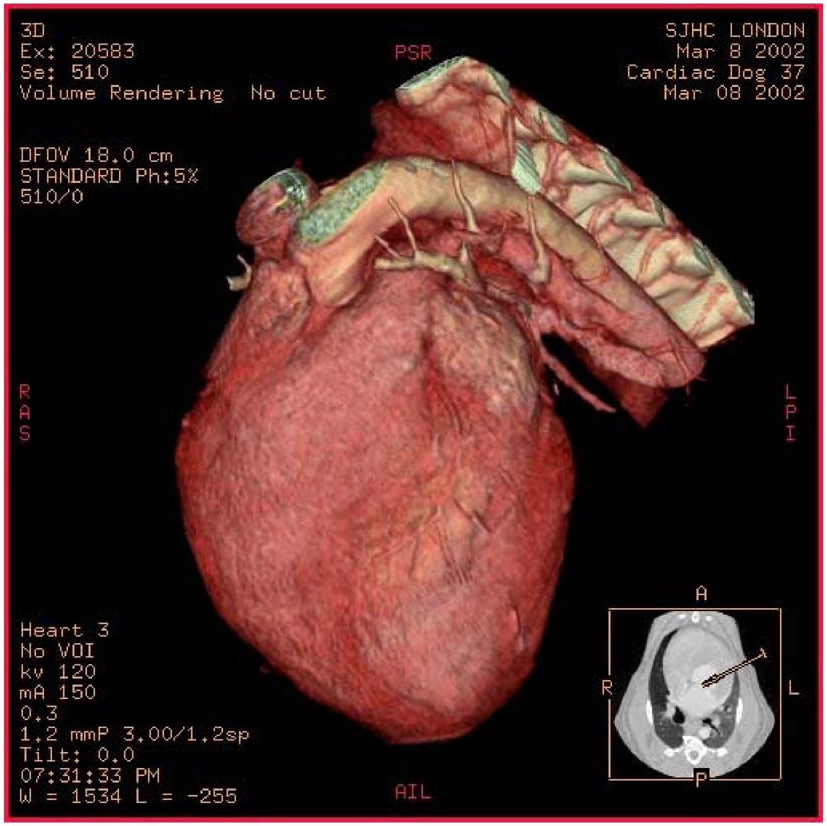
Dynamic CT


3D
Ex: 20583
Se: 510
Volume Rendering No cut
DFOV 18.0 cm
STANDARD Ph:5%
510/0
PSR
SJHC LONDON
Mar 8 2002
Cardiac Dog 37
Mar 08 2002
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Heart 3
No VOI
kv 120
mA 150
0.3
1.2 mmP 3.00/1.2sp
Tilt: 0.0
07:31:33 PM
W = 1534 L = -255
AIL
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R
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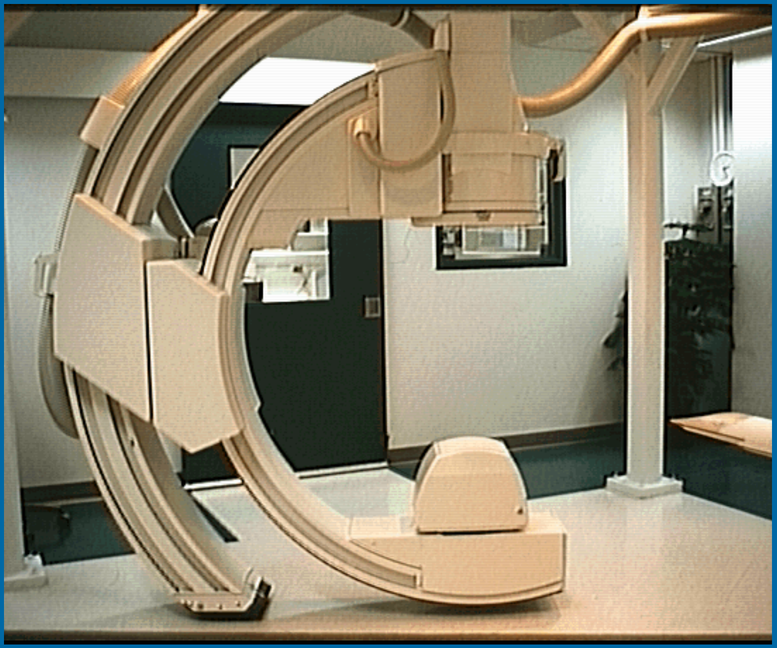
P

Digital Subtraction Angiography

- Inject x-ray contrast into arterial system
- Acquire images before and after injection
- Subtract "before" image from "after" image
- Result is image of vessels only
- Early promise of Intra-venous DSA not fulfilled

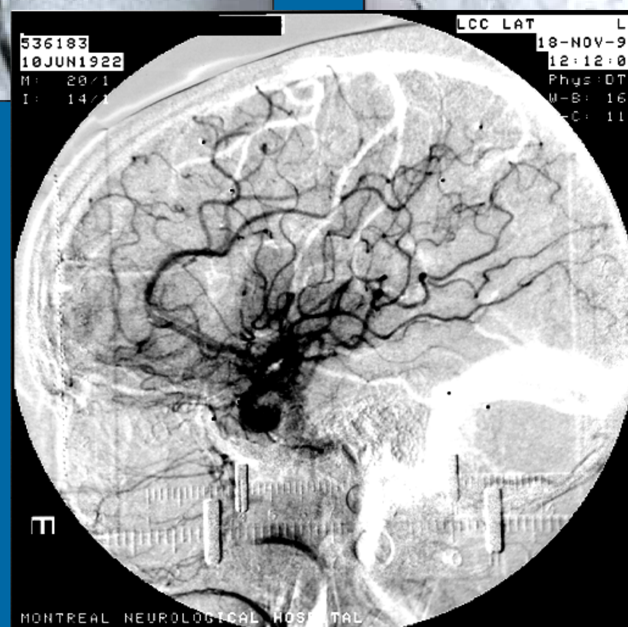


C-arm for DSA

DSA Examples

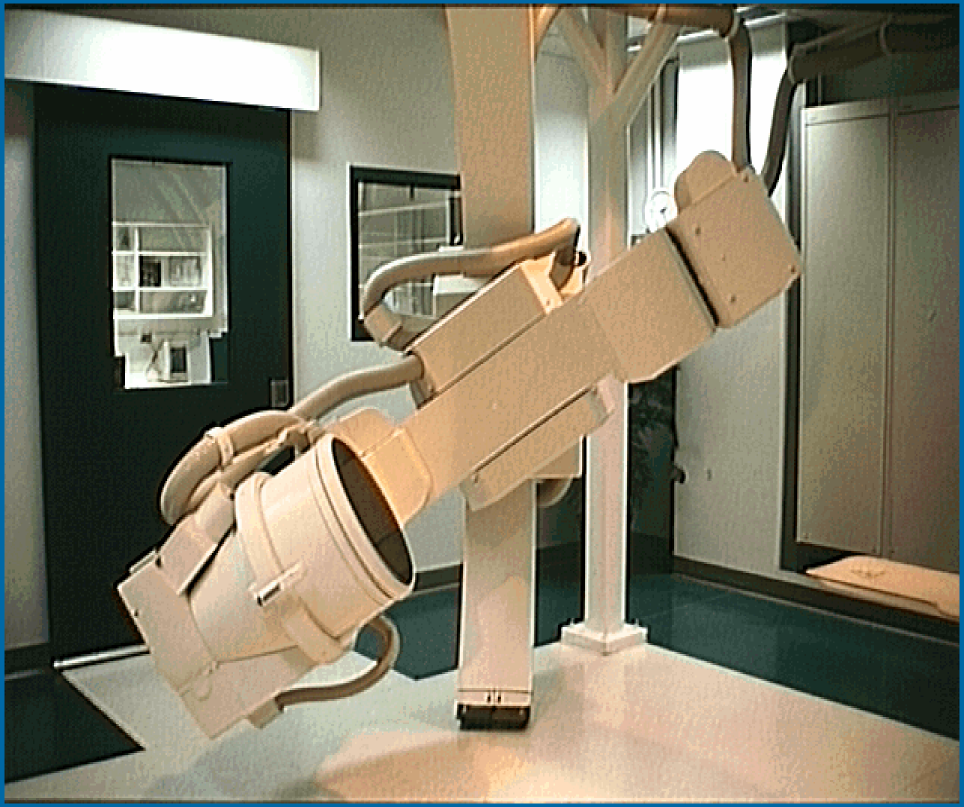
Arterial phase

Venous phase



Double-subtracted

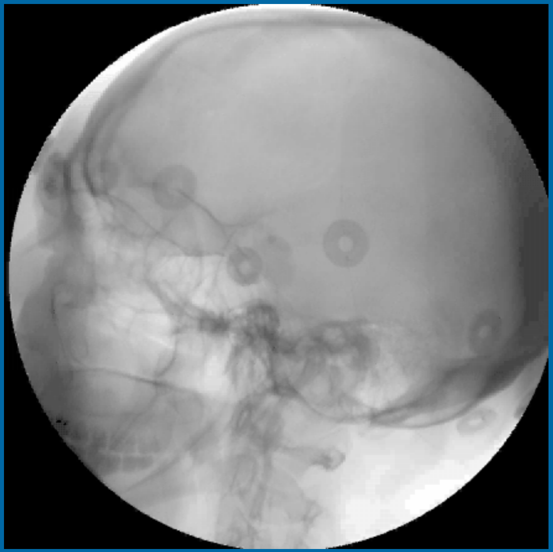
C-arms are not just for Angiography!



3-D Angiography

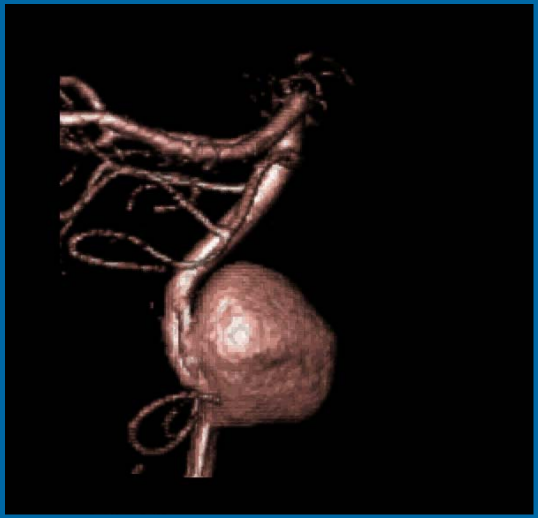
- Computed Rotational Angiography – CRA
- Cone-beam CT acquired with C-arm geometry
- Volumetric data collected
- 4-sec rotation
- 0.4mm isotropic resolution
- 3D images of vessels and bone

C-Arm CT for Vascular Disease



Projections

MIP Reconstruction



Volume-rendering

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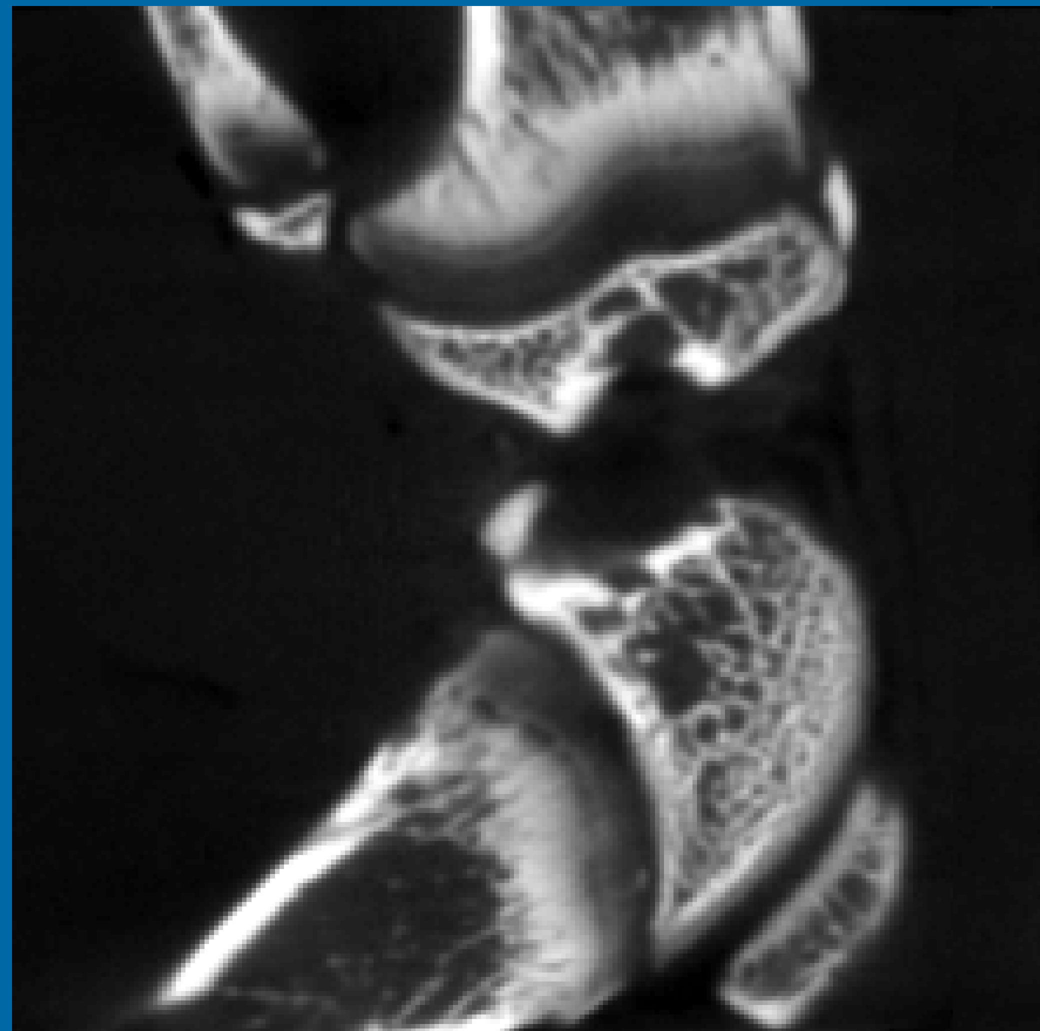
3-D µQCT: Specimen scanner

- Bench-top system for small specimens/animals

Results: in vitro 3-D µQCT

- rat knee; 55 kVp,
- 0.025 mm isotropic voxels,
- 20 minute acquisition



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Results: in vitro 3-D μQCT

- rat spine; 55 kVp, 0.025 mm isotropic voxels, 20 minute acquisition

NMR

- Nuclear Magnetic Resonance
- Imaging via magnetic properties of tissue
- Roots in Physics and Chemistry labs
- Built on mathematical foundation of CT
- Became MRI in medical imaging community …. "Nuclear" considered politically incorrect!
- "Most important medical breakthrough since the invention of X-rays"

MRI

- Patient in magnetic field in tube
- RF signals excite protons
- Wobbling H nuclei emit radio waves
- Varying spatial fields create different radio frequencies
- Received signals reconstructed into images

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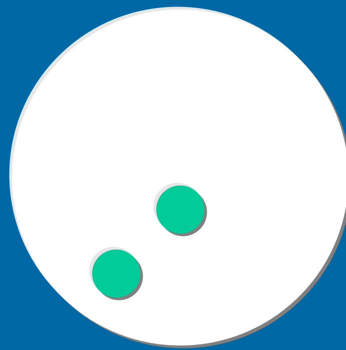
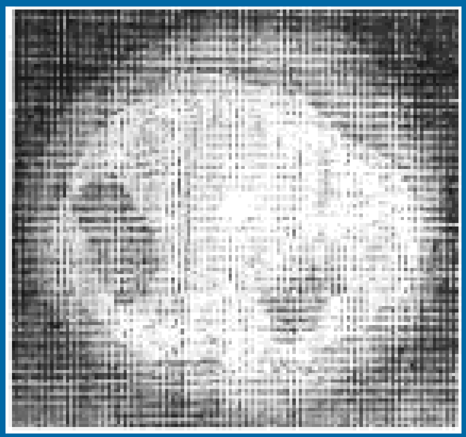
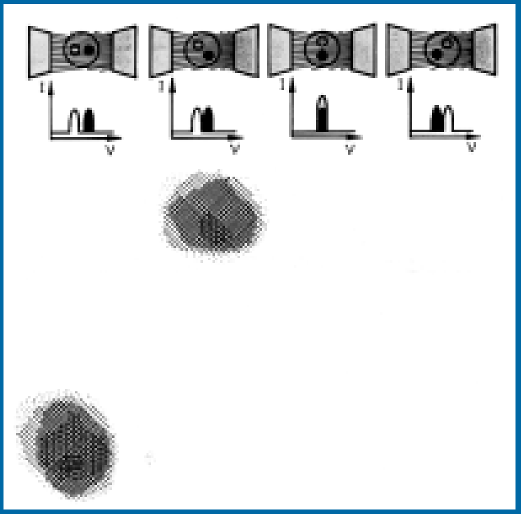
Birth of MRI

- Paul Lauterbur 1973 -Nature – “Image formation by induced local interaction; examples employing magnetic resonance”.
- 1975 Presented at CT meeting Stanford
  - “Zeugmatography”
    - **Magnets!?**
    - **Gradients?!**
    - **Clinical Applications?**
- Raymond Damadian 1977 – relaxation times and cancer
- Sir Peter Mansfield - early 1980’s
  - Slice-selection
  - Rapid imaging





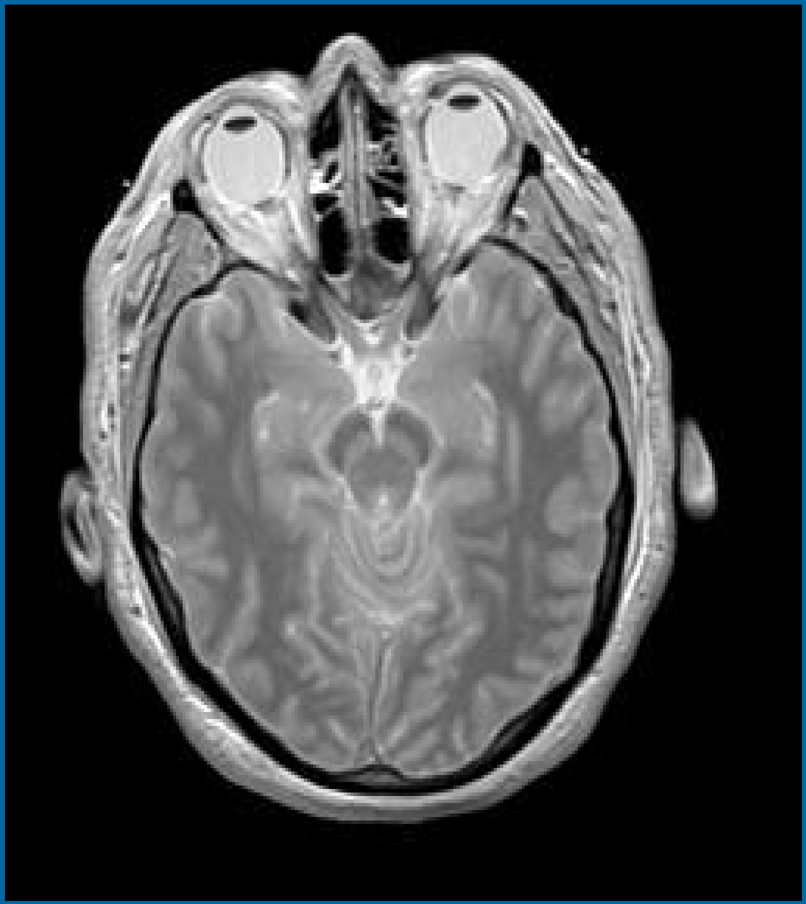
Early Thorax Image Nottingham



Zeugmatography image of Water-filled test tubes

30 Years of MRI

First brain MR image



Typical T2-weighted MR image

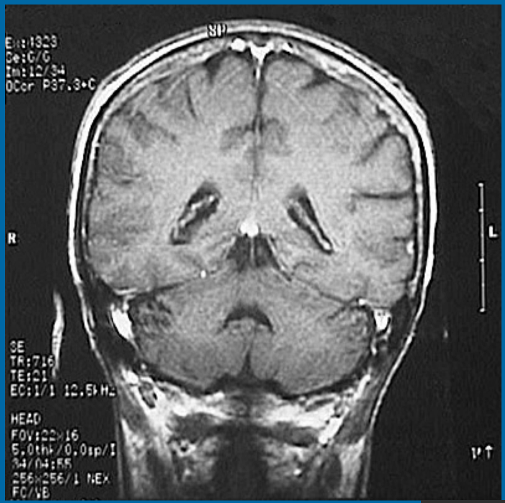
MR Imaging

- “Interesting images, but will never be as useful as CT”
  - (A different) neuroradiologist, 1982

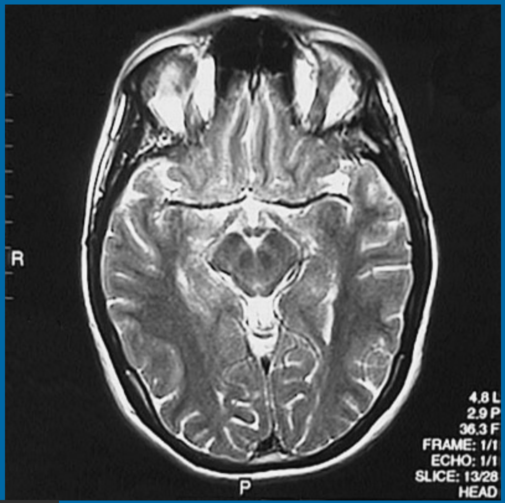
MR Image Contrast

- CT – Electron density
- MRI – Proton density
  - T1 Relaxation
  - T2 Relaxation
  - Diffusion
  - Perfusion
  - Flow
  - Spectral frequency

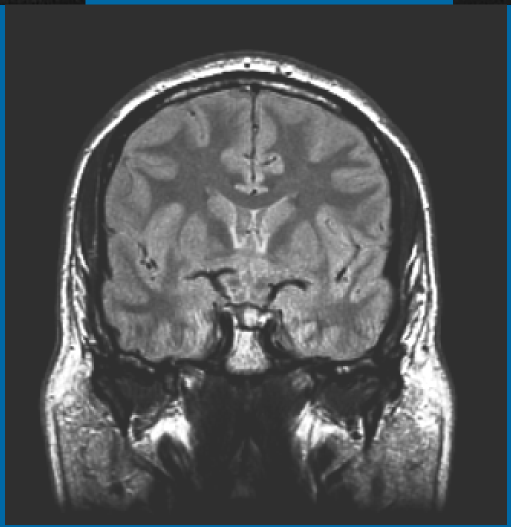
MRI Contrast



T1



T2



PD

MR Imaging …more than T1 and T2

- MRA - Magnetic resonance angiography
  - images of vessels
- MRS - Magnetic resonance spectroscopy
  - images of chemistry of the brain and muscle metabolism
- fMRI - functional magnetic resonance imaging
  - image of brain function
- PW MRI – Perfusion-weighted imaging
- DW MRI – Diffusion-weighted MRI
  - images of nerve pathways

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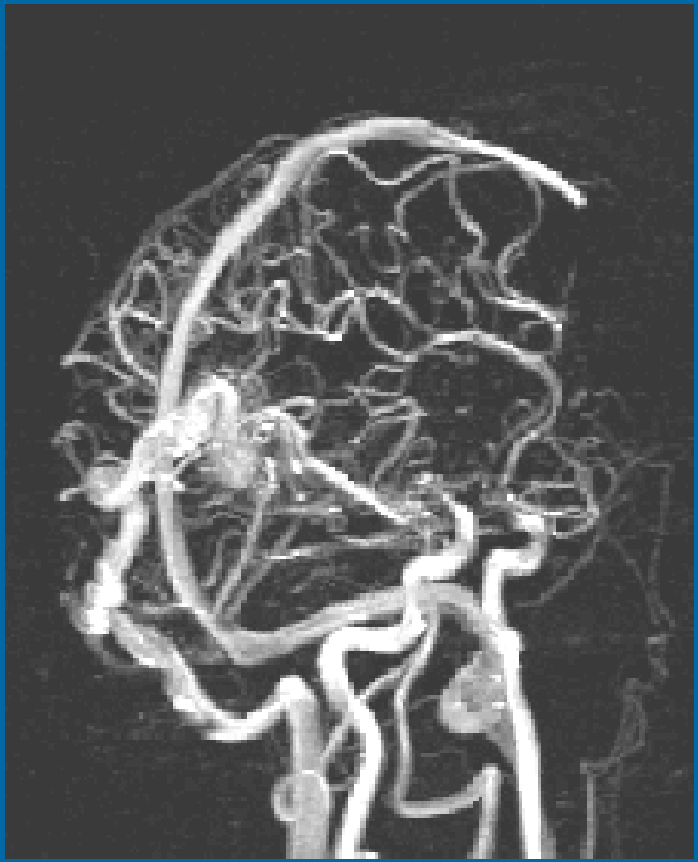
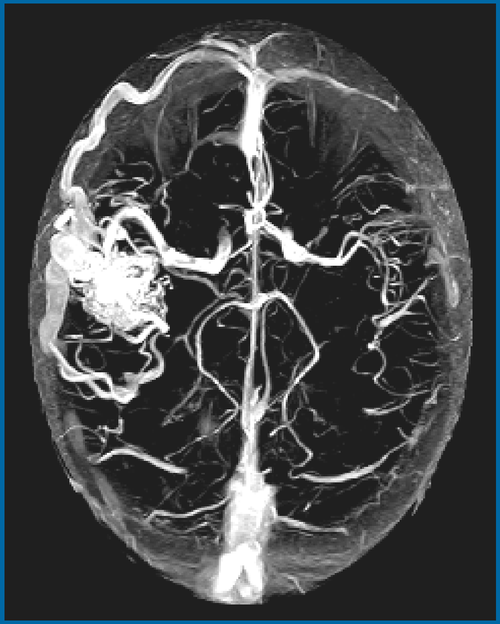
Magnetic Resonance Angiography

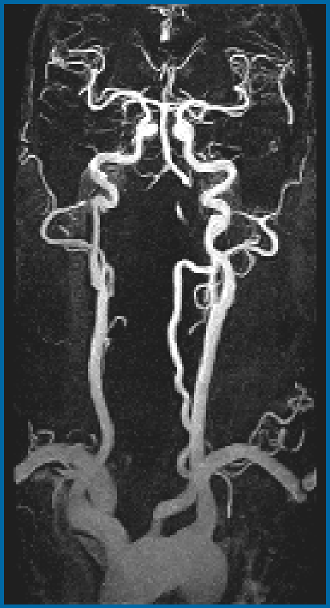
- MR scanner tuned to measure only moving structures
- “Sees” only blood - no static structure
- Generate 3-D image of vasculature system
- May be enhanced with contrast agent e.g. Gd-DTPA



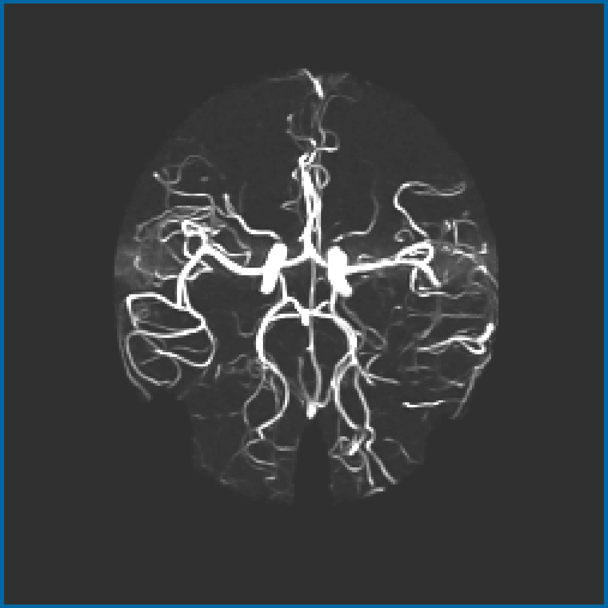
MR Angiography



GD-enhanced



GD-enhanced



Phase-contrast

In-flow

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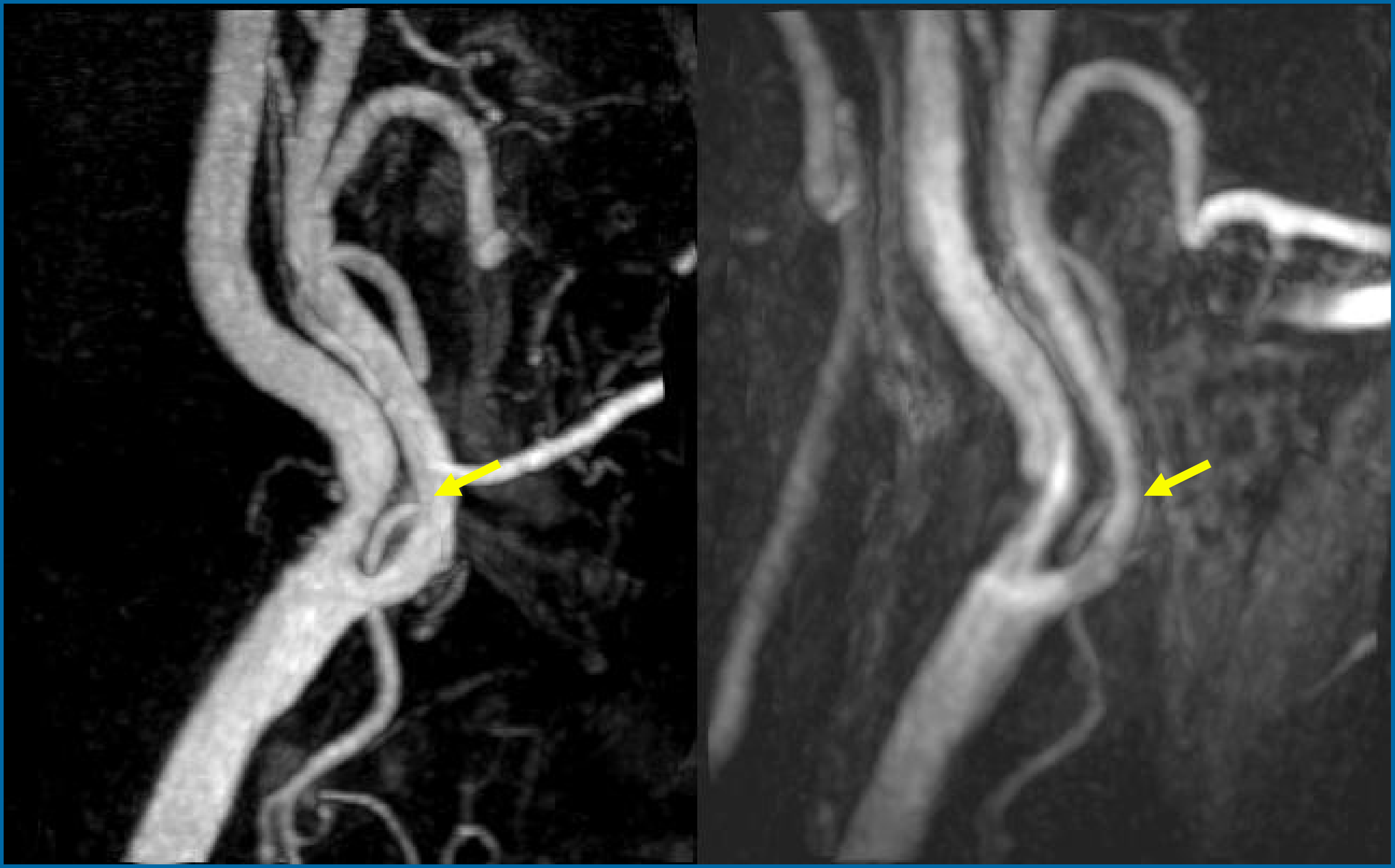
3D X-ray vs high-resolution MR



- excellent depiction of lumen surface

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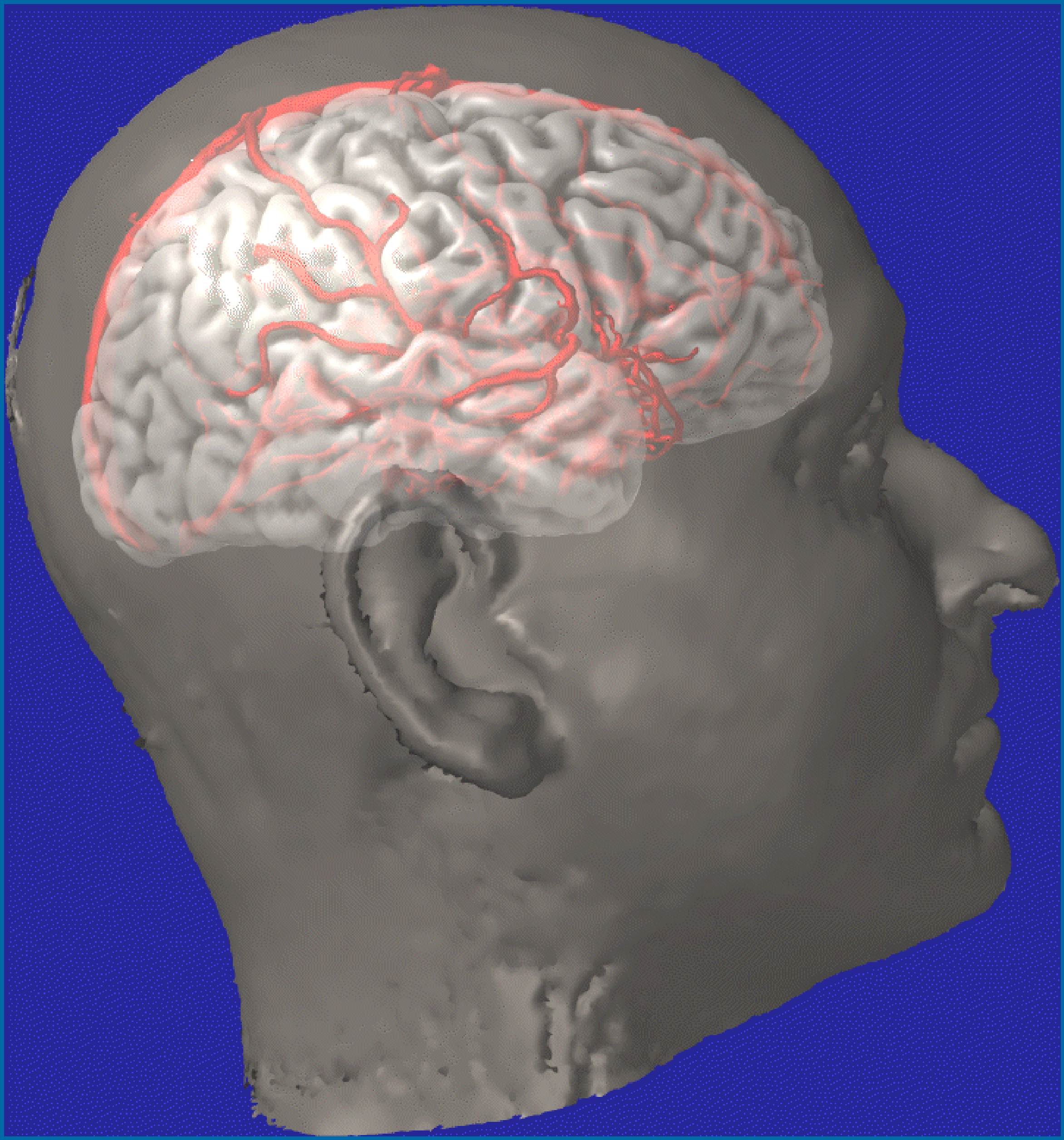

Dr. Bruce Pike MNI

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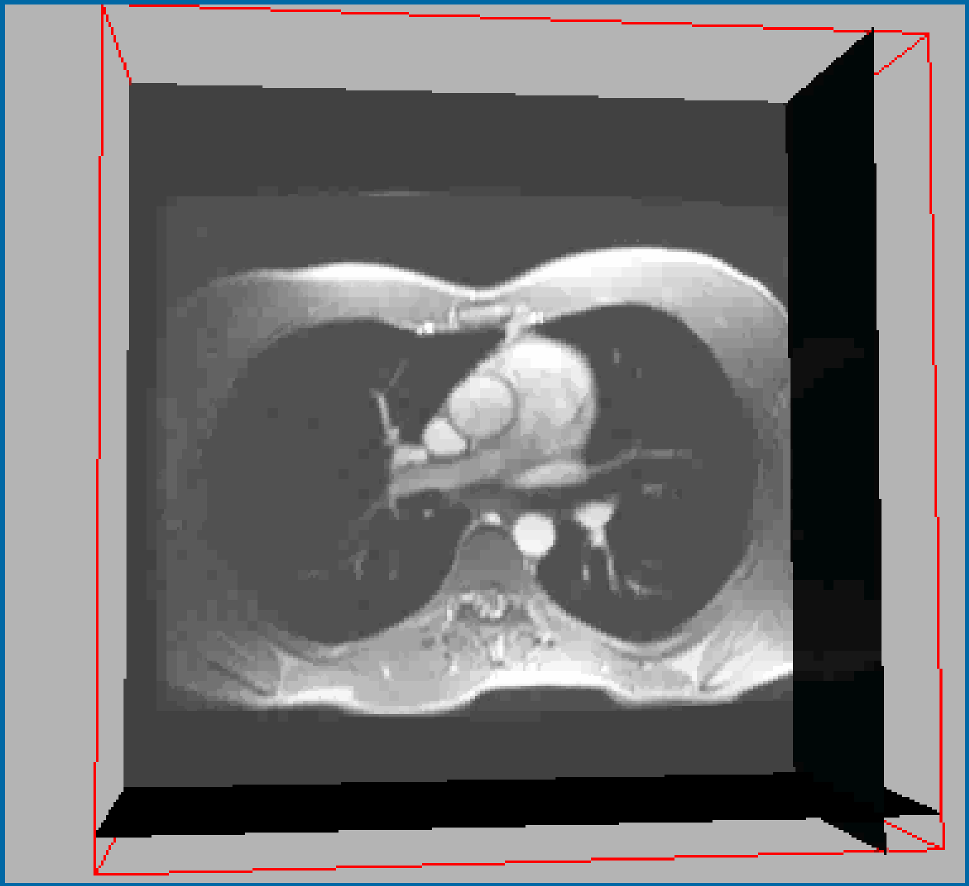
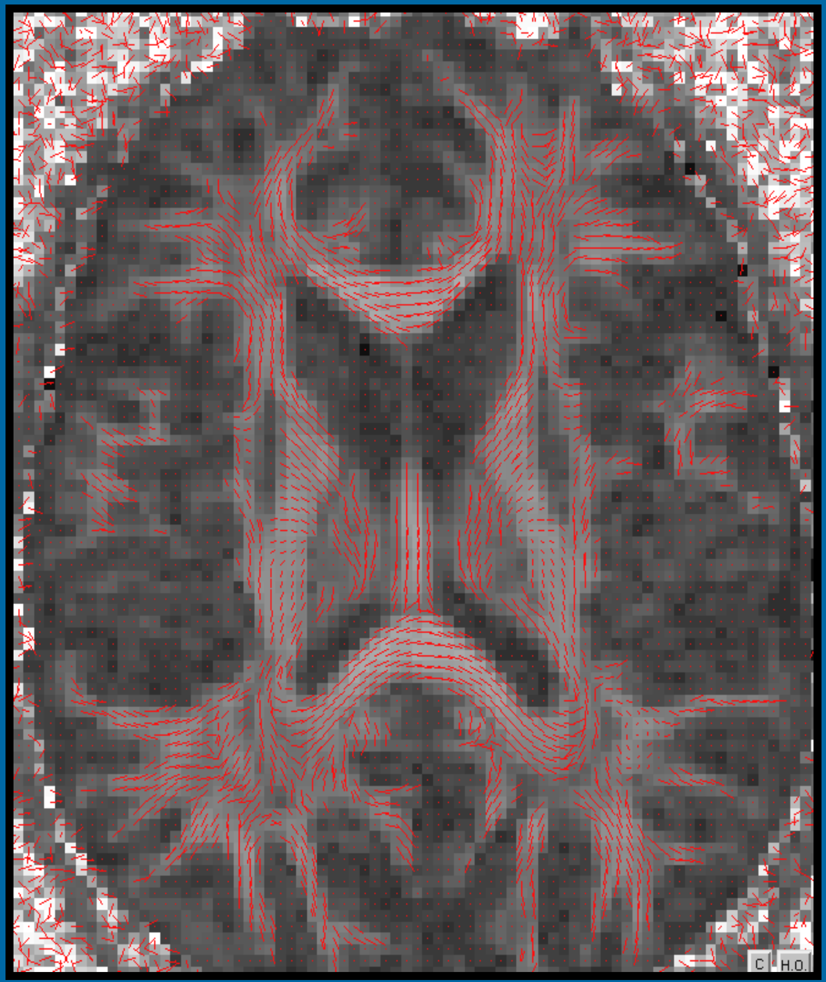
Dynamic 3-D MRI of the thorax



1 www.atamai.com

Diffusion-Weighted MRI

- Image diffuse fluid motion in brain
- Construct “Tensor image” – extent of diffusion in each direction in each voxel in image
- Diffusion along nerve sheaths defines nerve tracts.
- Create images of nerve connections/pathways



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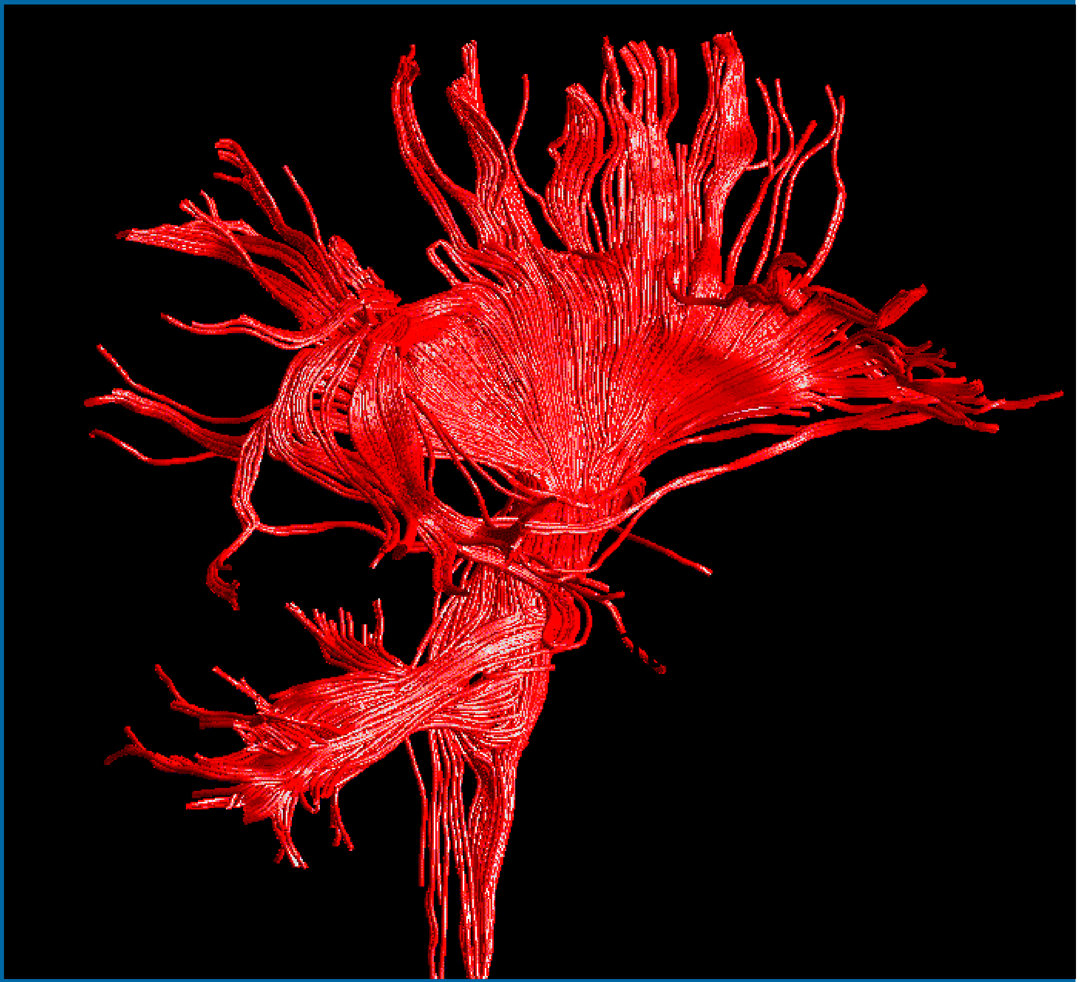
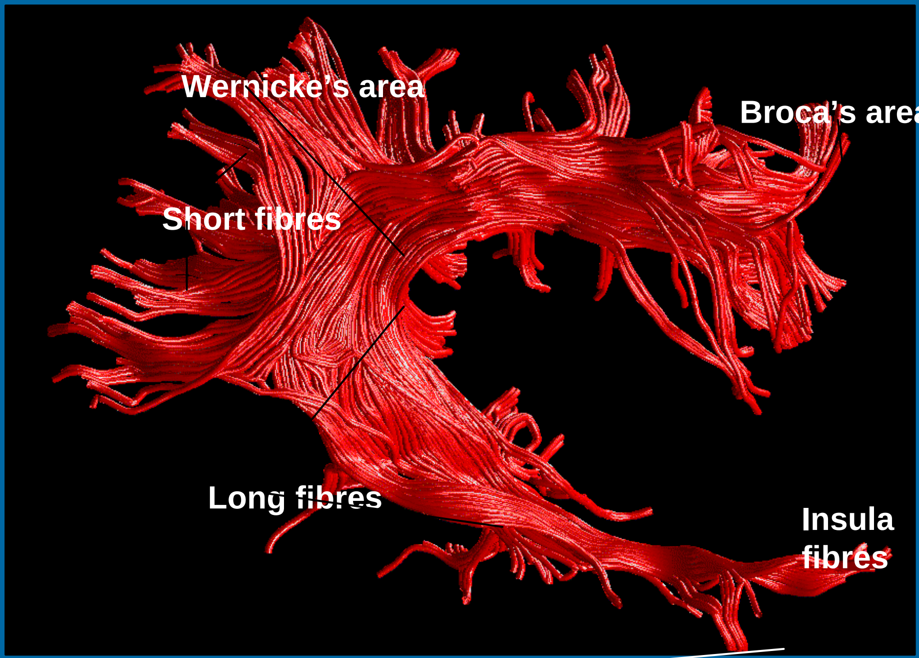
Tractography

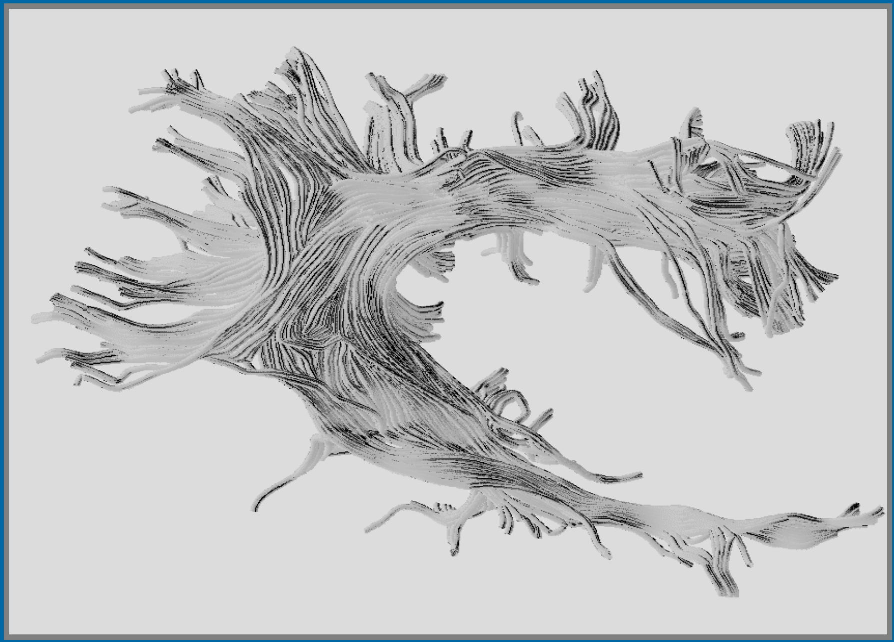
- Data analysed after scanning
- Identify "streamlines" of vectors
- Connect to form fibre tracts
- 14 min scan time



- Dr. D Jones, NIH

Tractography





"just like Gray's Anatomy"!

Superior

Longitudinal Fasciculus

- Dr. D Jones, NIH USA

Functional MRI (fMRI)

- Active brain regions demand more fuel (oxygen)
- Activate brain regions with specific tasks
- Oxygenated blood generates small (~1%) signal change
- Correlate signal intensity change with task
- Represent changes on anatomical images

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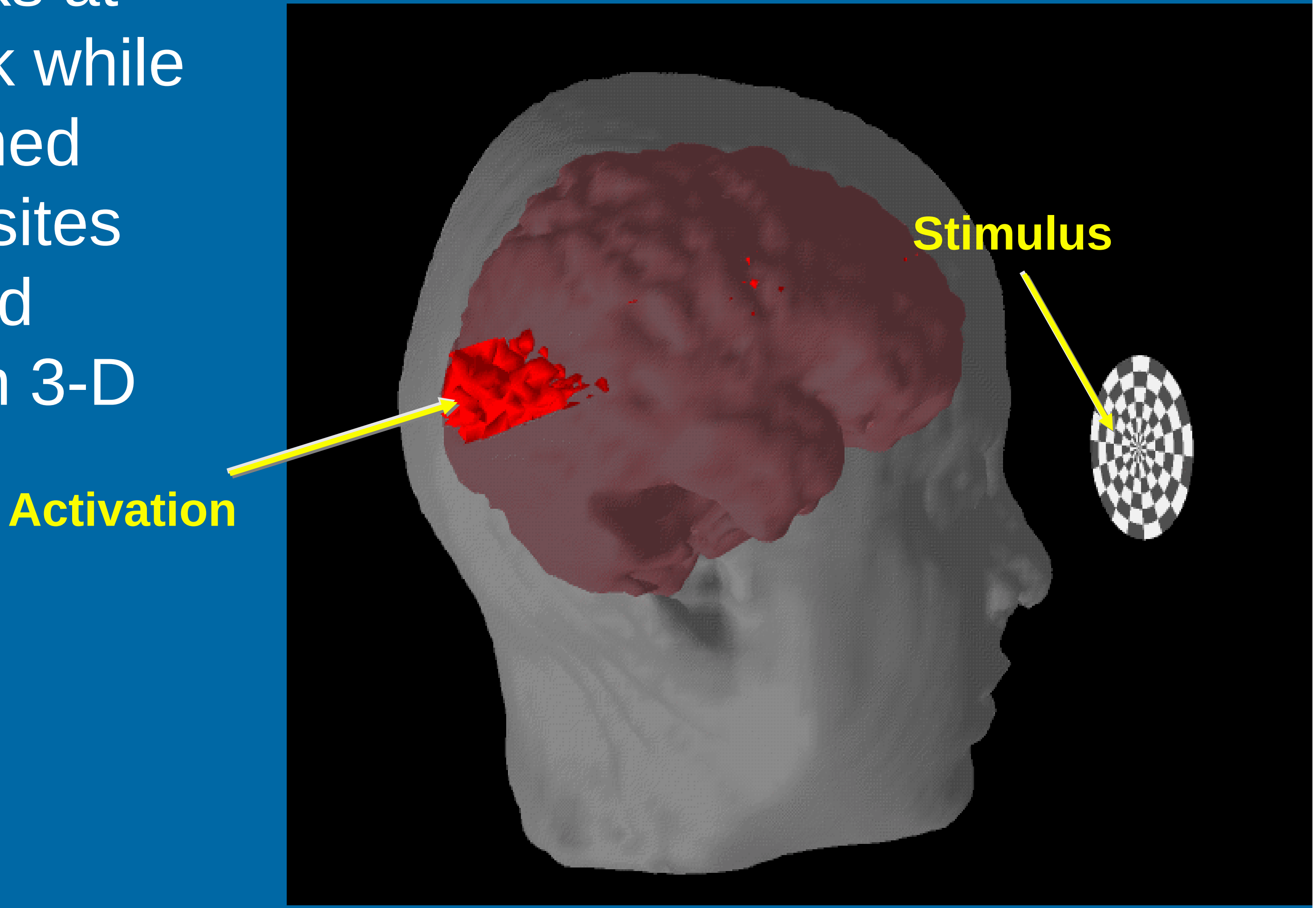
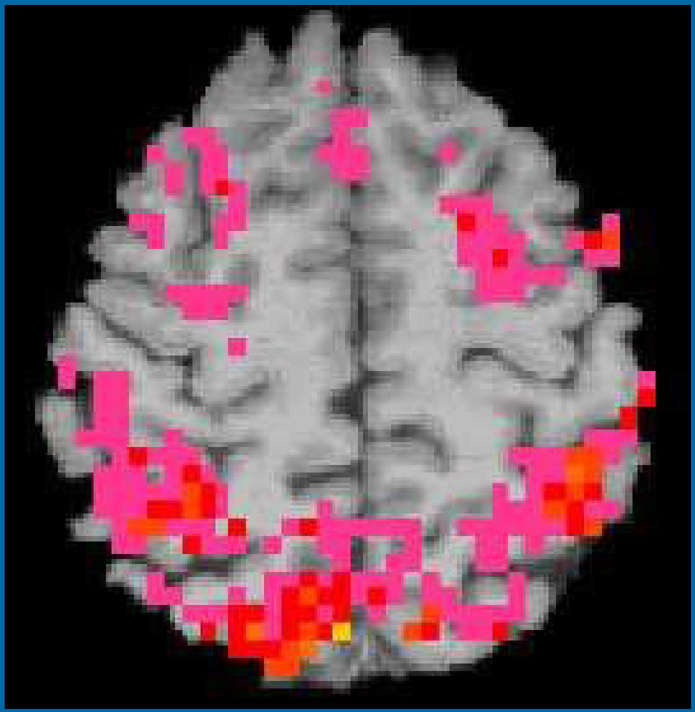
fMRI

Subject looks at flashing disk while being scanned
"Activated" sites detected and merged with 3-D MR image

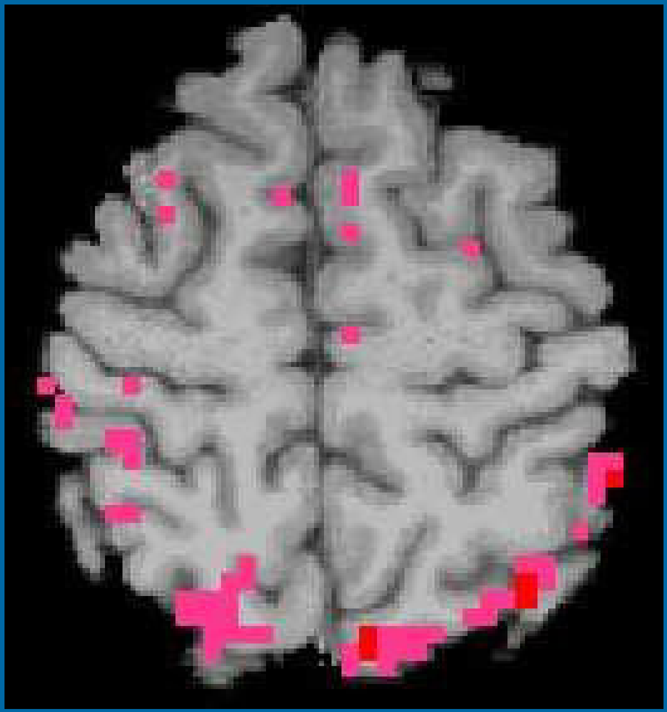


fMRI

Subjects performing non-verbal working memory task:
(Mental problem solving)



Non-drinker



Alcoholic

S. A. Brown, and G.G. Brown, UCSD

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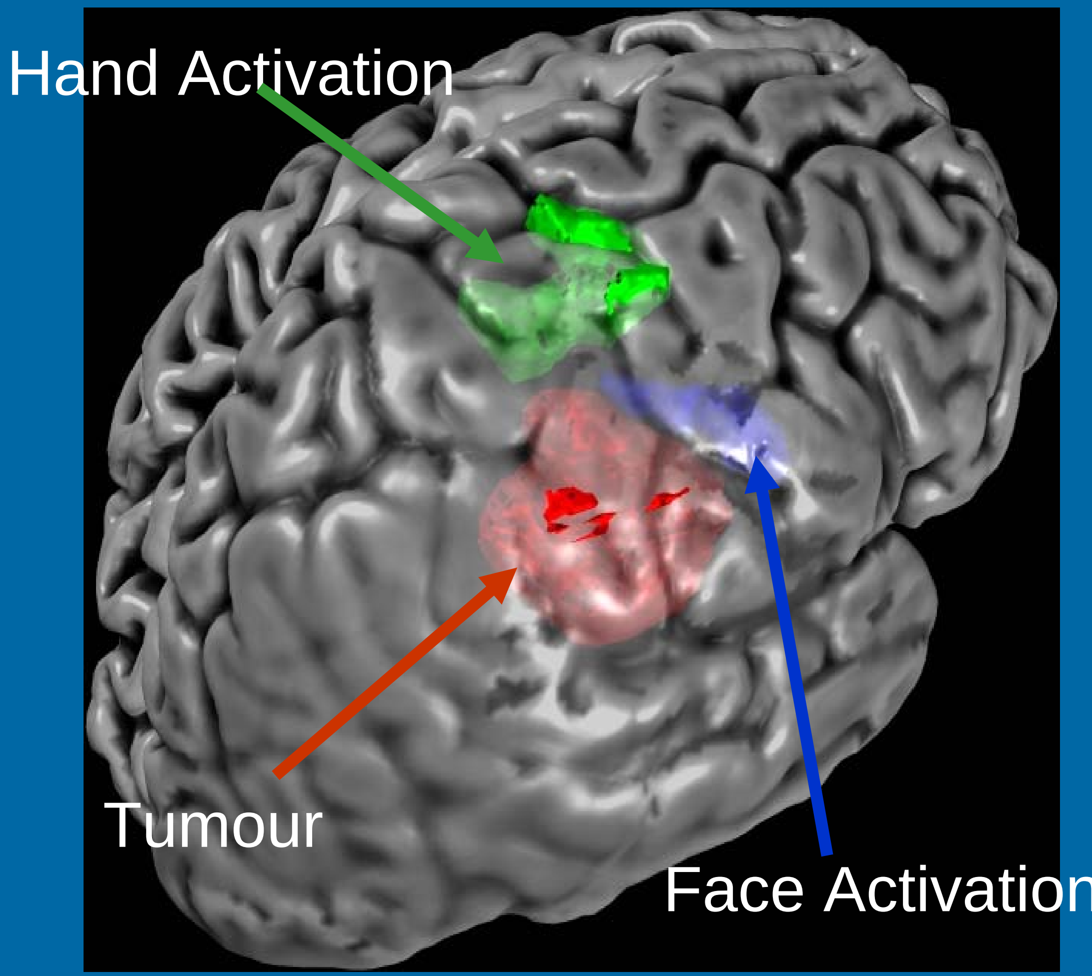
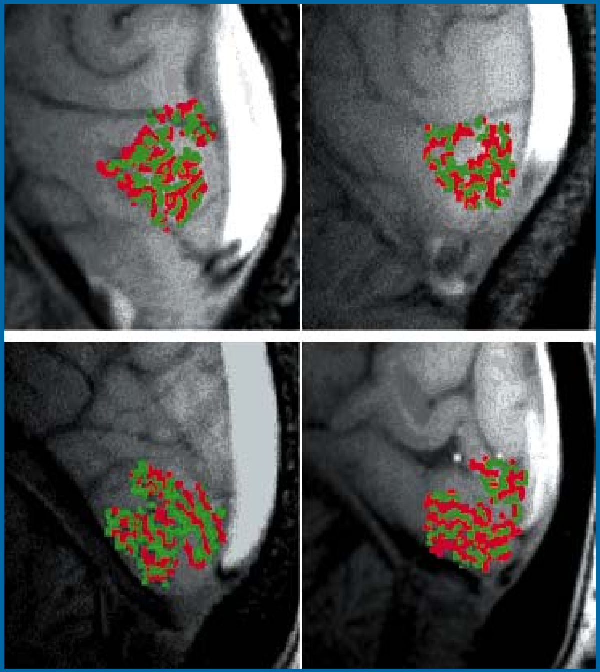
fMRI in Neurosurgery Planning

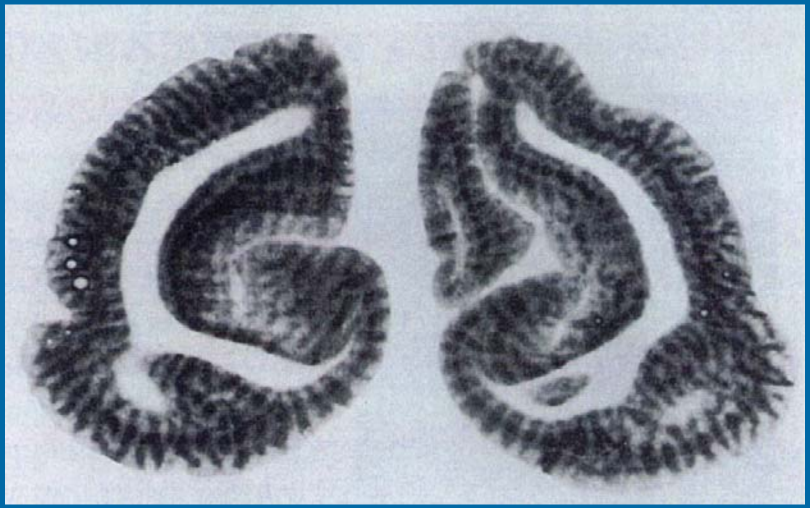


Ocular Dominance Columns

by [^{3}H] proline labeling (Hubel and Wiesel, 1977)



by Goodyear & R. Menon, 2001



by 2-[^{14}C] deoxy-Glucose method (Kennedy et al., 1976)

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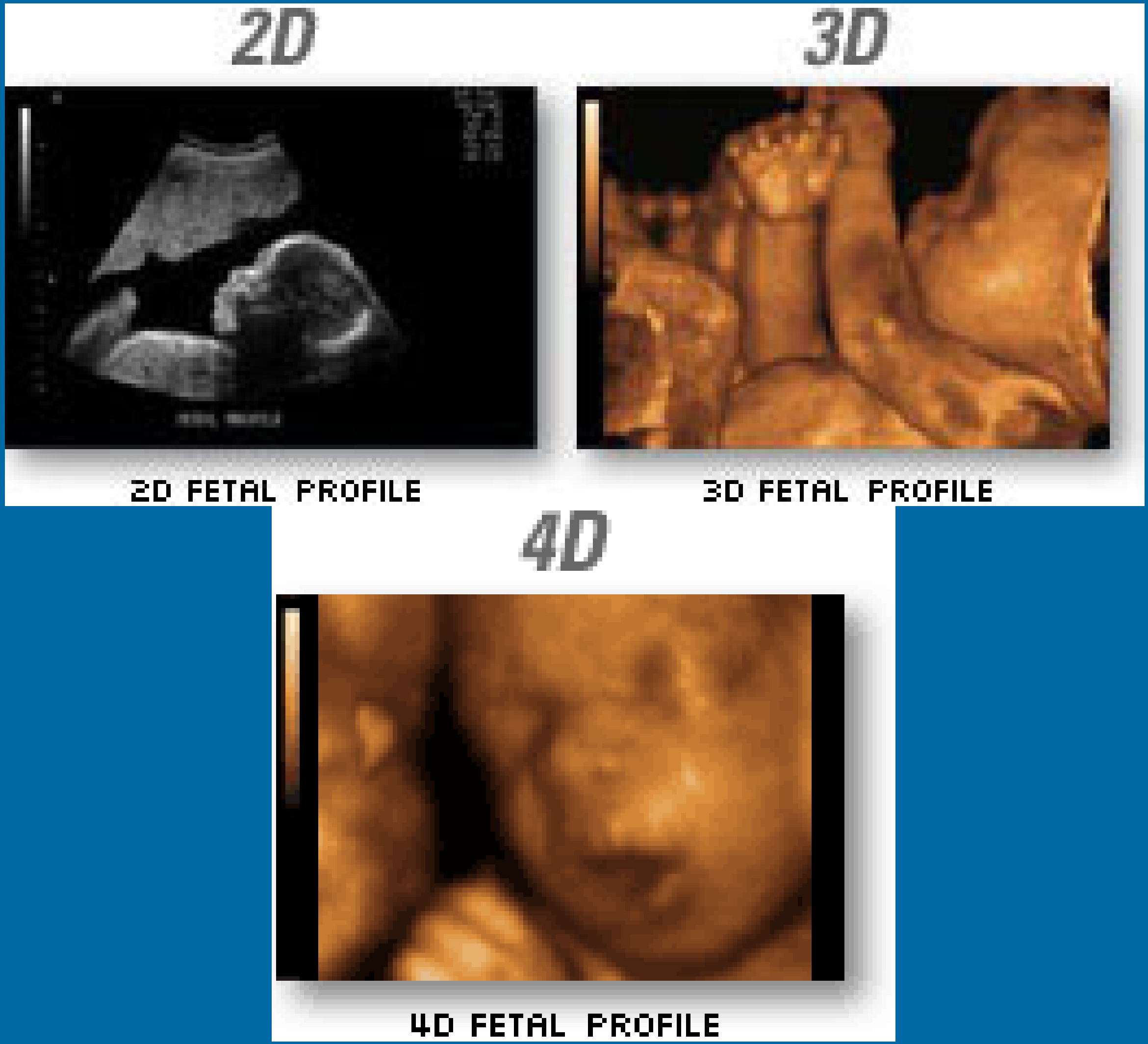
Ultrasound



Images courtesy GE Medical

Medical Imaging

- Beyond Diagnosis
- Major role in surgical planning/guidance
  - Procedures increasingly minimally-invasive
  - often “blind”
  - surgeon often lacks critical information
  - replace unseen view with 3D images

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Intra-operative MRI

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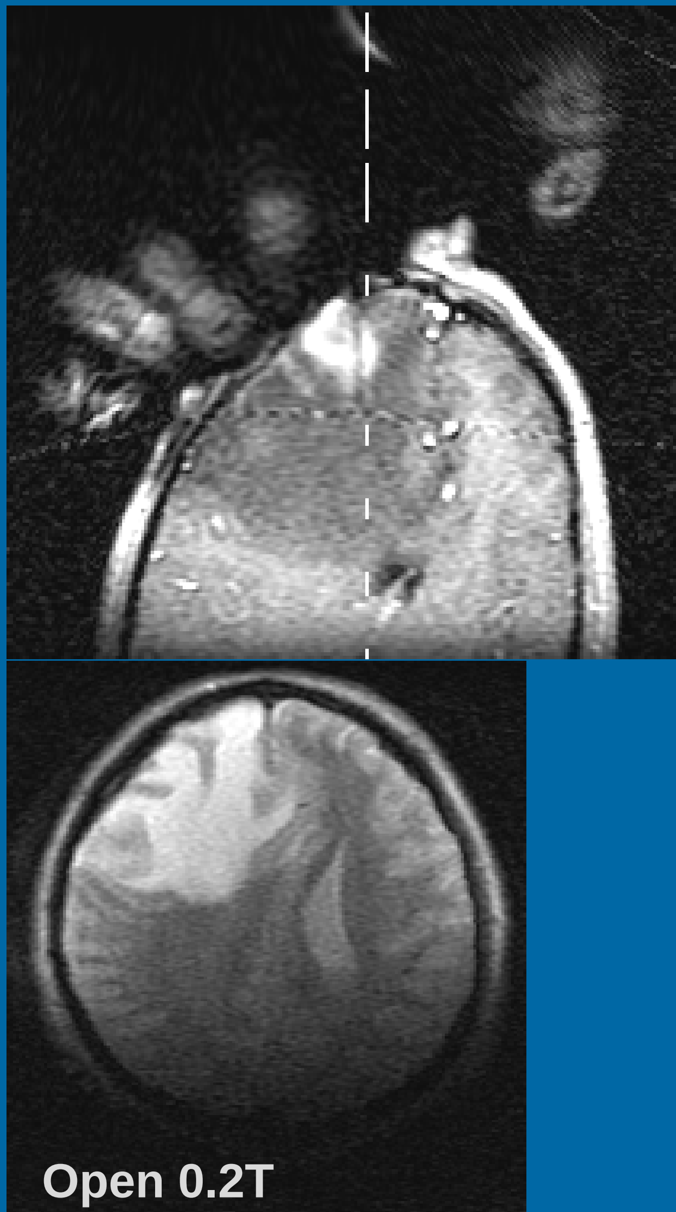
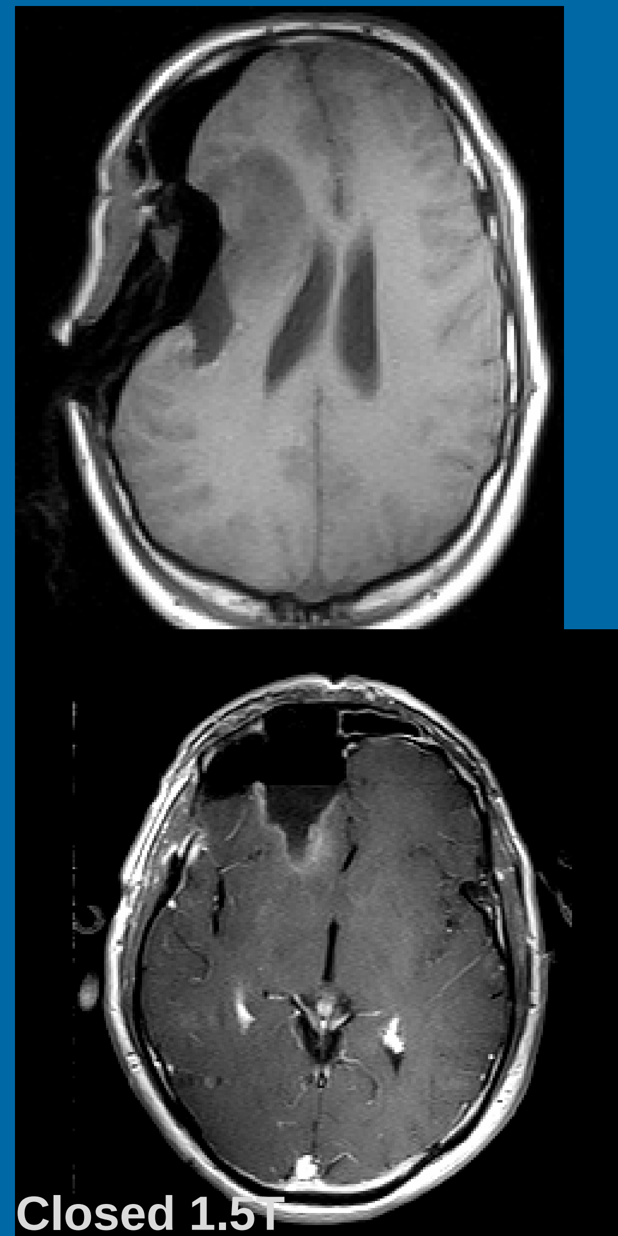
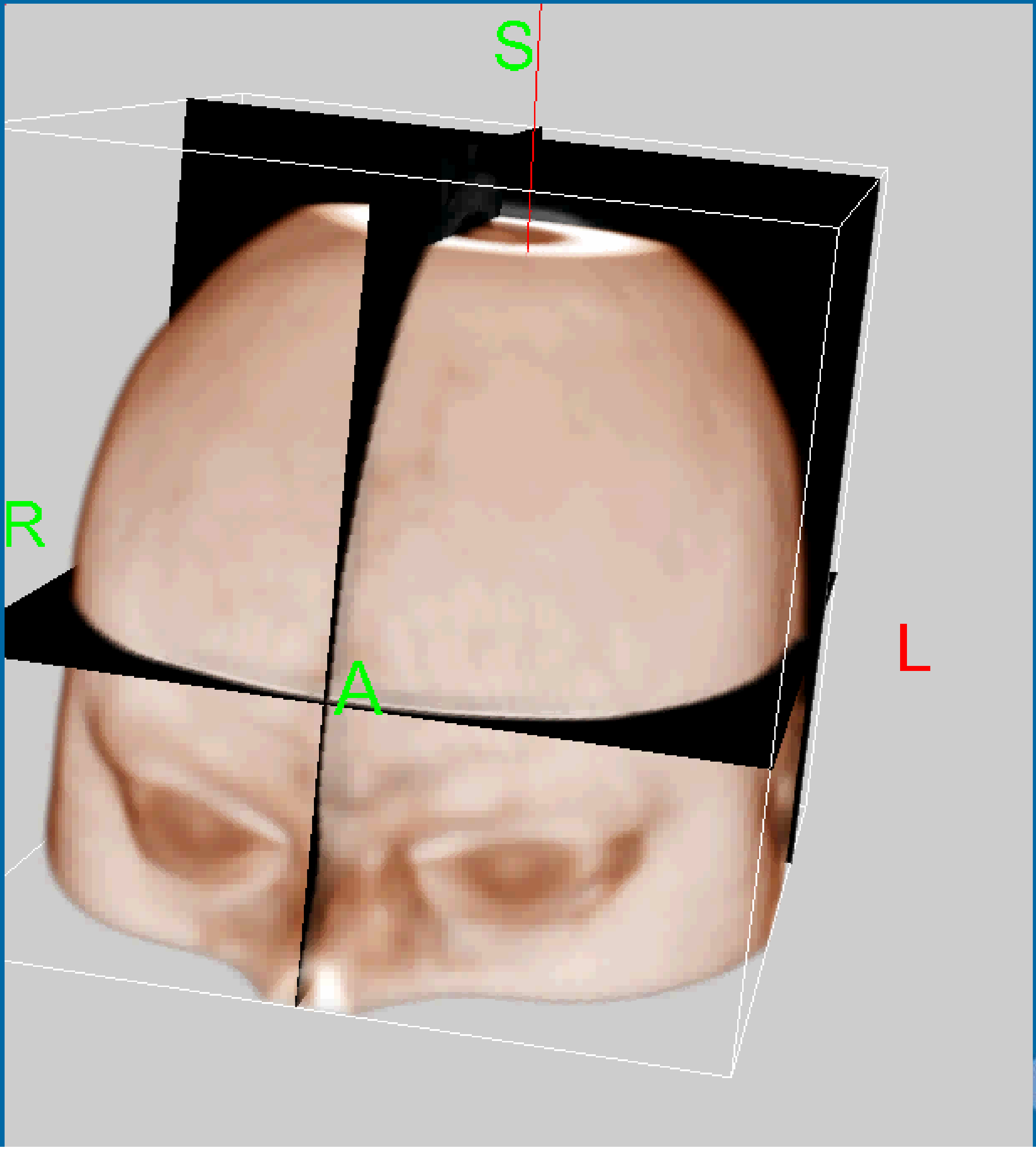


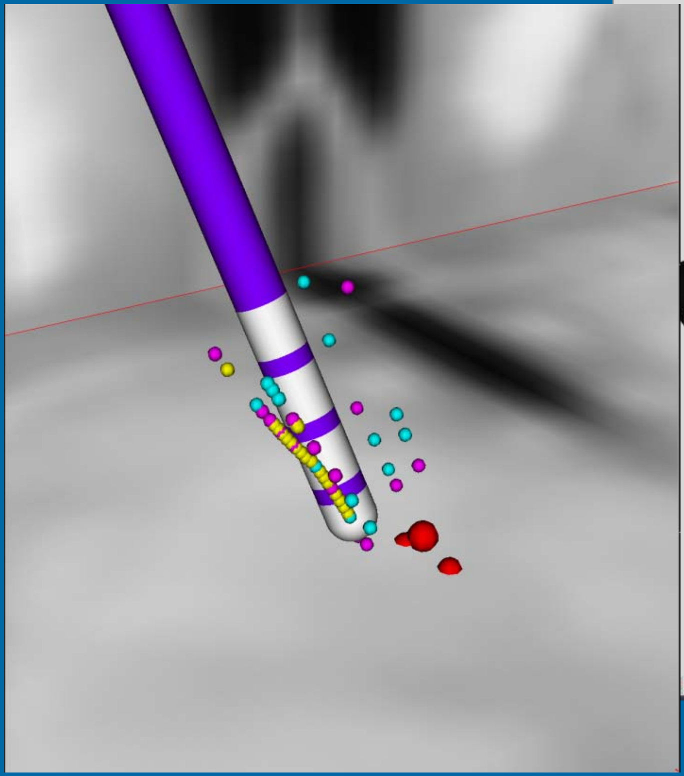


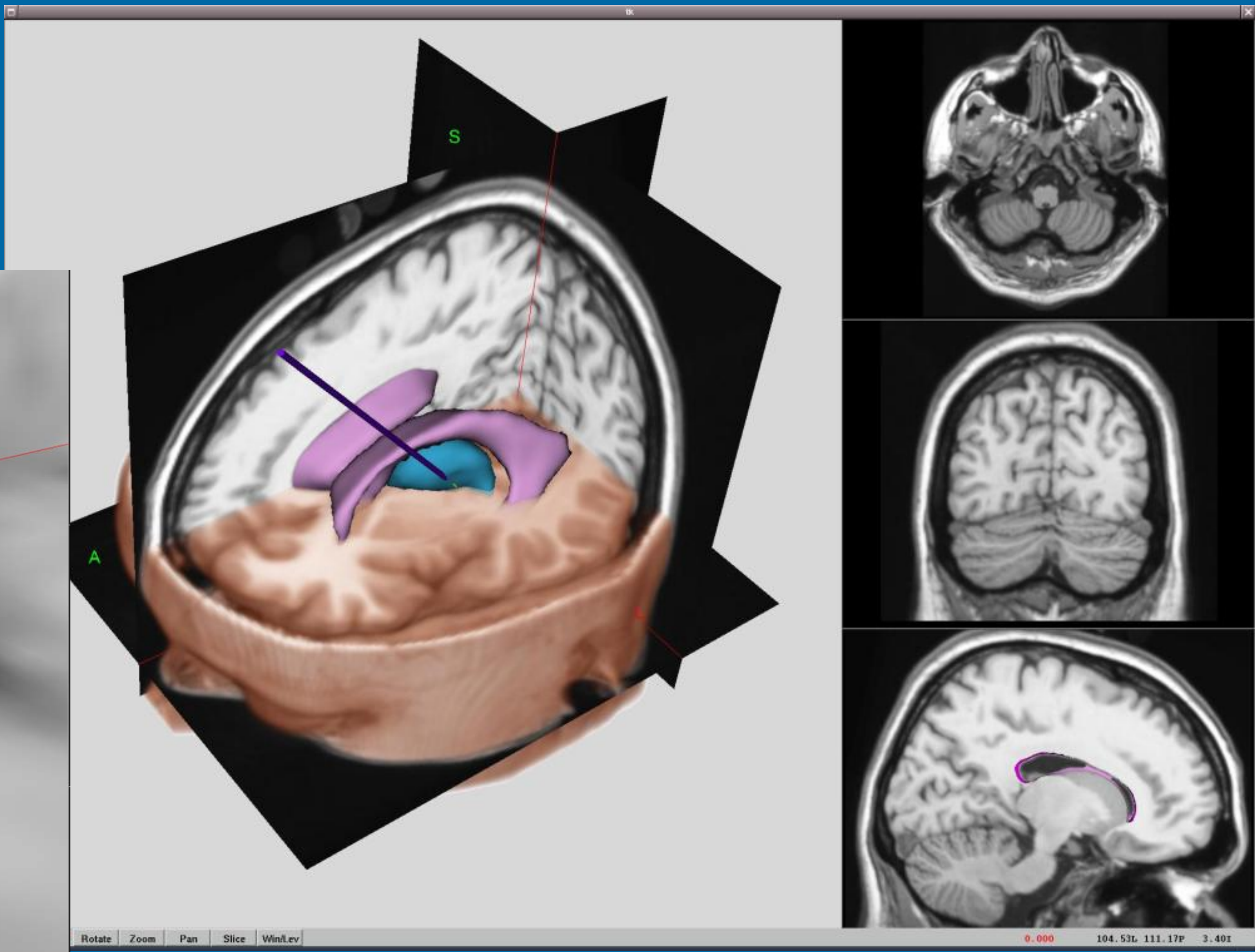
Courtesy Dr W Kucharzyck, Toronto; Dr. G Sutherland, Calgary

Surgical Planning Platform



Planning for Parkinson's Surgery





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Intra-operative Imaging

- Pre-operative images are 3D, high quality
- Tissue shifts after craniotomy; during procedure
- Morphological correspondence between pre-op images and intra-op anatomy is lost
- Options:
  - Image during procedure
  - Update pre-op image to reflect current brain geometry

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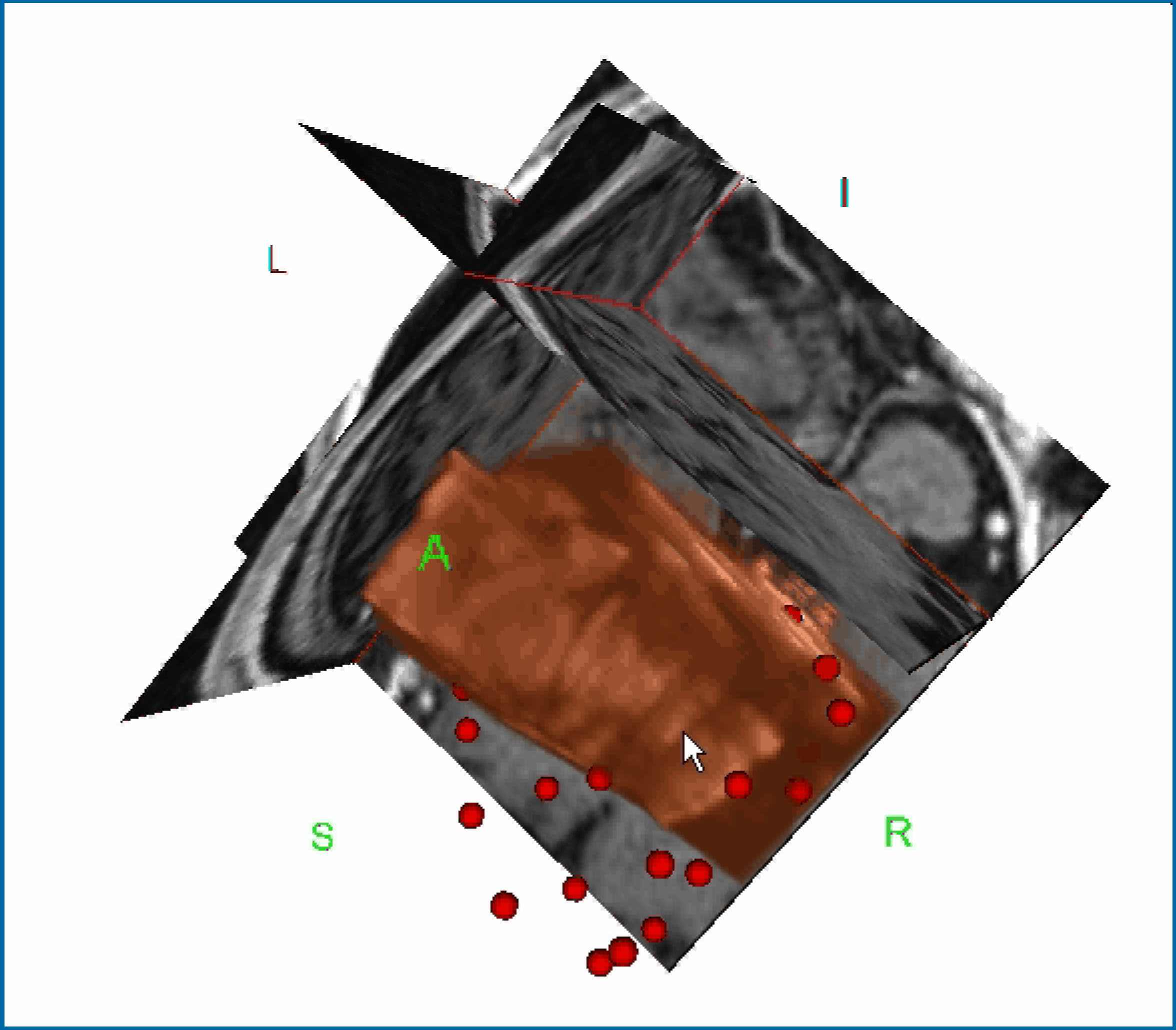
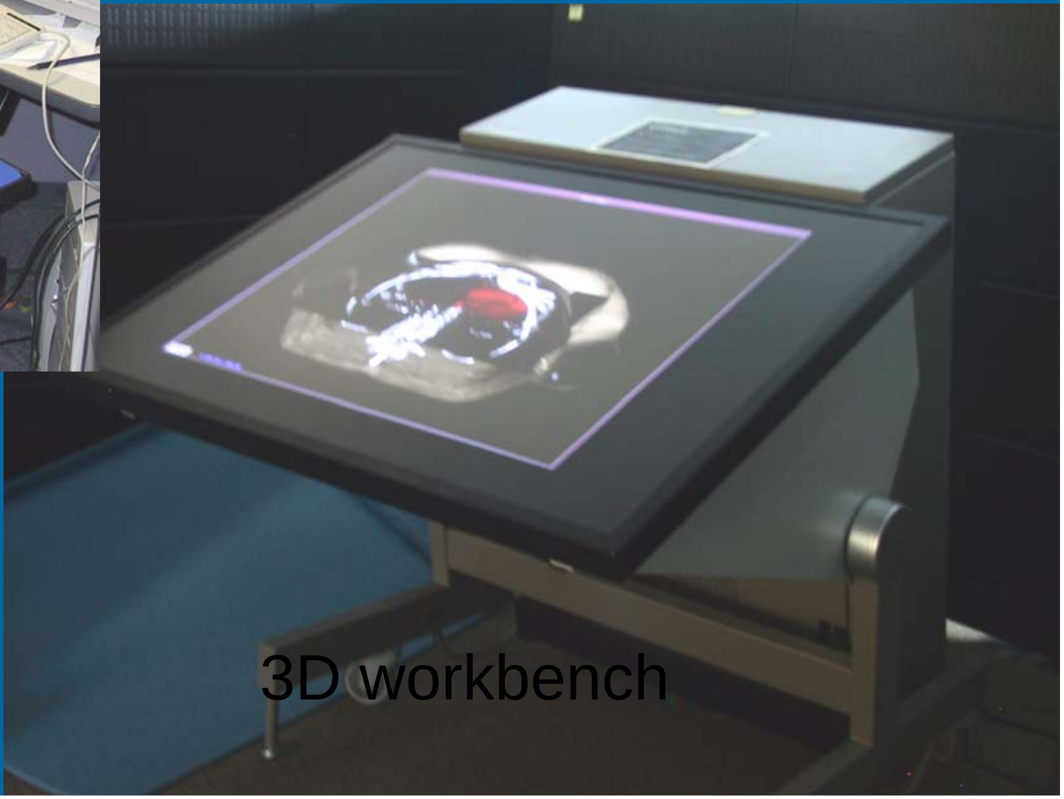
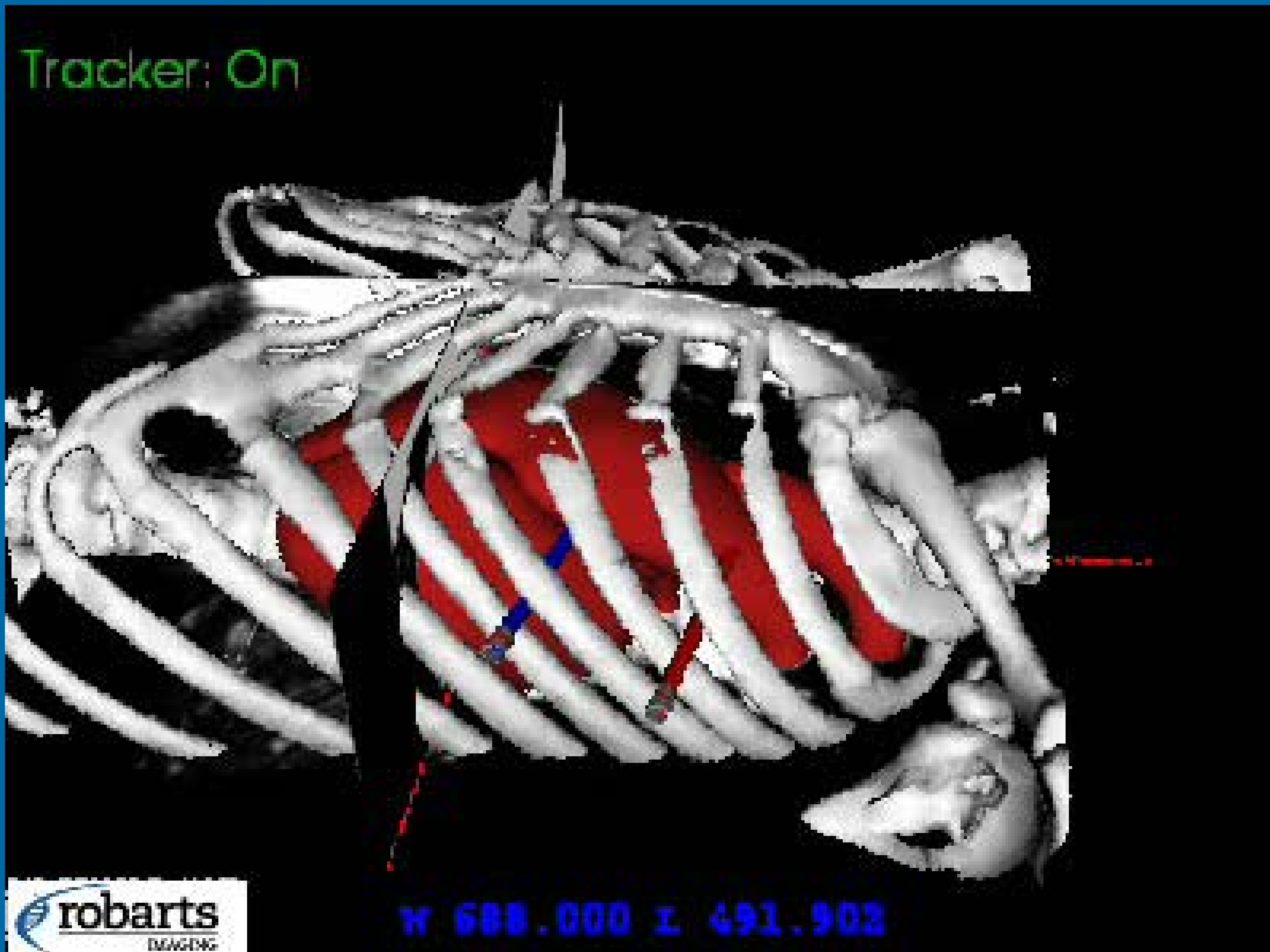
3D MRI - Ultrasound



Virtual Cardiac Simulation Platform



3D workbench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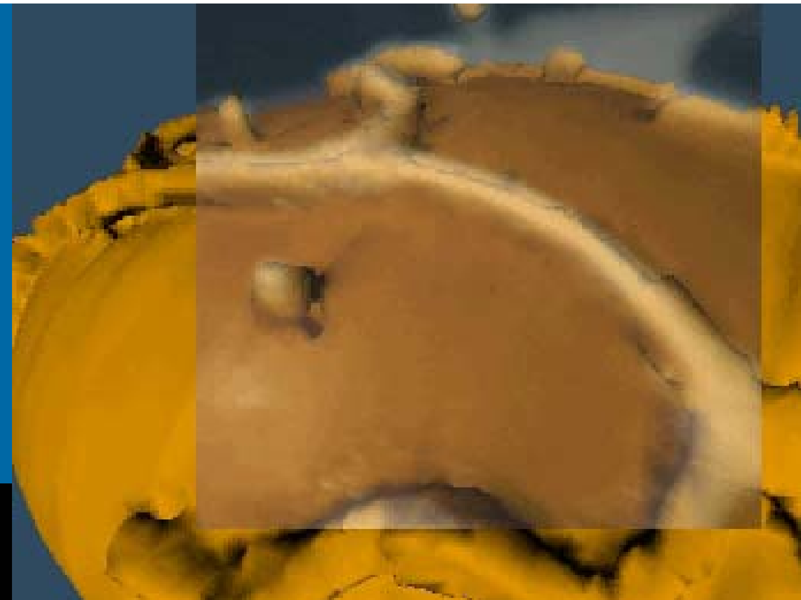
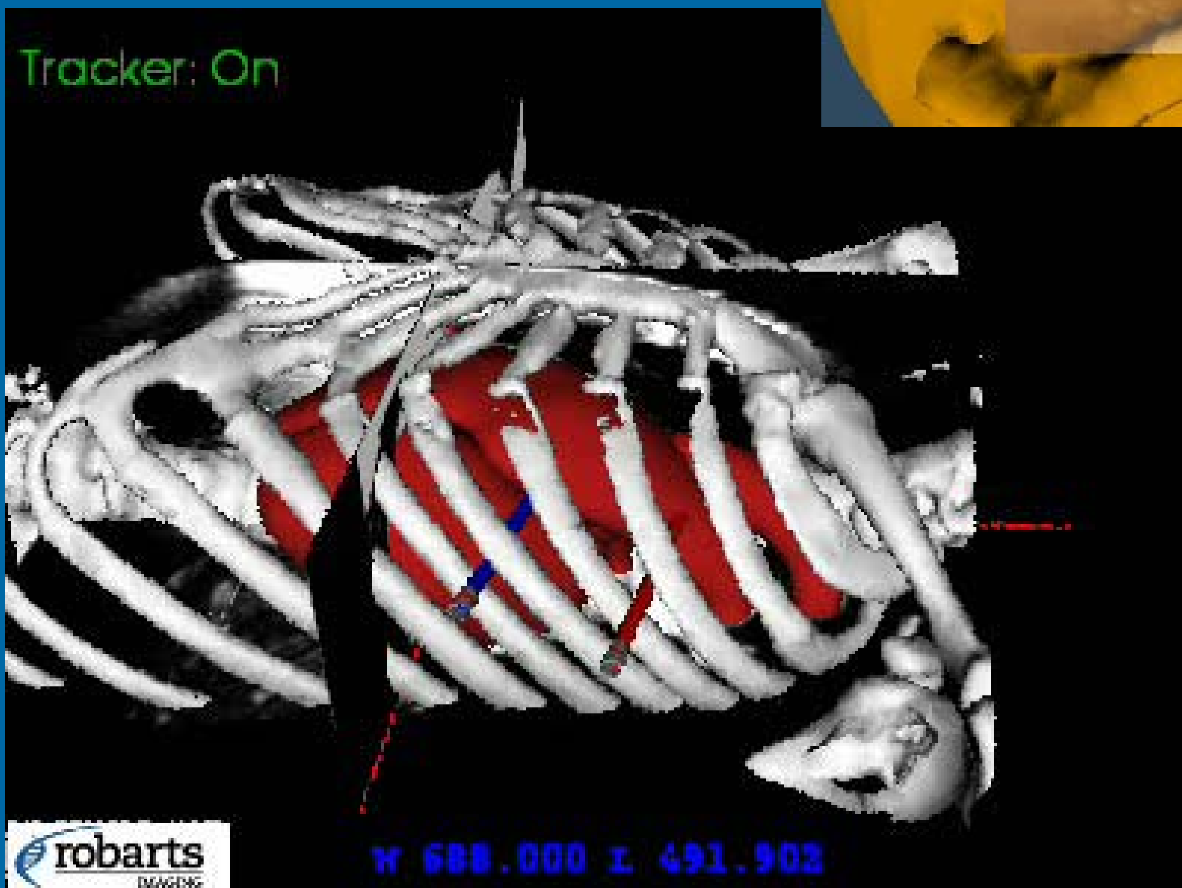
W 688.000 L 491.902





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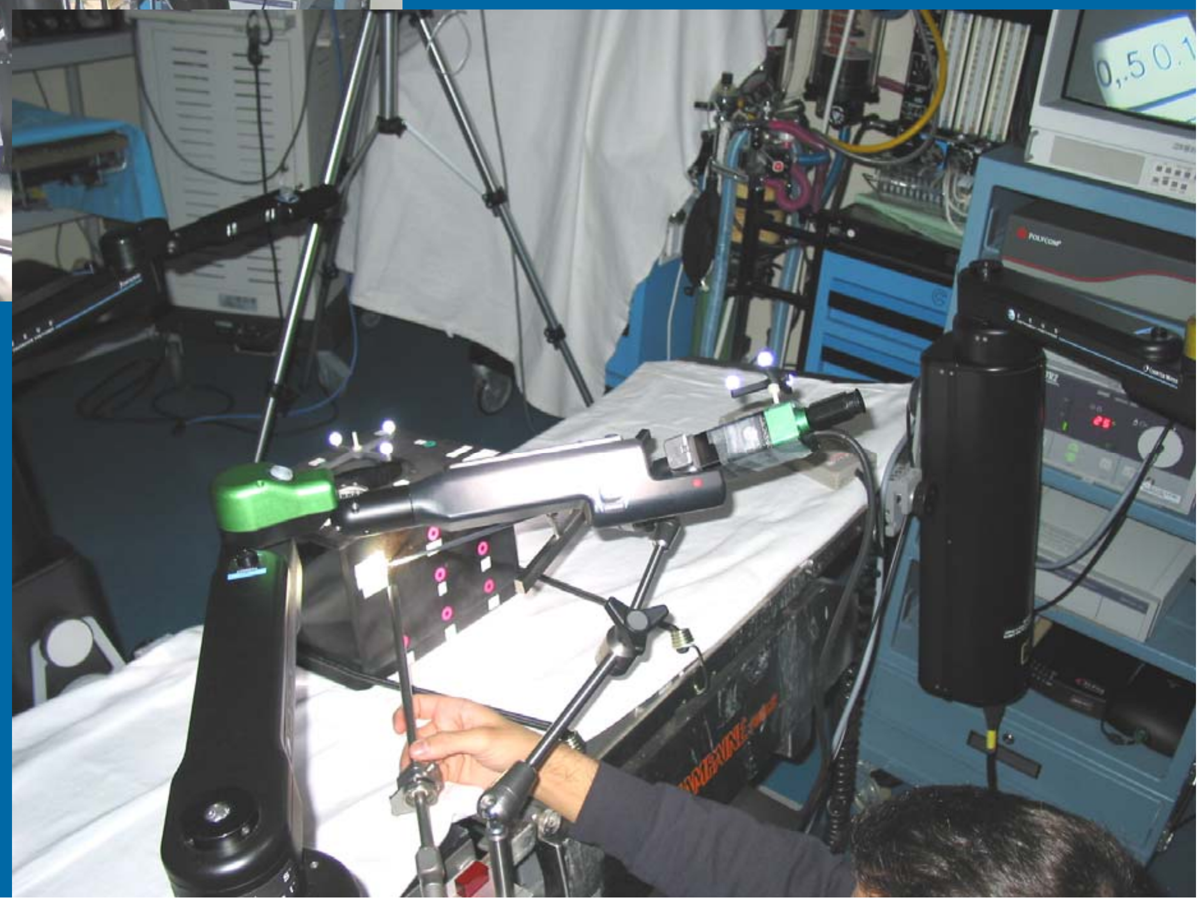


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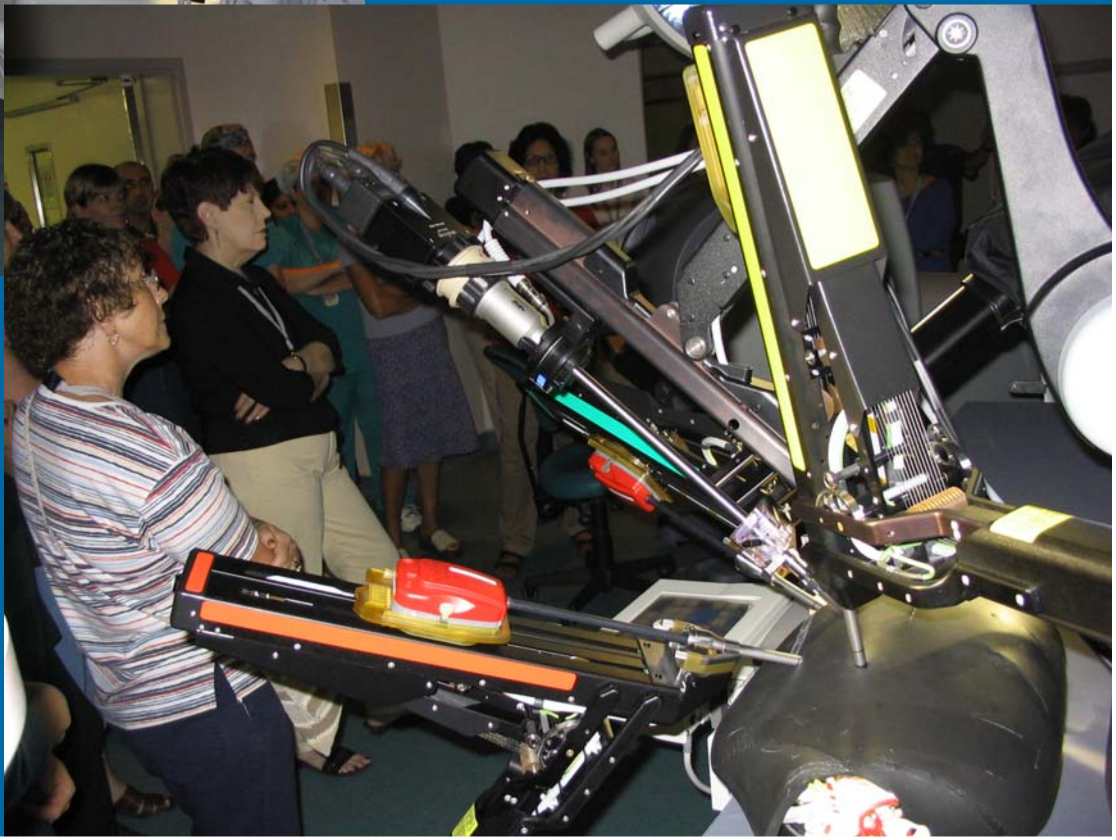

Conclusion

- Future - driven by IT explosion
- Contemporary imaging modalities become increasingly dynamic
- Resolution continues to increase for both CT, MRI
- Micro-imaging plays major role
- New tracers allow cellular MR imaging
- Truly film-less 3D visualization with ubiquitous PACS
- Seamless surgical image-guidance
- Surgery performed by robots guided by multi-modal images

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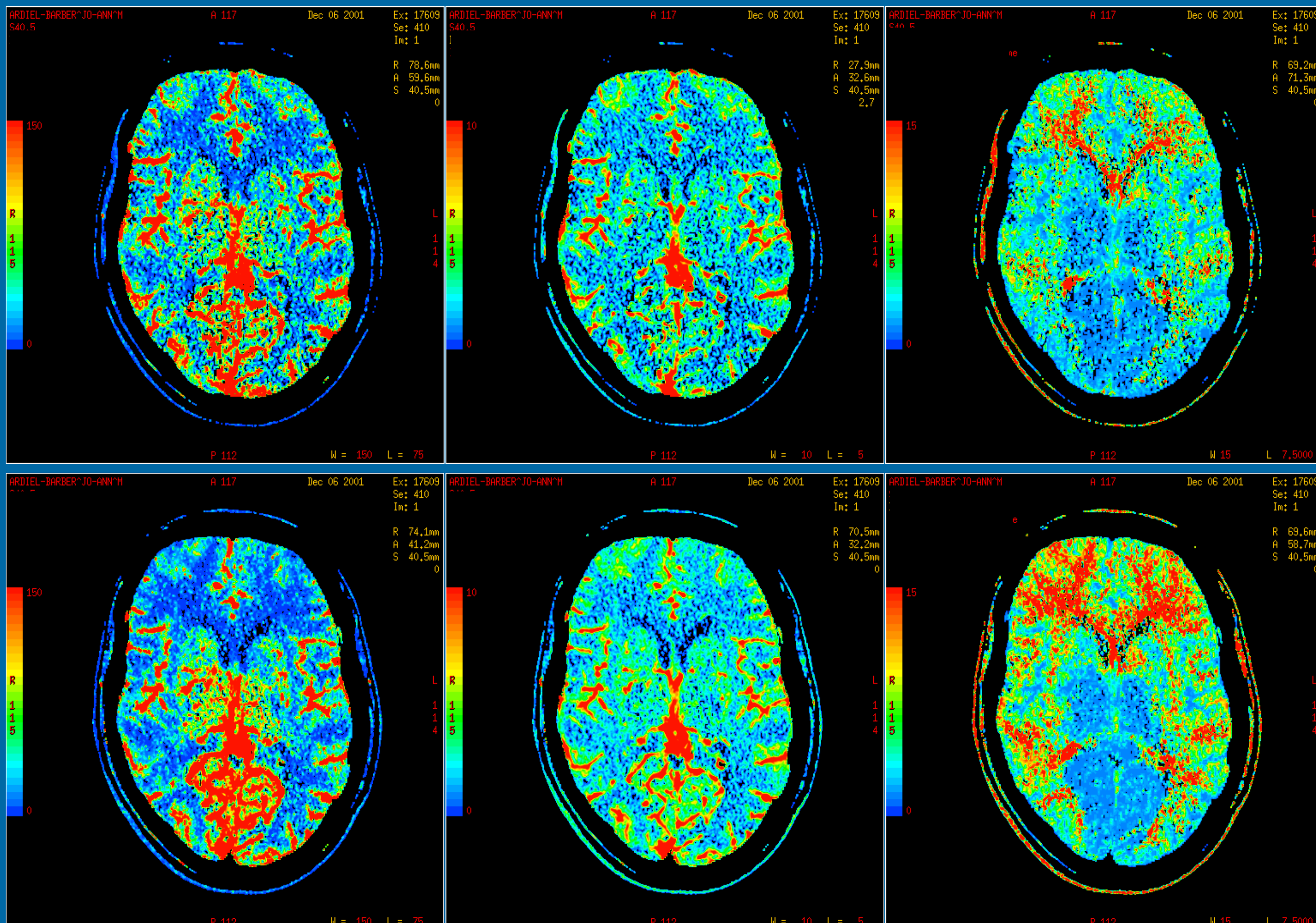
CT Perfusion Imaging

CBF ml/min/100g **CBV ml/100g** **MTT**

Before Diamox

After Diamox



Abnormal response to DIAMOX in PT with bilateral ICA occlusion

Dr. T-Y Lee, London ON

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CT Perfusion Imaging

- Examine dynamics of injected contrast agent in single or several adjacent slices
- Requires rapid state-of-the-art scanner
- Continuous rotation of X-ray system
- Continuous data acquisition
- Fit dynamic attenuation data to theoretical models
- Compute quantitative CBF, CBV and MTT
- Competitor to PET

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