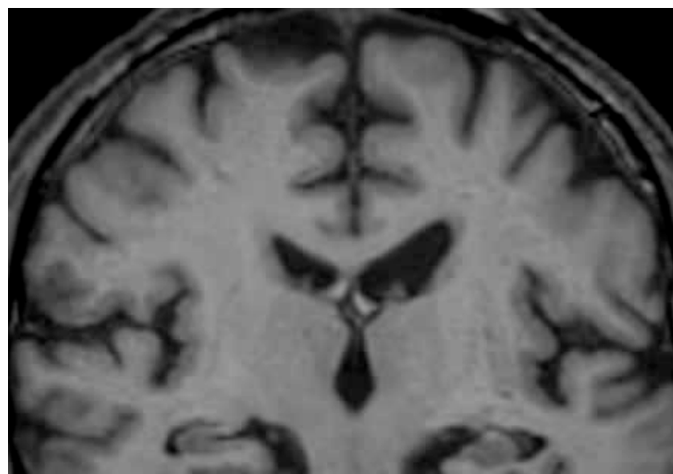
Information Processing for Medical Imaging

IPMI Module - MPHYGB06

Marc Modat - m.modat@ucl.ac.uk

University College London



Centre for Medical Image Computing

- ~ 50 post docs & 50 PhD students

- Healthcare
  - Screening
  - Diagnosis
  - Guiding and monitoring therapy

- Pharmaceutical Industry
  - Imaging biomarkers

- Medical Research
  - Neurology
  - Oncology
  - Cardiology

cmic
Centre for Medical Image Computing

Image acquisition
Image reconstruction
Image segmentation
Image registration/fusion
Image guided interventions
Atlas generation
Group statistics
Biological function
Modelling
Shape
Biomechanics
Motion
Biological function
Classification

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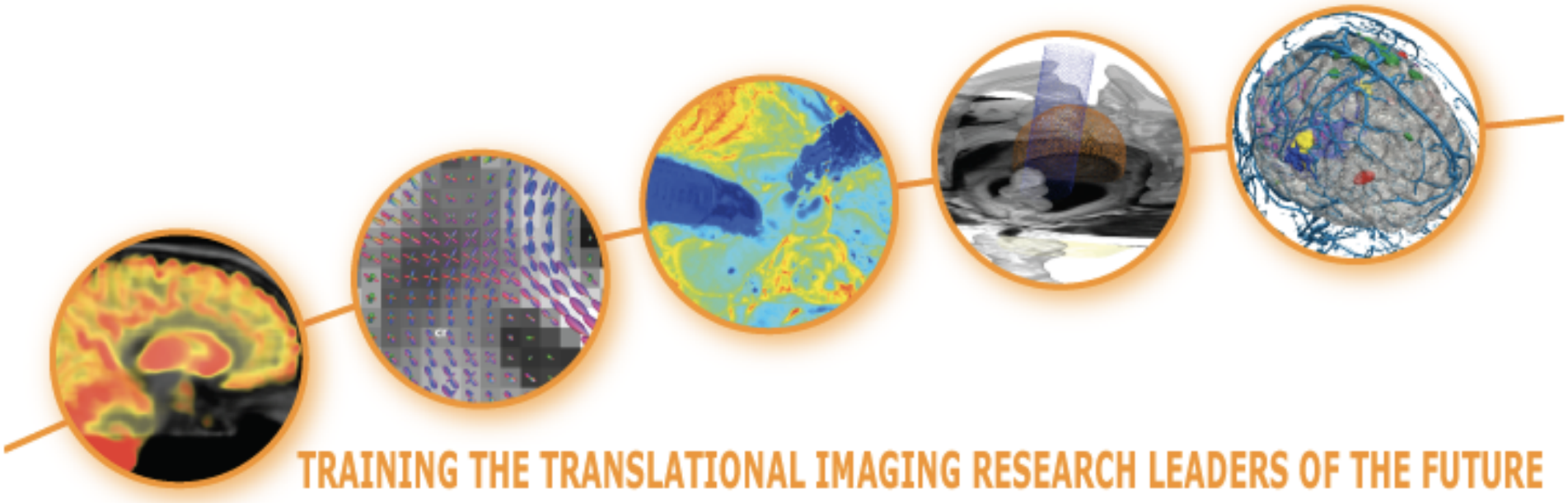
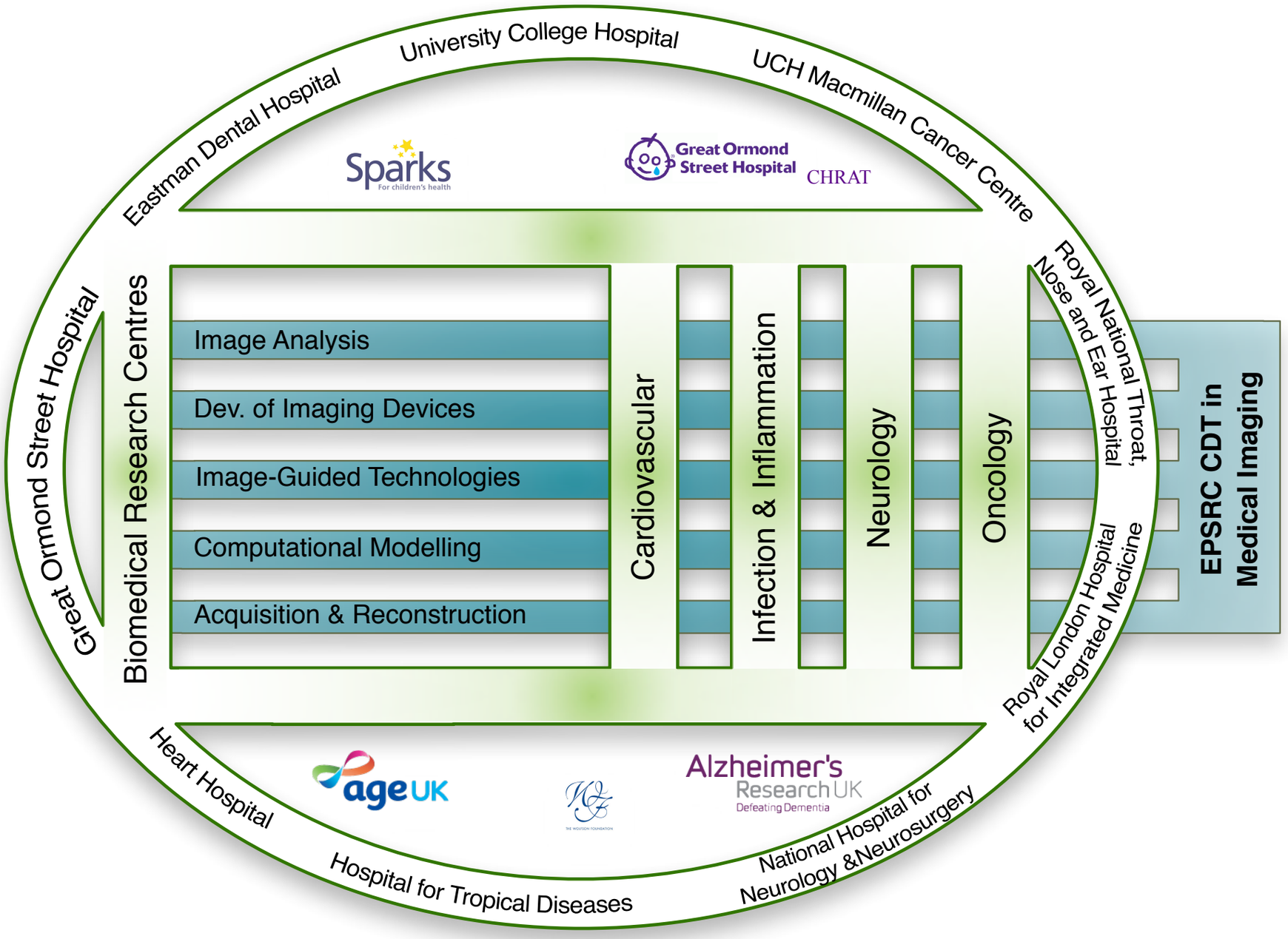


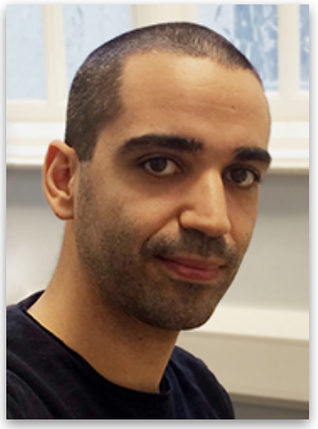
TRAINING THE TRANSLATIONAL IMAGING RESEARCH LEADERS OF THE FUTURE

Our vision is to train the translational imaging research leaders of the future, filling a critical gap identified in academia, pharmaceutical and medical devices industries, while delivering internationally competitive research. Our innovative training has a strong focus on new image acquisition technologies, novel data analysis methods and integration with computational modelling.


University College Hospital
Eastman Dental Hospital
UCH Macmillan Cancer Centre
Sparks
For children's health
Great Ormond Street Hospital
CHRAT
Great Ormond Street Hospital
Biomedical Research Centres
Image Analysis
Dev. of Imaging Devices
Image-Guided Technologies
Computational Modelling
Acquisition & Reconstruction
Cardiovascular
Infection & Inflammation
Neurology
Oncology
Royal National Throat, Nose and Ear Hospital
EPSRC CDT in Medical Imaging
Royal London Hospital for Integrated Medicine
National Hospital for Neurology &Neurosurgery
Alzheimer's Research UK
Defeating Dementia
ageUK
Hospital for Tropical Diseases
Heart Hospital

Structure of the module

- Lecturers
  - Maria A Zuluaga (statistical shape modelling) *maria.zuluaga@ucl.ac.uk*
  - M Jorge Cardoso (segmentation) *m.jorge.cardoso@ucl.ac.uk*
  - Marc Modat (registration) m.modat@ucl.ac.uk



- Assessment
  - 50% Coursework
    - Python code + report
    - Combining medical image registration and segmentation
  - 50% Sat Exam

Structure of the MPHYGB06 module

- Thursday 15th January
  - 10:00 - 13:00 - Module introduction
    and Medical Image Registration I (Marc Modat)
    Engineering Front Suite 104

- Thursday 22nd January
  - 10:00 - 13:00 - Medical Image Registration II (Marc Modat)
    Wilkins Gustave Tuck LT
  - 14:00 - 17:00 - Workshop - Medical Image Registration I (Marc Modat)
    Malet Place Eng. 105

- Thursday 29th January
  - 10:00 - 13:00 - Statistical Shape Model (Maria A. Zuluaga)
    Chadwick G08
  - 14:00 - 17:00 - Workshop - Simple ITK (Maria A. Zuluaga)
    Malet Place Eng. 105

Structure of the MPHYGB06 module

- Thursday 5th February
  - 10:00 - 13:00 - Medical Image Segmentation I (M. Jorge Cardoso)
    Engineering Front Suite 104
  - 14:00 - 17:00 - Workshop - Medical Image Segmentation I
    (M. Jorge Cardoso)
    Malet Place Eng. 105

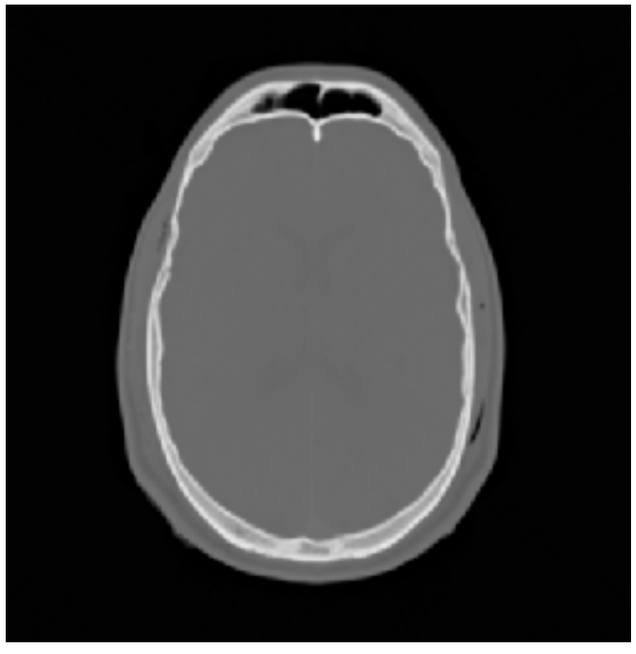
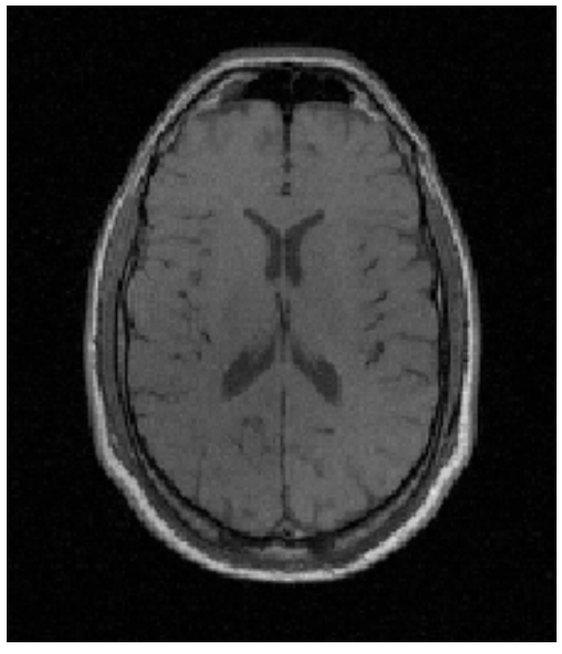
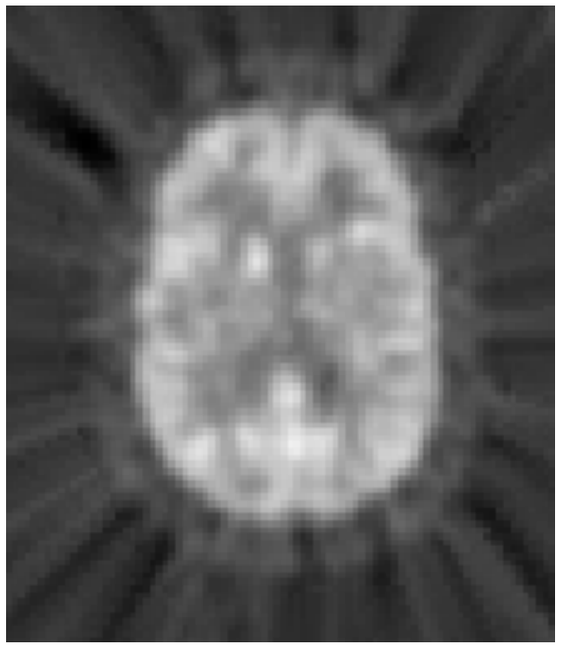
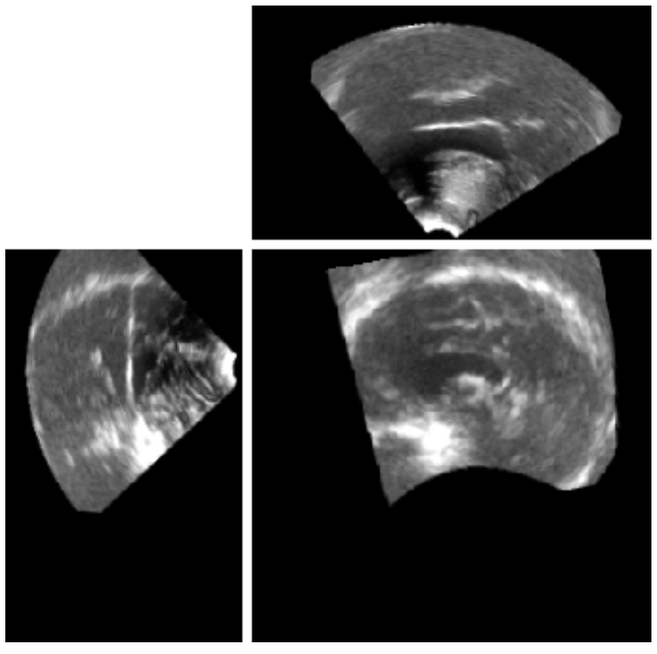
- Thursday 12th February
  - 10:00 - 13:00 - Medical Image Segmentation II (M. Jorge Cardoso)
    Engineering Front Suite 104
  - 14:00 - 17:00 - Workshop - Medical Image Segmentation II
    (M. Jorge Cardoso)
    Malet Place Eng. 105

- Thursday 19th February
  - 10:00 - 13:00 - Medical Image Registration III (Marc Modat)
    Engineering Front Suite 104
  - 14:00 - 17:00 - Workshop - Medical Image Registration II (Marc Modat)
    Malet Place Eng 1.04

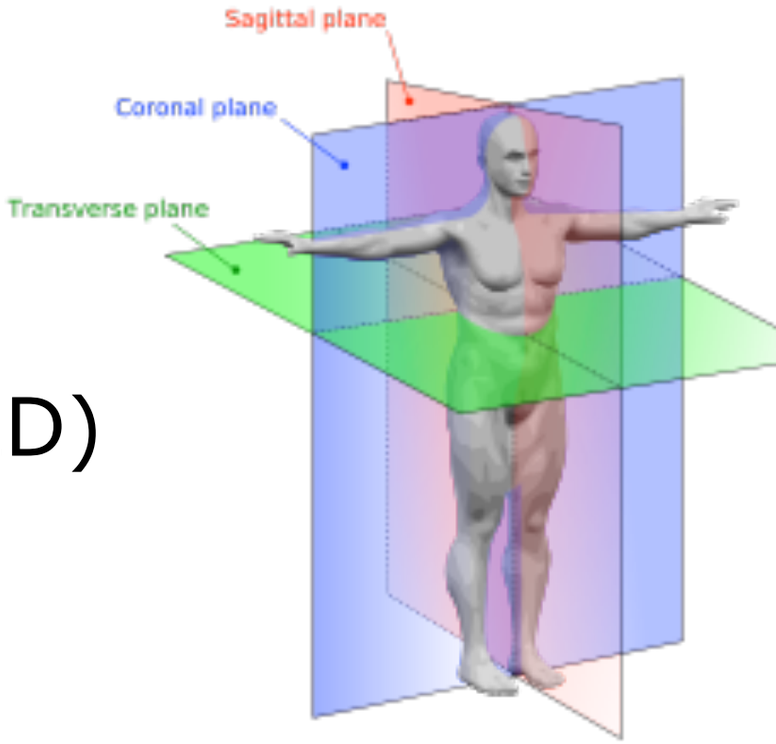
Different imaging modalities

- Some imaging examples
  - 2D and 3D X-ray imaging
  - Micro-CT imaging
  - MRI imaging at 1.5T, 3T and 7T
  - Diffusion imaging
  - Functional MRI
  - Ultrasound imaging
  - PET imaging in dementia and oncology

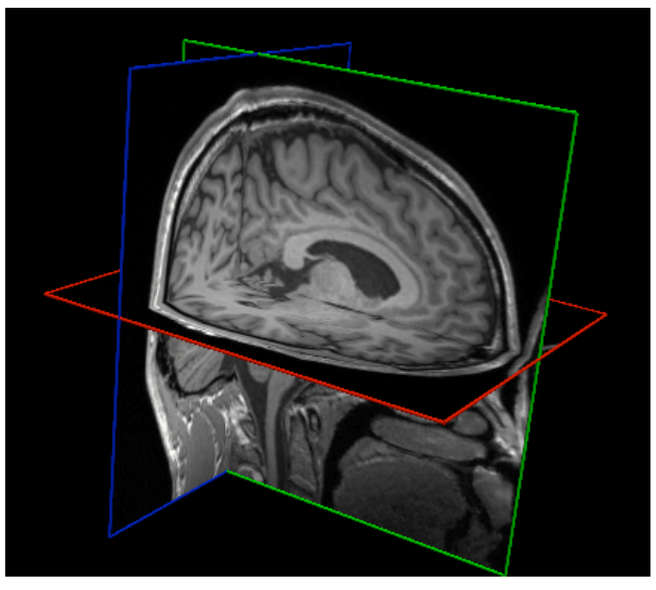
Different imaging modalities

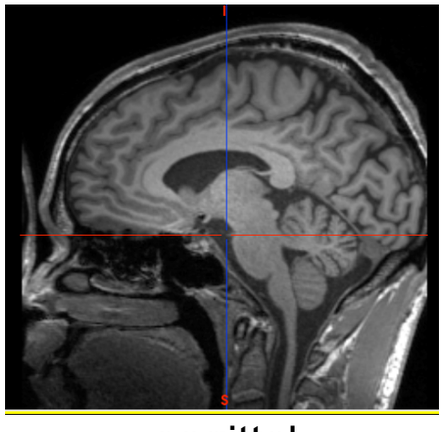





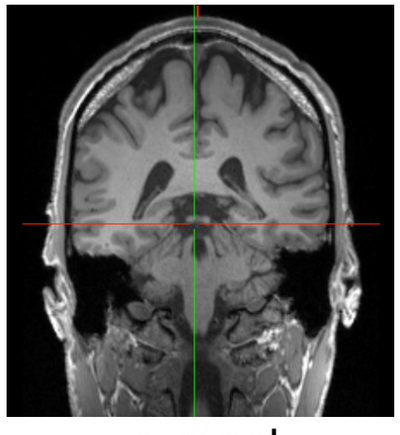
Medical imaging is mainly in 2D, 3D, 4D…

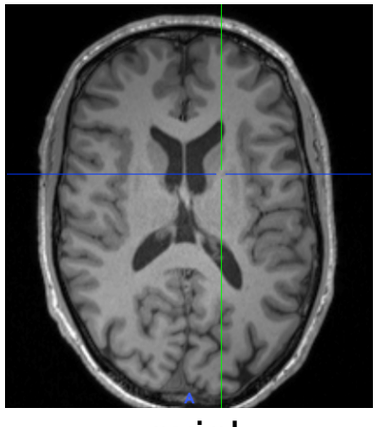


- We will talk about voxel in 3D (pixel in 2D)



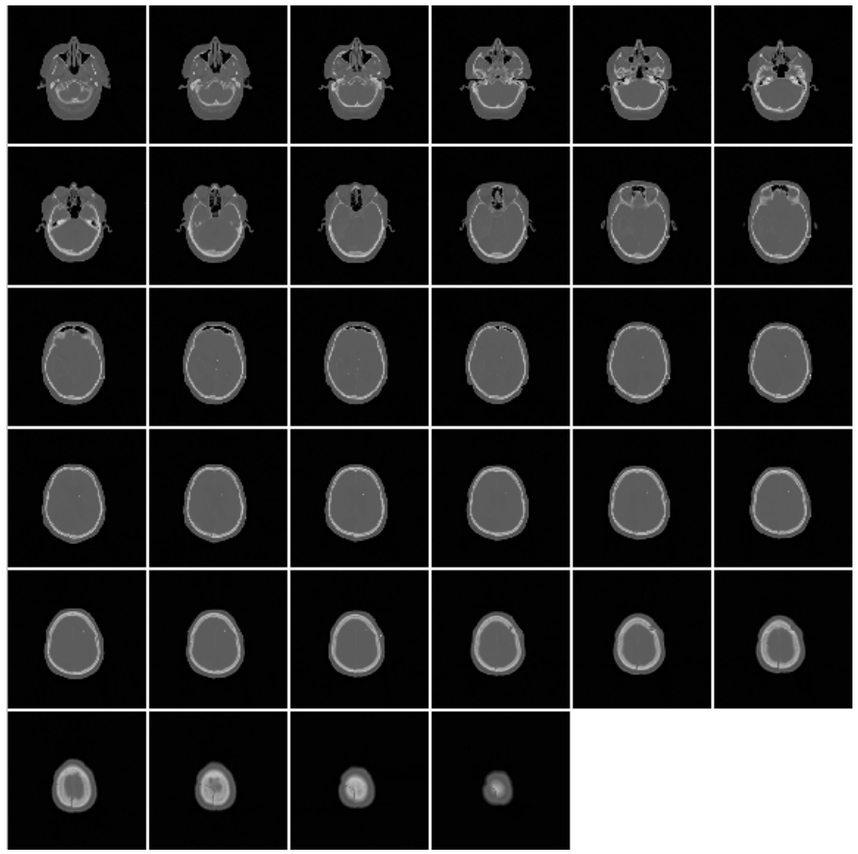

sagittal

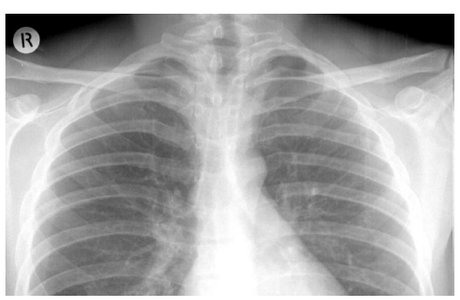

coronal

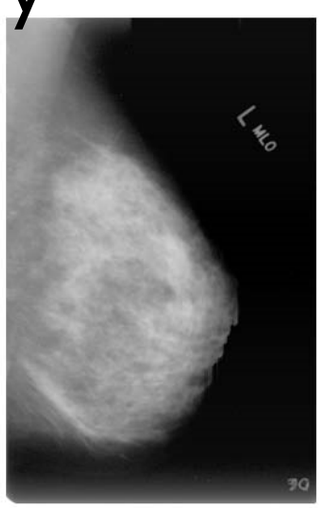

axial

X-rays

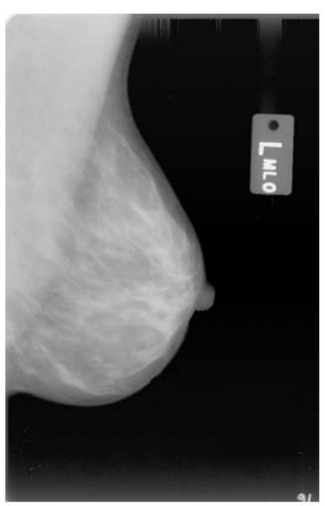
- A beam of high energy electrons crashes into a metal target and x-rays are produced.
- Can traverse the body along straight lines
- Are attenuated by the different tissues
- Be detected and measured outside of the body



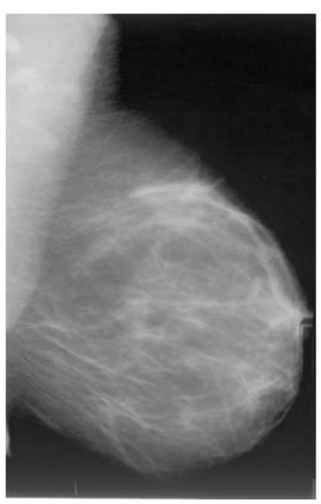




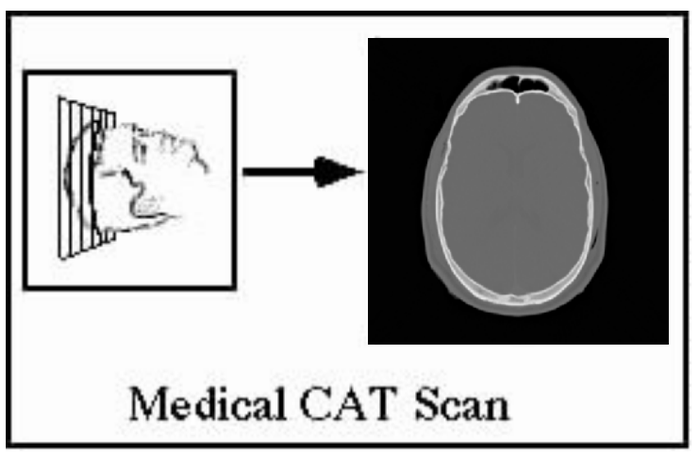
Dense breast



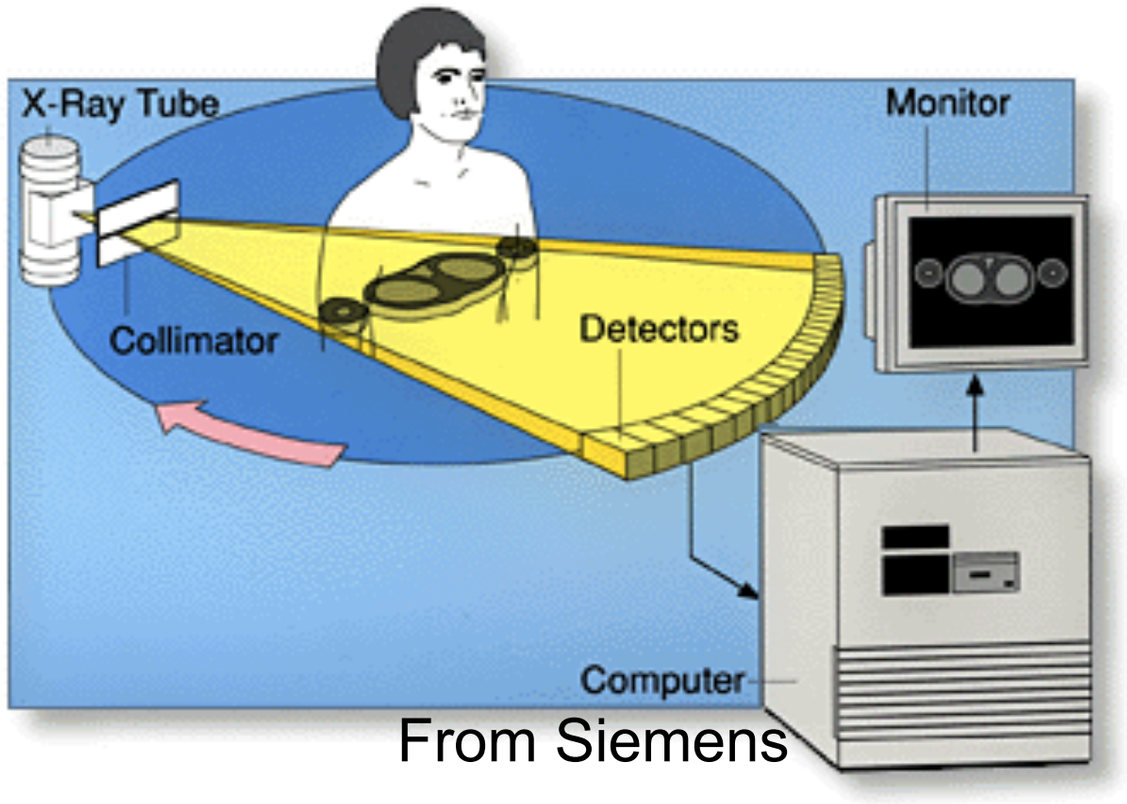
50-50 breast



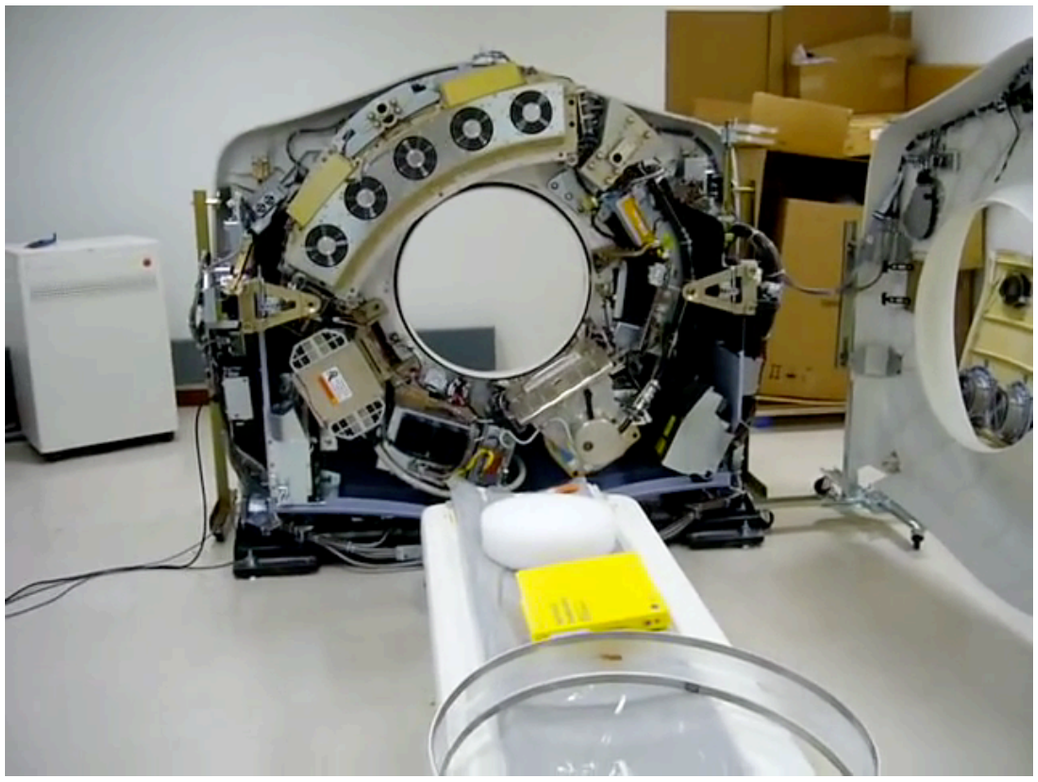
Fatty replaced breast



X-ray Computed tomography



From Siemens

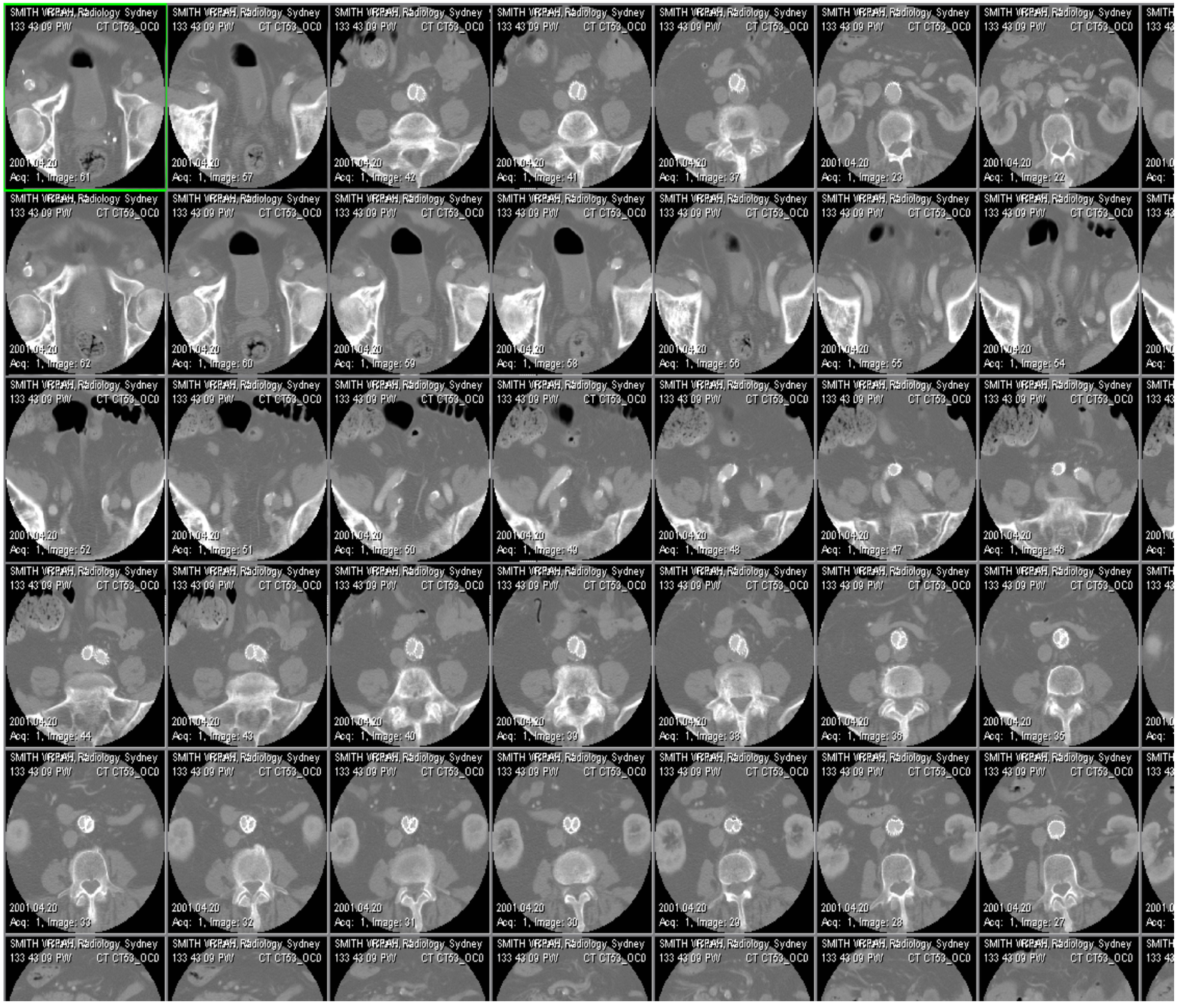


https://www.youtube.com/watch?v=2CWpZKuy-NE

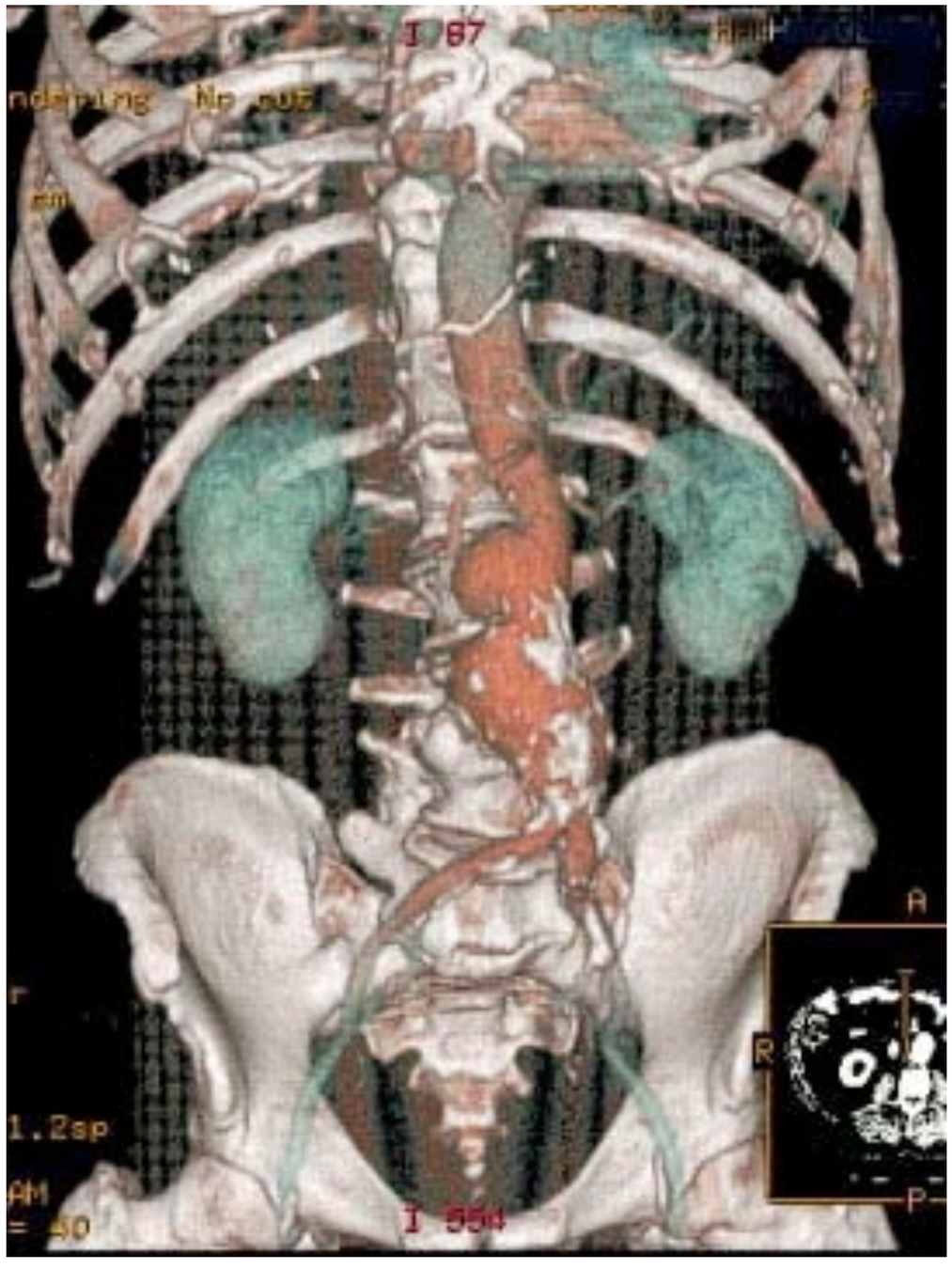
Nobel prizes:

Roentgen (1901): Discovery of X-rays
Hounsfield & Cormack (1979): Computed Tomography

X-ray Computed tomography

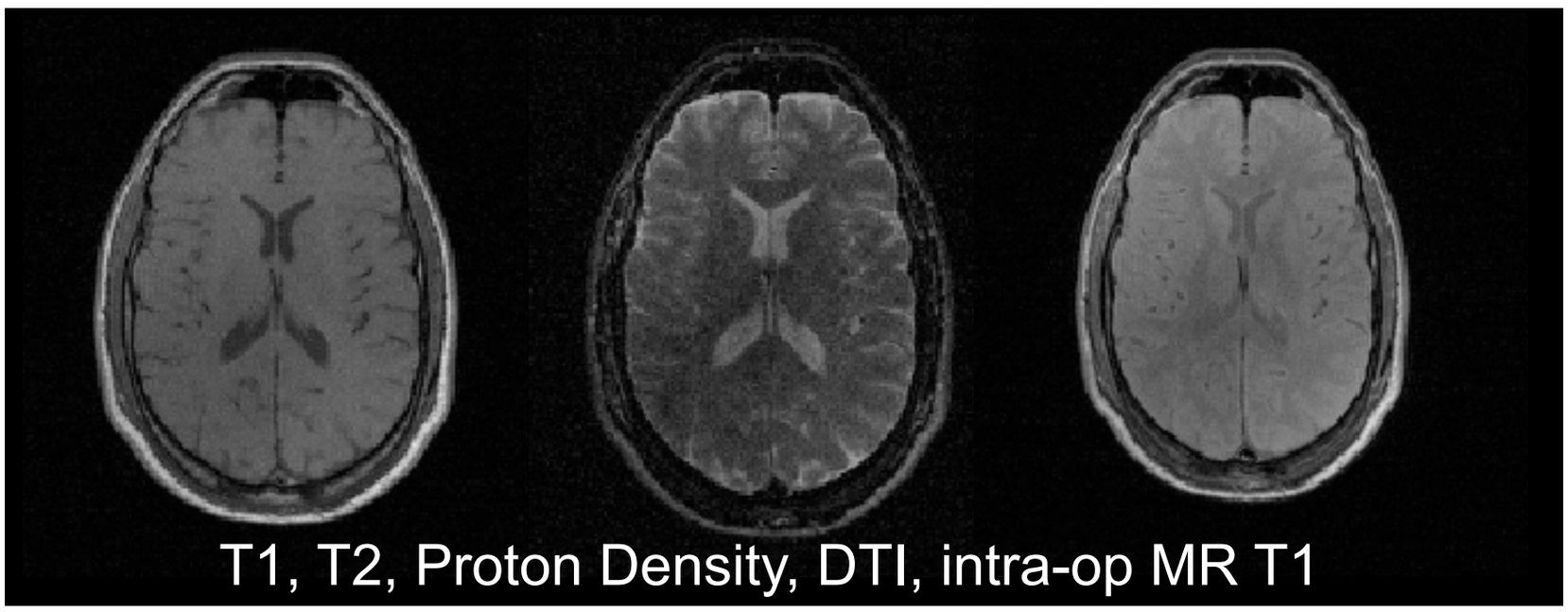


X-ray Computed tomography

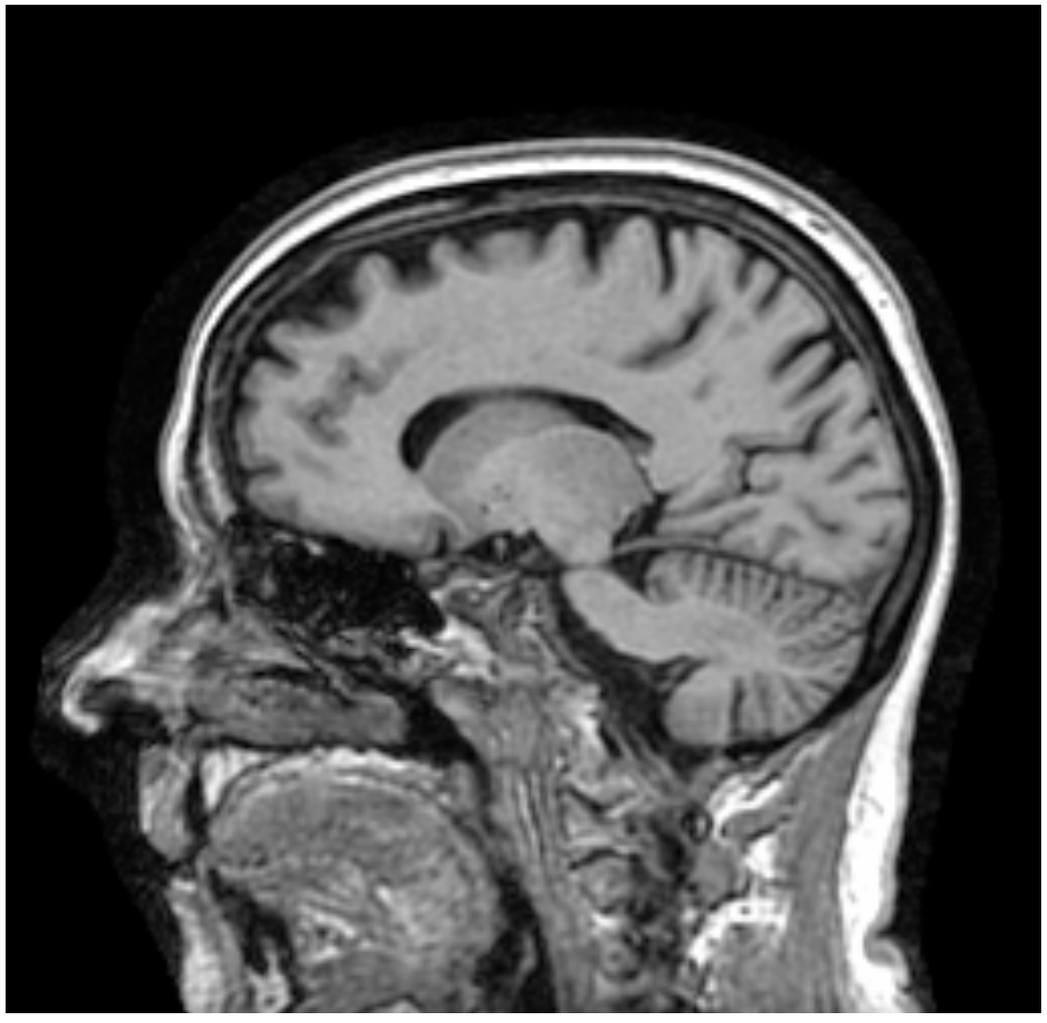


Magnetic Resonance Imaging (MRI)

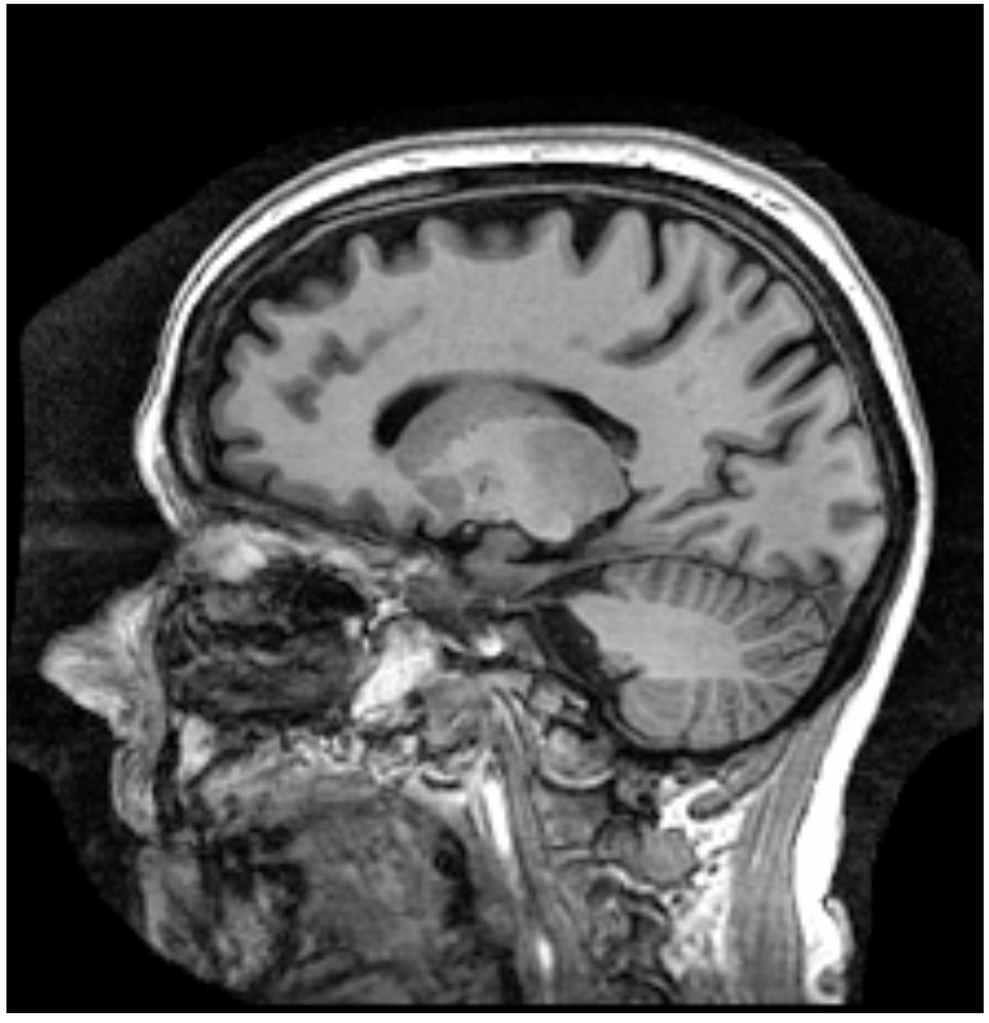
- Based on imaging nuclear spins.
- Excellent soft tissue contrast.
- Non-ionising. Gd contrast is usually safe.
- Image in planes/volumes with any orientation.
- Images often arbitrarily scaled, intensity fluctuations and geometrical distortions.
- low: motion / limited SNR.



Magnetic Resonance Imaging (MRI)



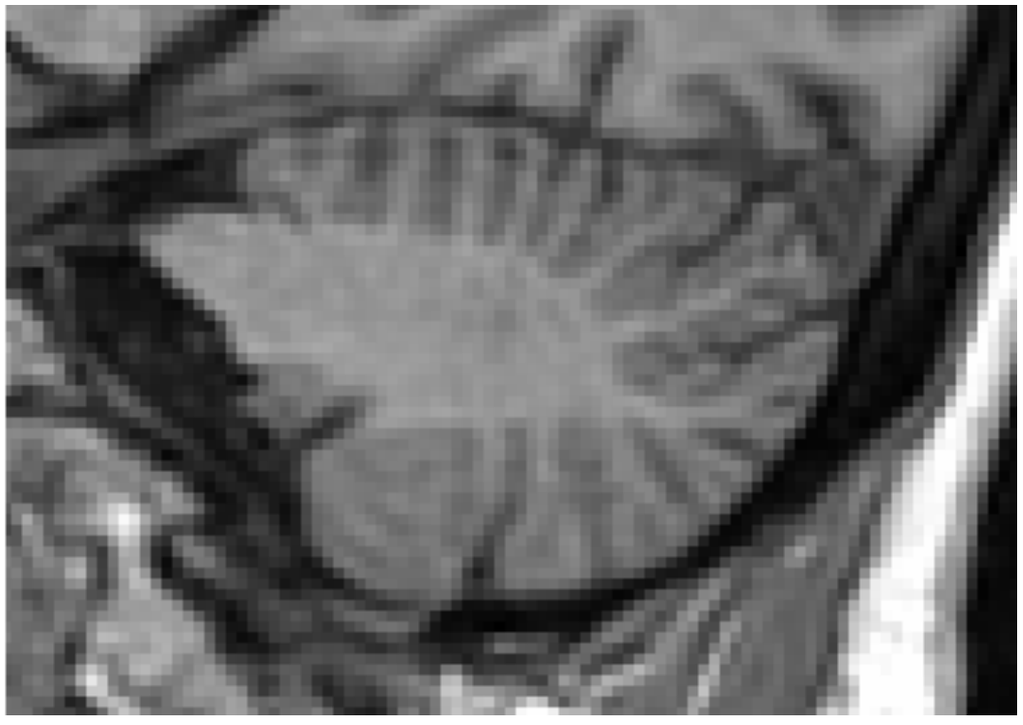
1.5 Tesla
0.94×0.94×1.2



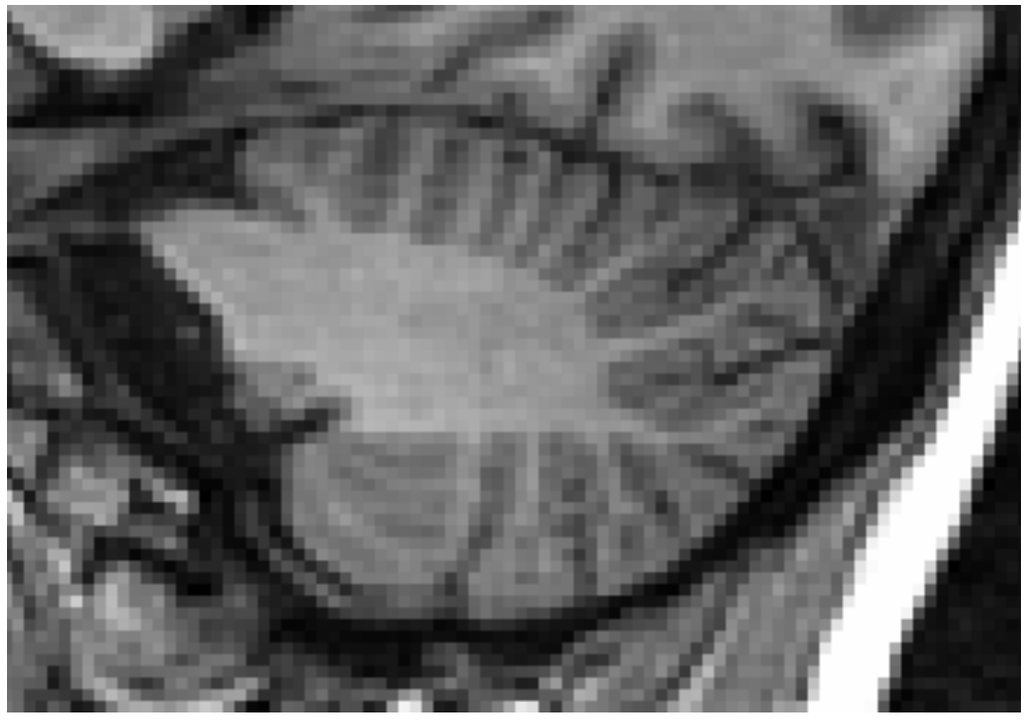
3 Tesla
1.02×1.02×1.2

Images from the ADNI database

Magnetic Resonance Imaging (MRI)



1.5 Tesla
0.94×0.94×1.2

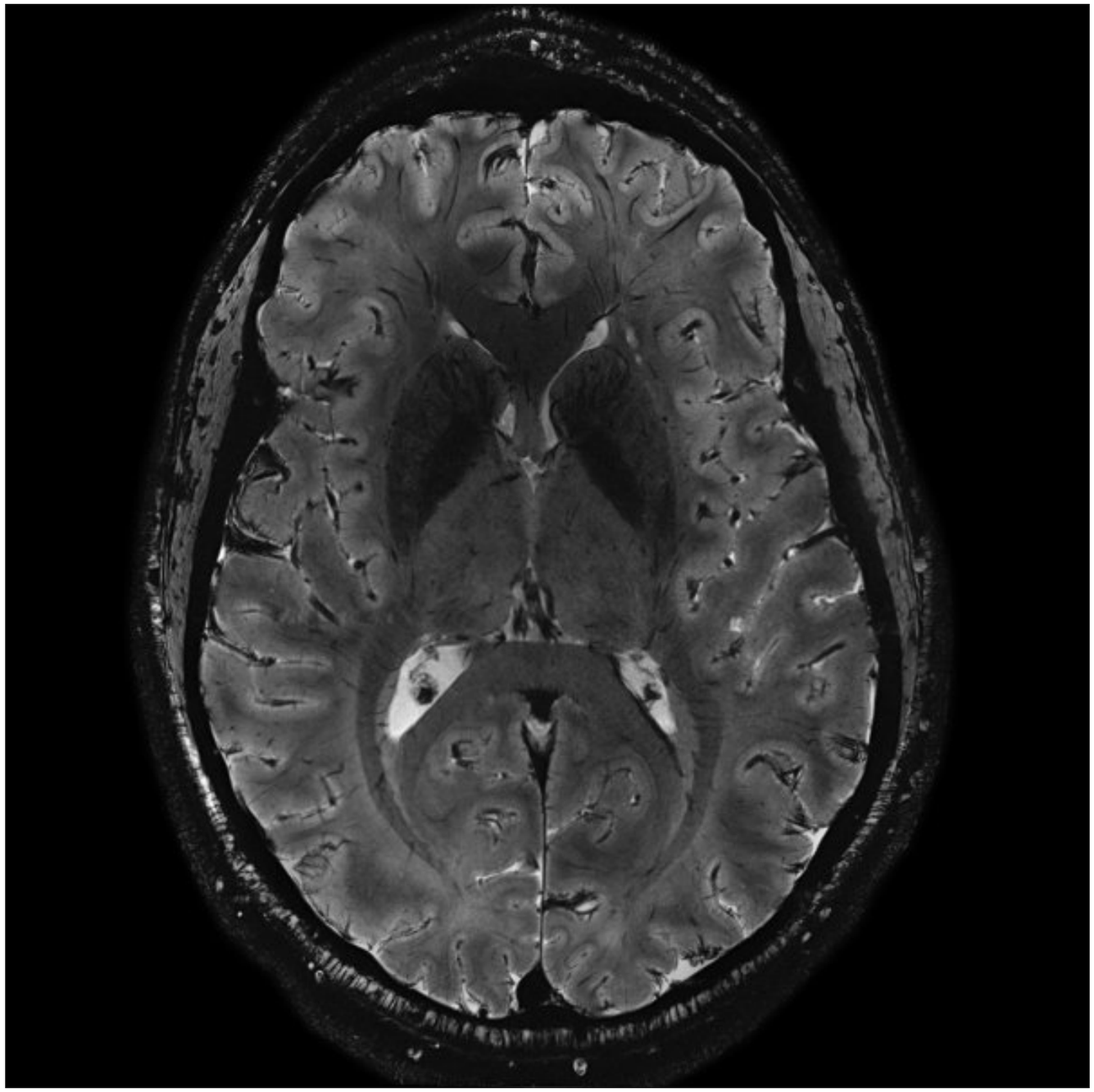


3 Tesla
1.02×1.02×1.2

Images from the ADNI database

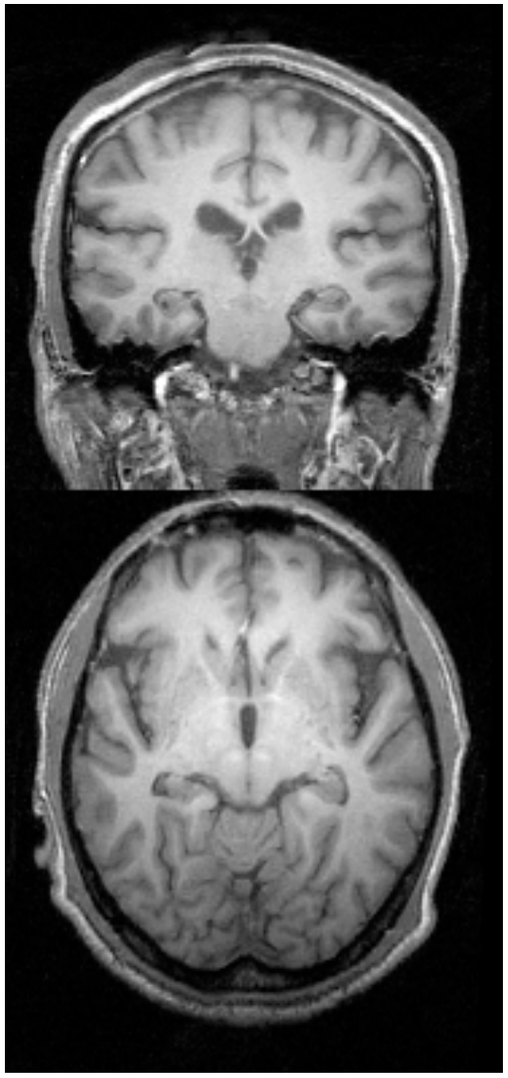
Magnetic Resonance Imaging (MRI)

- 7T

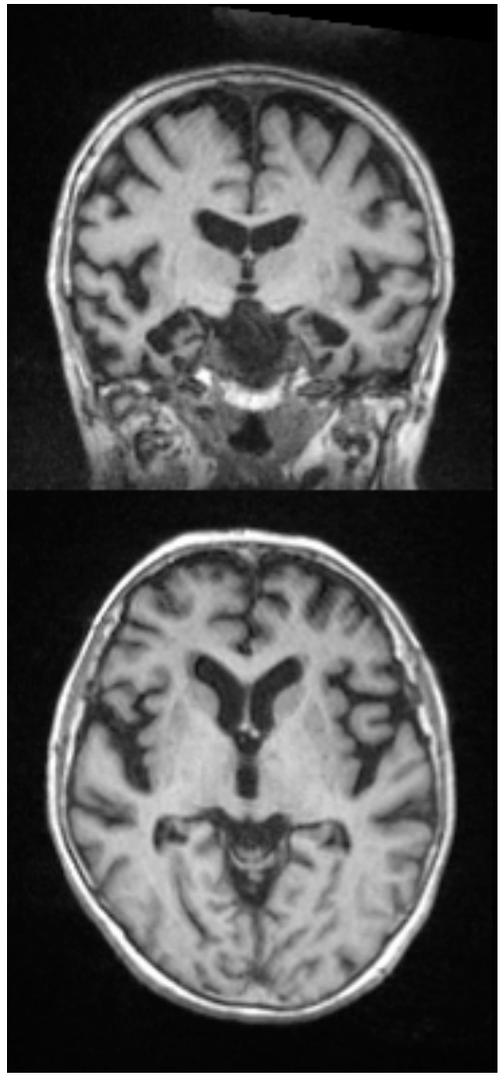


Magnetic Resonance Imaging (MRI)

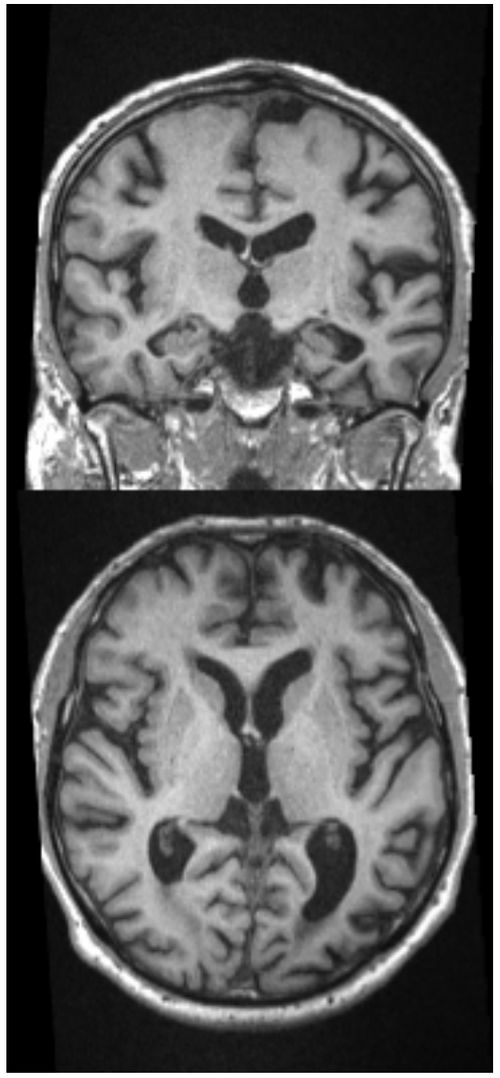
- Structural changes



Normal Control



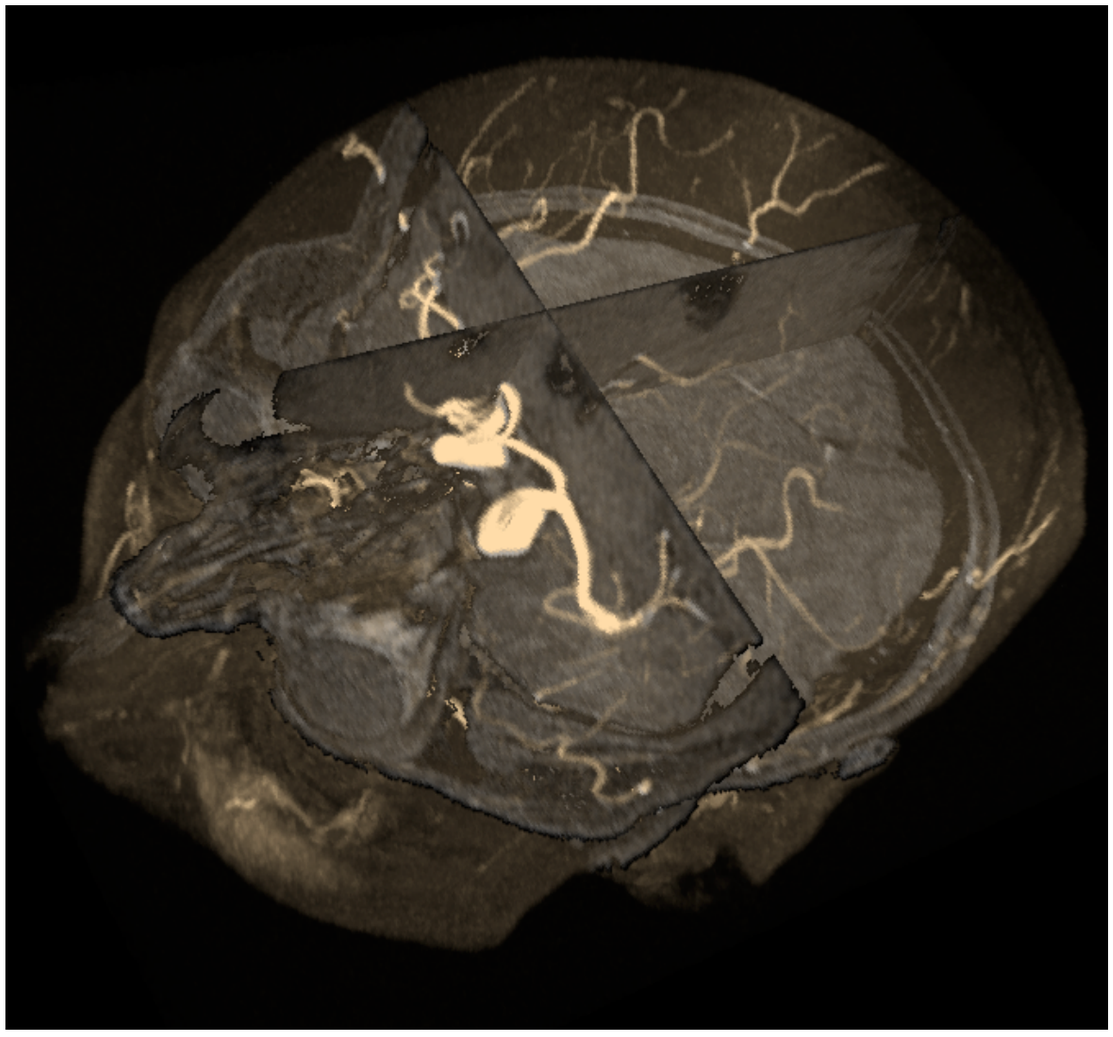
Mild Cognitive Impairment

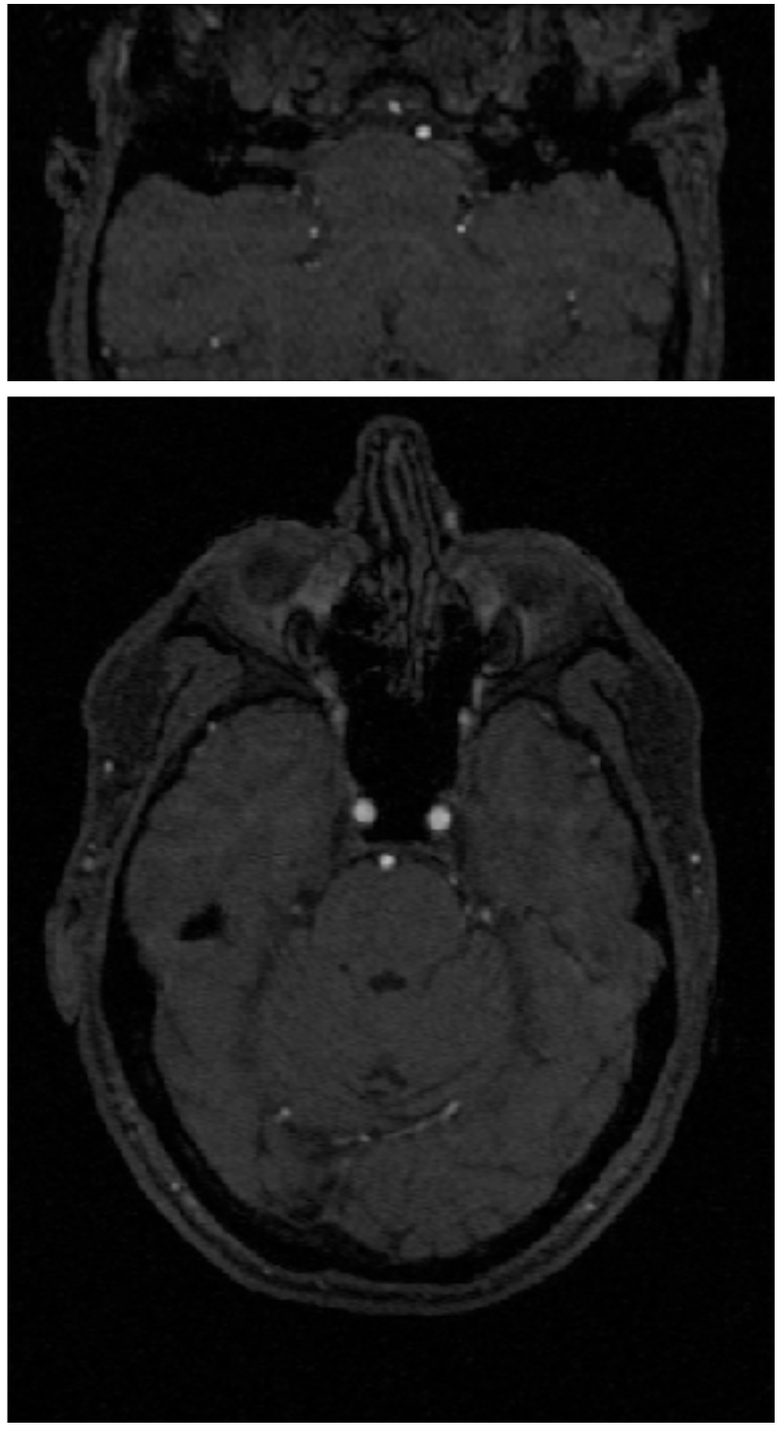


Alzheimer's disease

Magnetic Resonance Imaging (MRI)

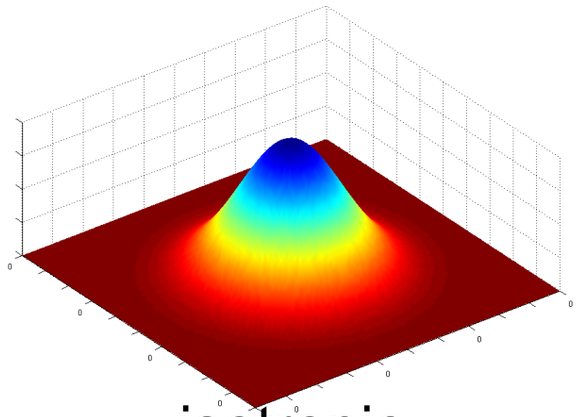
- Angiography



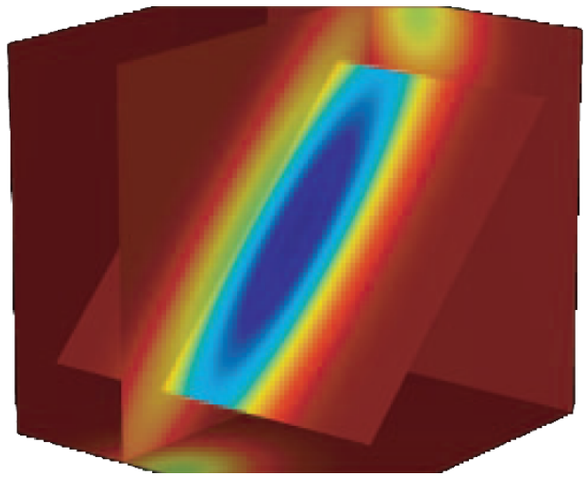


Magnetic Resonance Imaging (MRI)

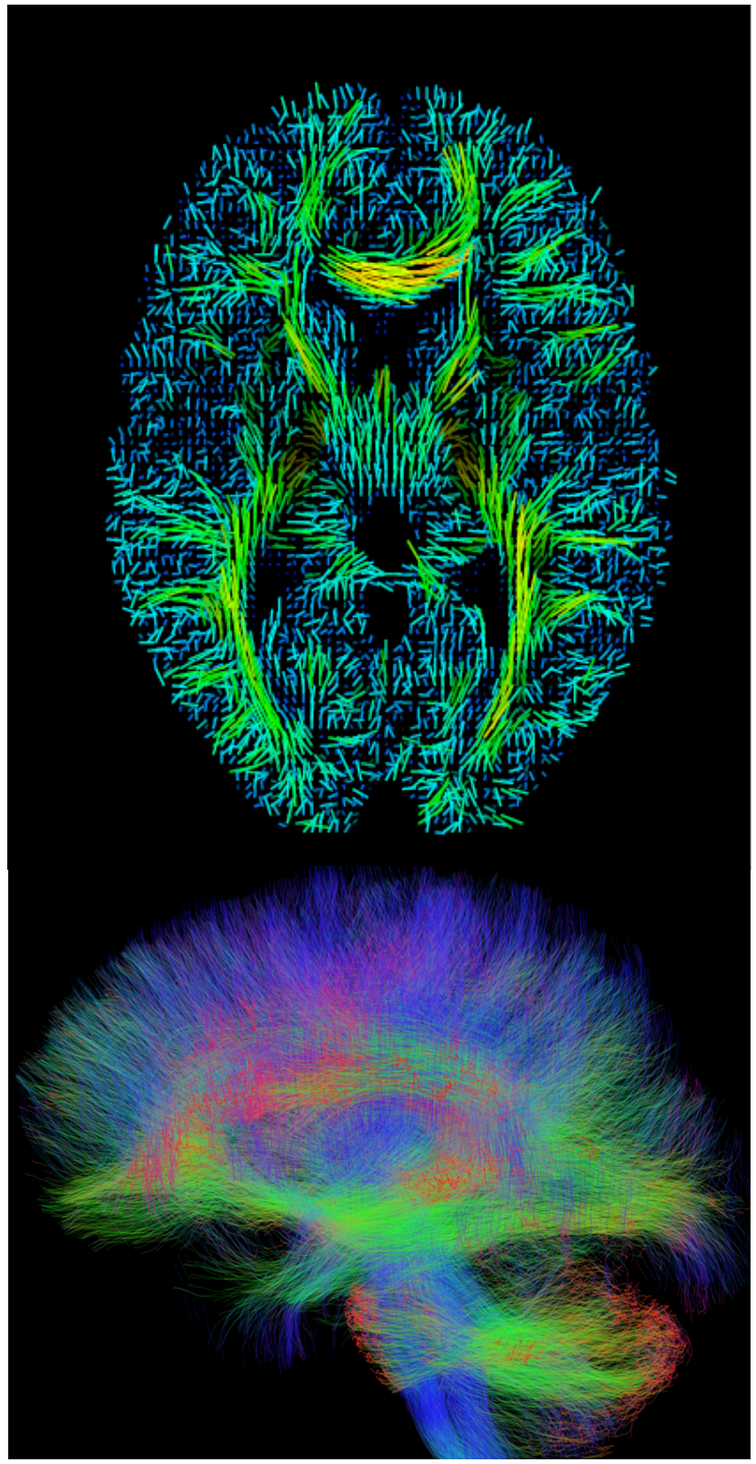
- Diffusion Imaging



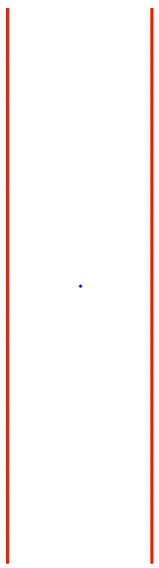
isotropic



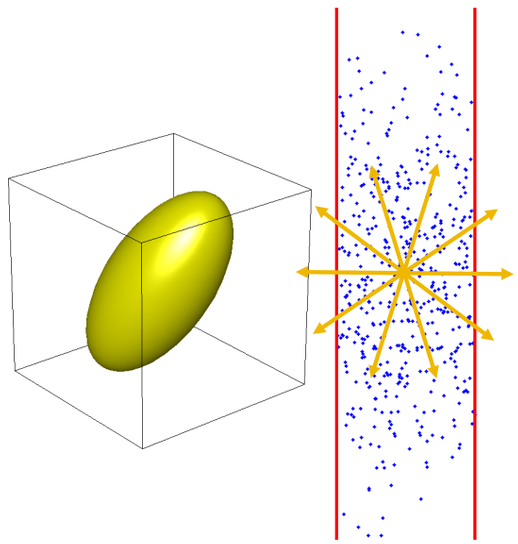
anisotropic diffusion propagator



free diffusion



restricted diffusion



diffusion tensor

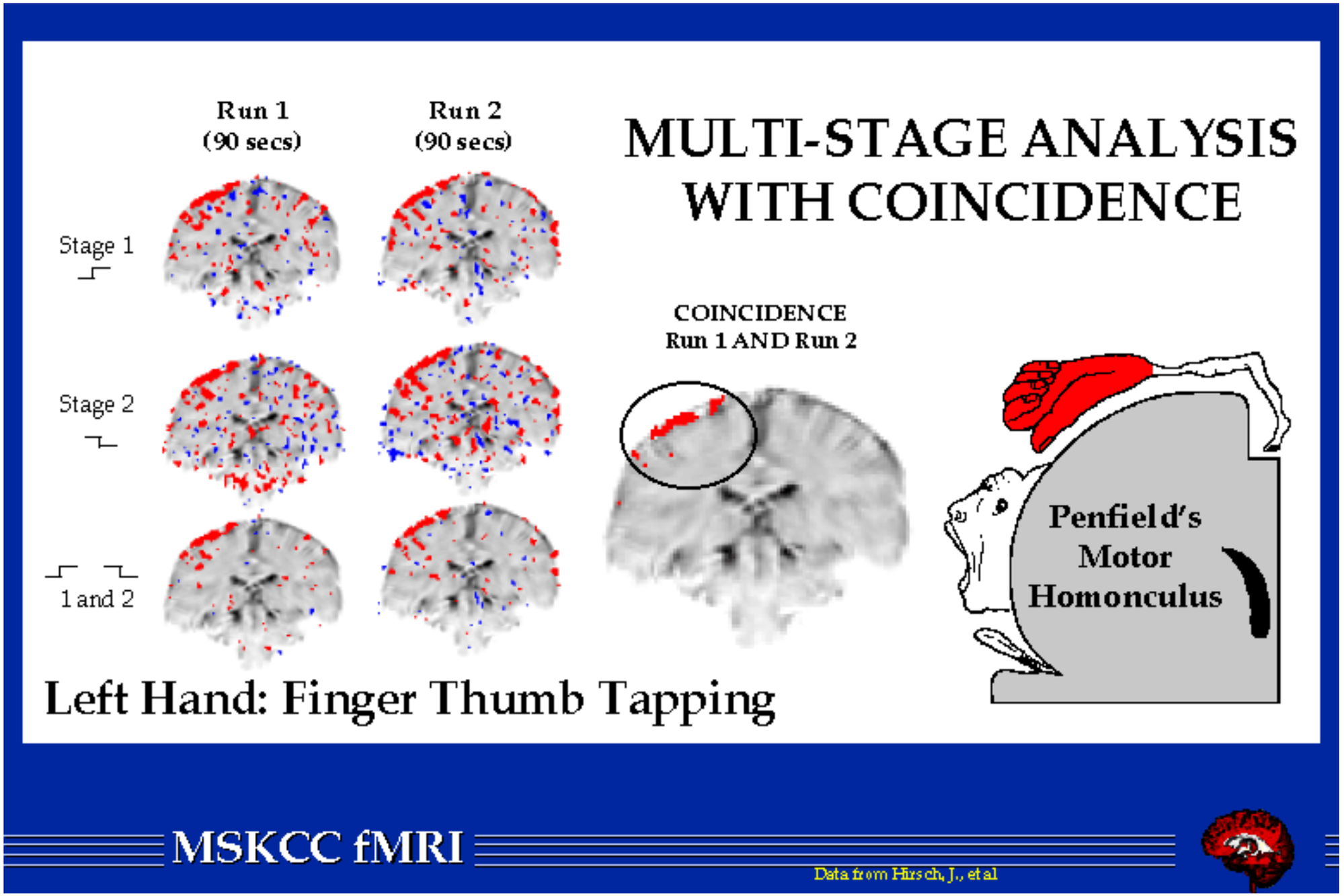
Magnetic Resonance Imaging (MRI)

- Functional MRI (fMRI), based on:
  - Mapping changes in brain hemodynamic
  - Movement and flow
  - Blood oxygen level dependant signal: mental operations

- Identification and mapping of brain activity is critical:
  - Brain understanding (cognitive science)
  - Neurodegenerative disease understanding
  - Neurosurgery application

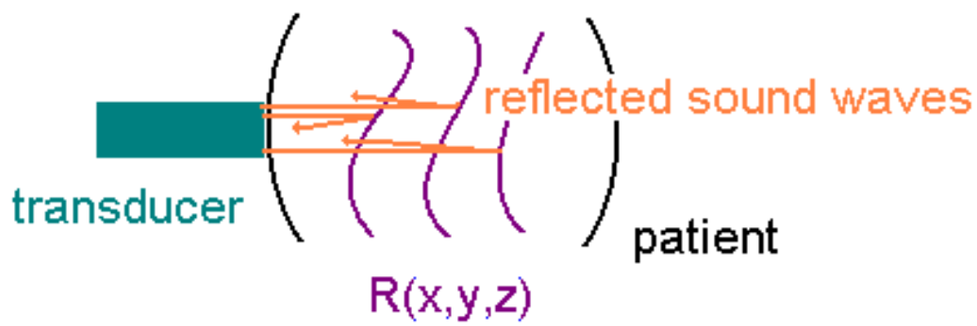
- It does not require injection of radioactive isotopes

Magnetic Resonance Imaging (MRI)



Ultrasound Imaging (US)

- Image based on:
  - Reflected waves
  - Tissue composition
  - Movement and flow

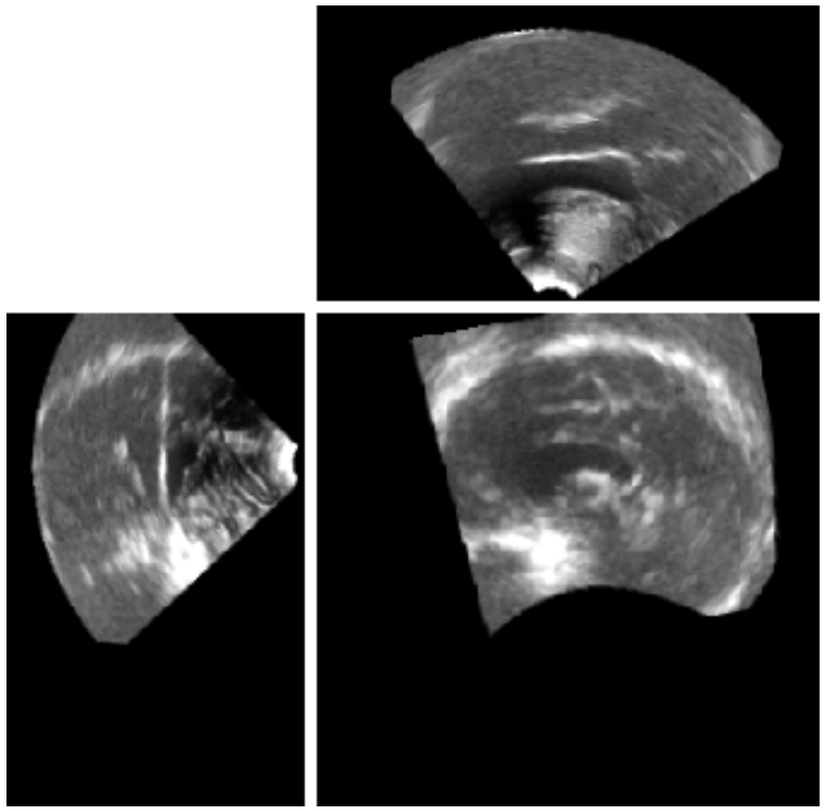


- A pulse is propagated and its reflection is received, both by the transducer
- Key assumption:
  - Sound waves have a nearly constant velocity of ~1500 m/s in H2O
  - Sound wave velocity in H2O is similar to that in soft tissue
  - Thus, echo time maps to depth

Ultrasound Imaging (US)

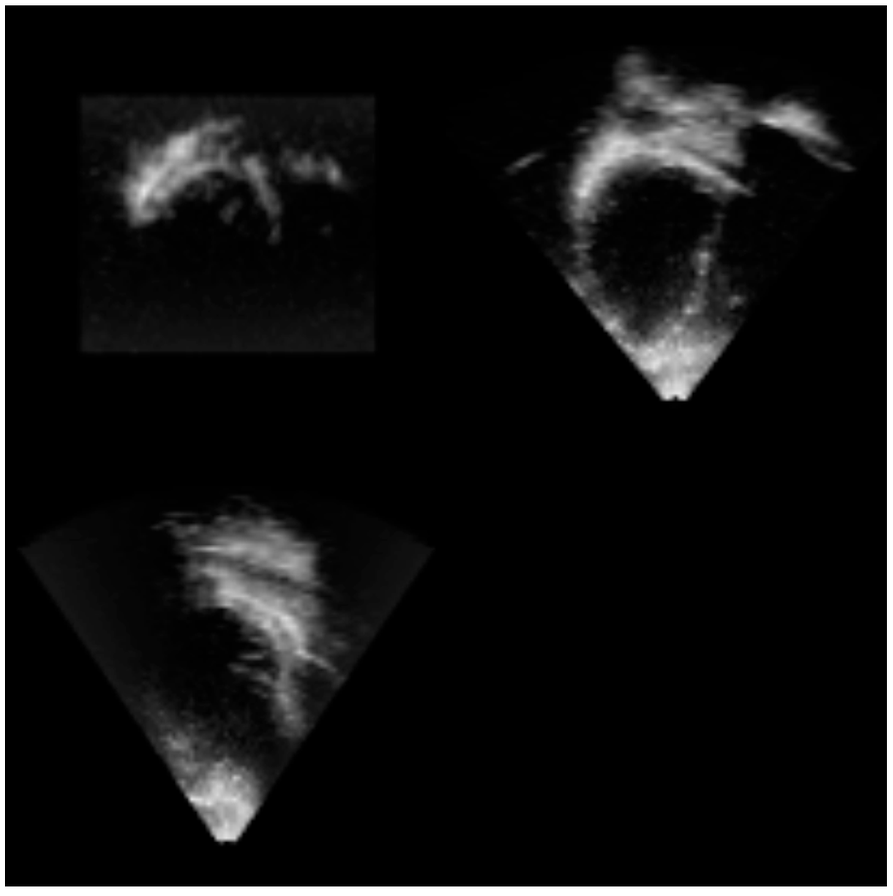
- Advantages:
  - Cheap, safe, portable "bed side", compact
  - Real-time imaging

- Weaknesses:
  - Images very operator dependent
  - Does not penetrate bone
  - Limited viewing angles
  - Image quality issues

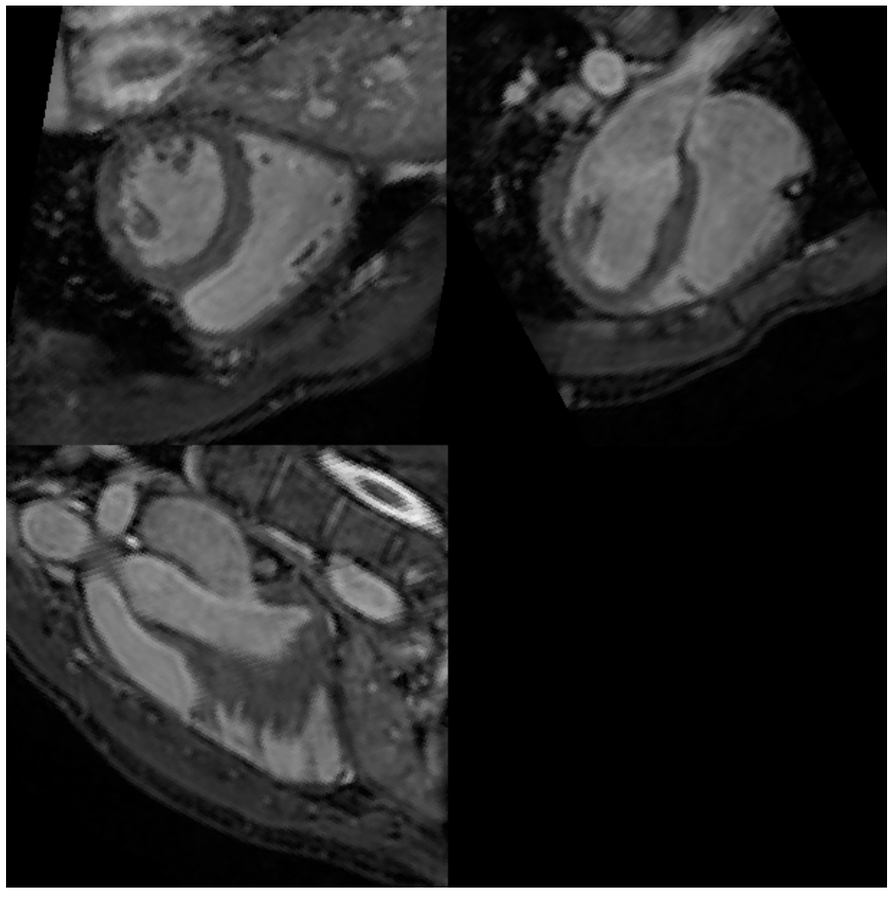


Ultrasound Imaging (US)

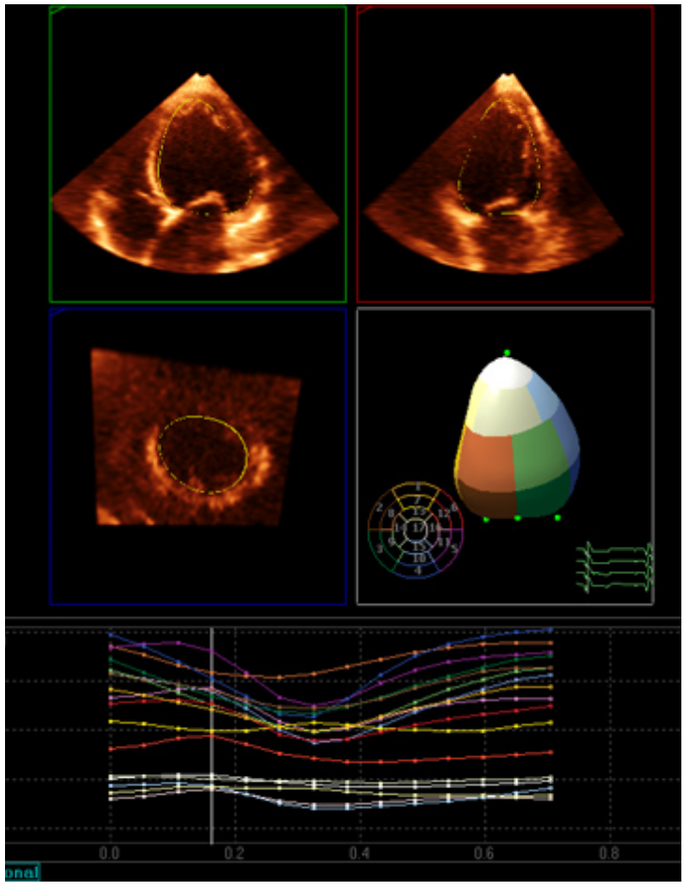
- Heart imaging example



3D ultrasound of the heart



MRI of the heart

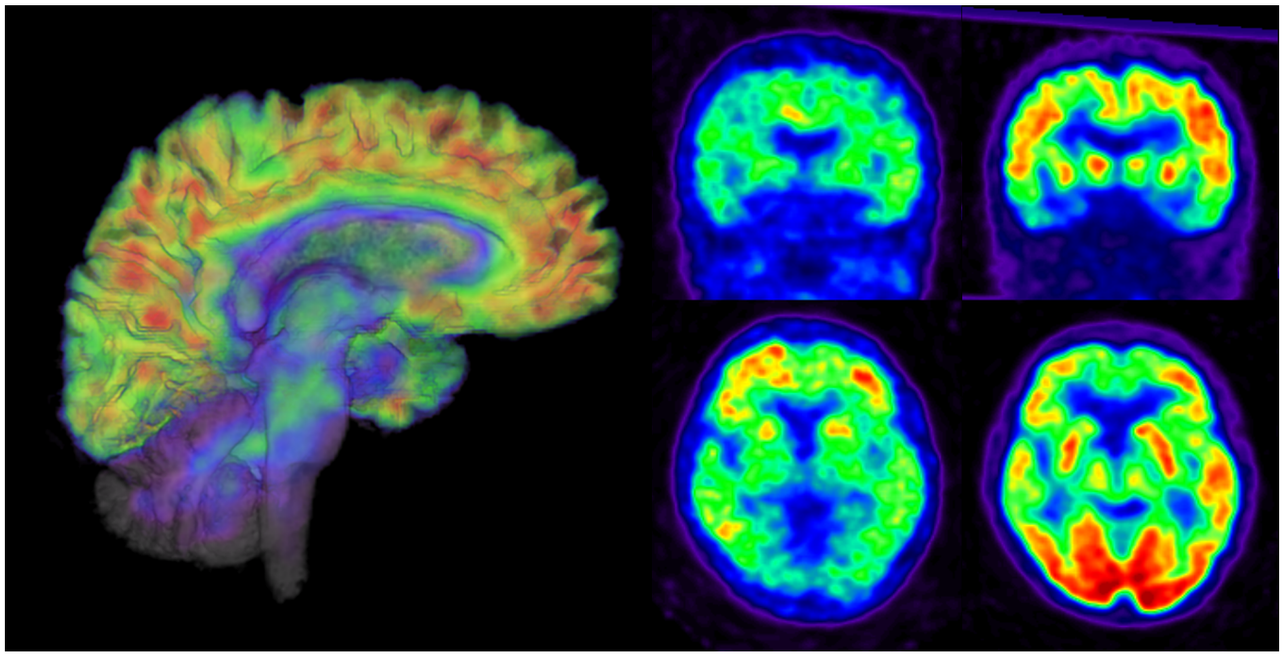


4D heart analysis

Positron Emission Tomography (PET)

- Image based on:
  - Radioactive isotope attached to metabolic marker (injected tracer: radionuclide)
  - Gamma radiation
  - Tissue biochemistry

Each patient is given a minute amount of a radioactive pharmaceutical that closely resembles a natural substance used by the body.



Positron Emission Tomography (PET)

- Tracer (FDG) concentrates in areas with increased glucose metabolism

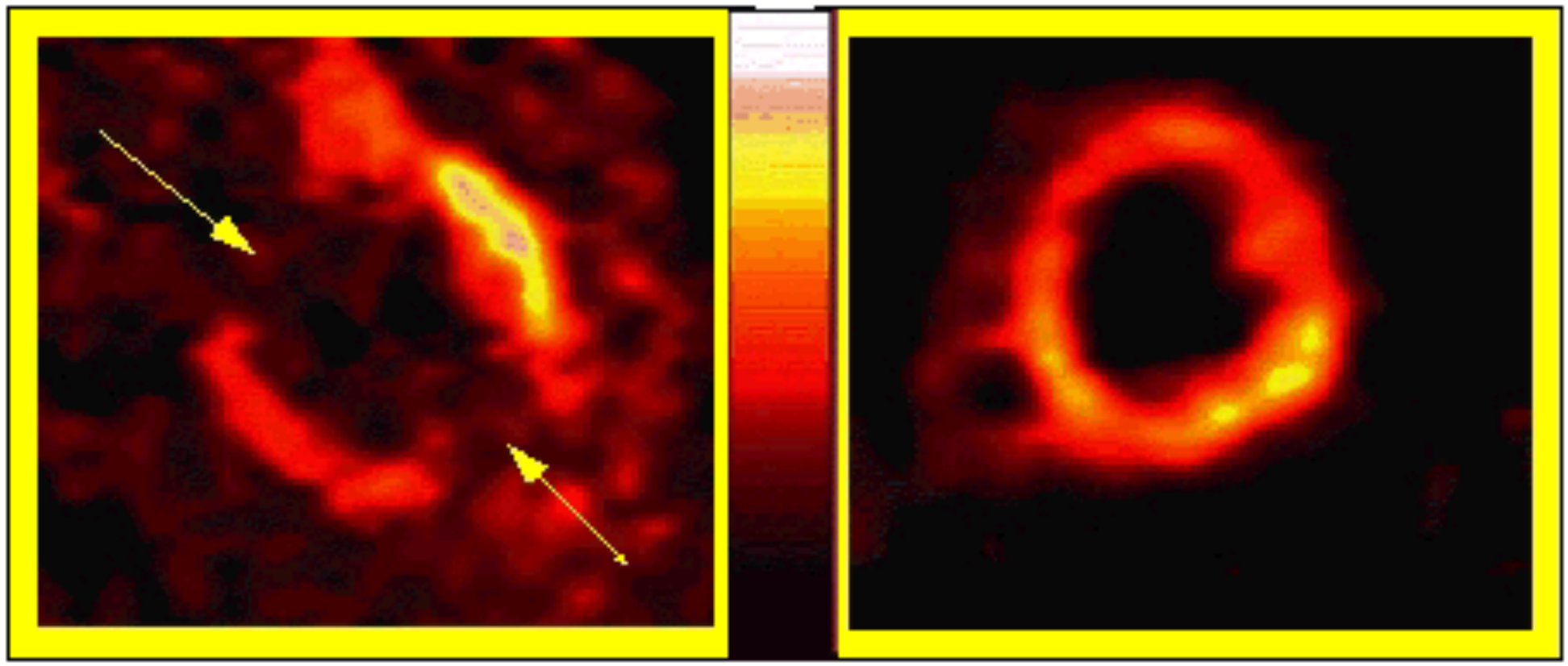
- Non specific uptake also seen in the kidneys, bladder, liver

- PET imaging can also show the region of the brain that is causing a patient's seizures

- Useful in evaluating degenerative brain diseases such as Alzheimer's, Huntington's, and Parkinson's

Positron Emission Tomography (PET)

- Example

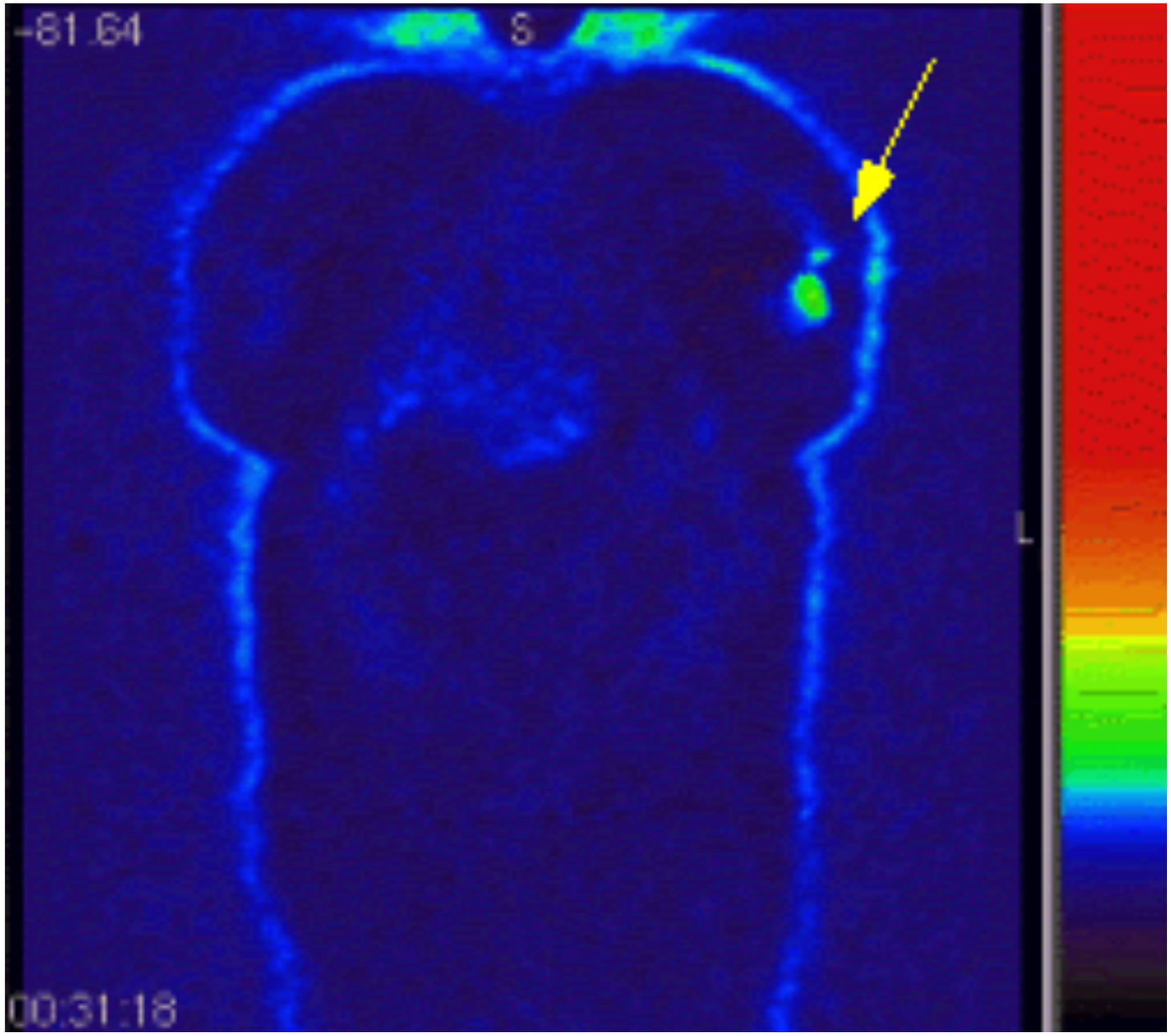


myocardial infarction
(heart attack)

normal heart

Positron Emission Tomography (PET)

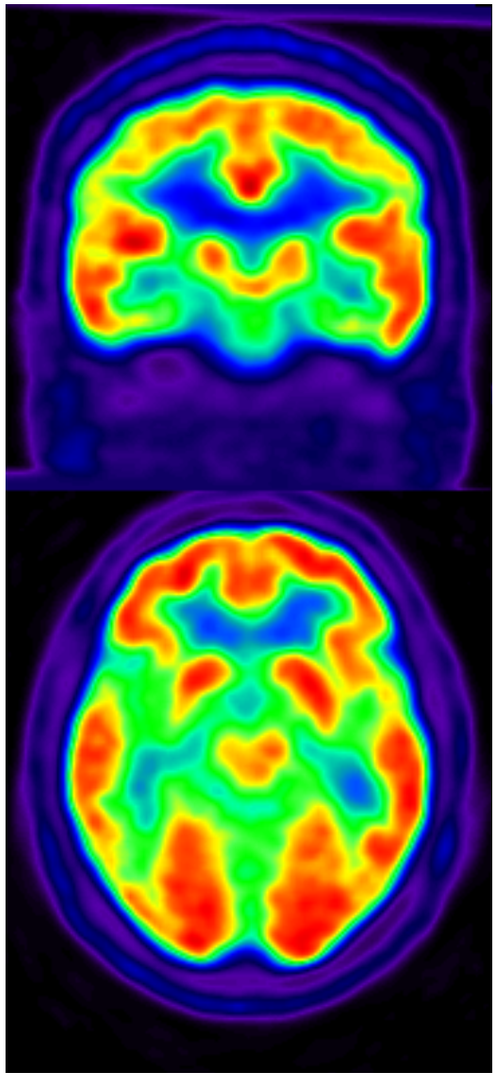
- Example



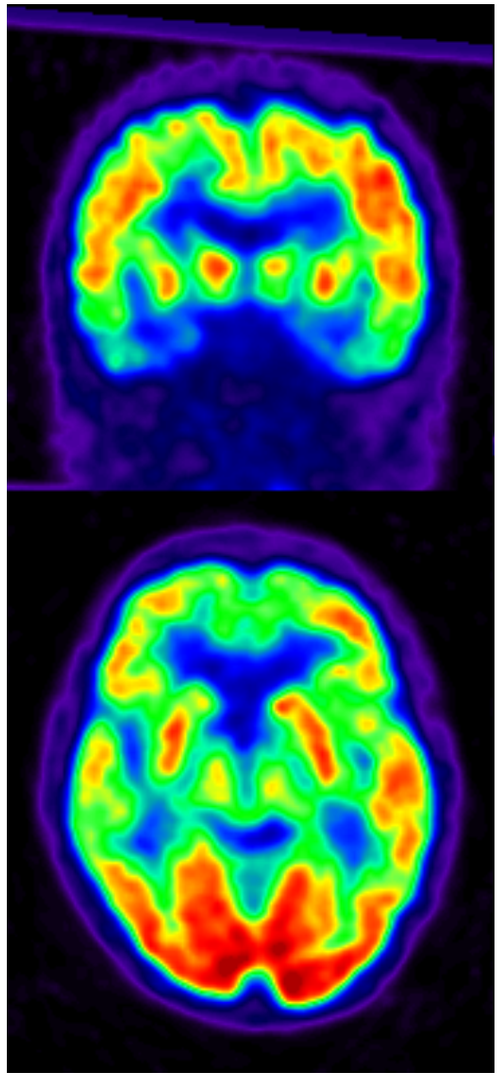
Malignant breast mass that was not revealed by conventional imaging techniques such as CT, MRI, and mammogram.

Positron Emission Tomography (PET)

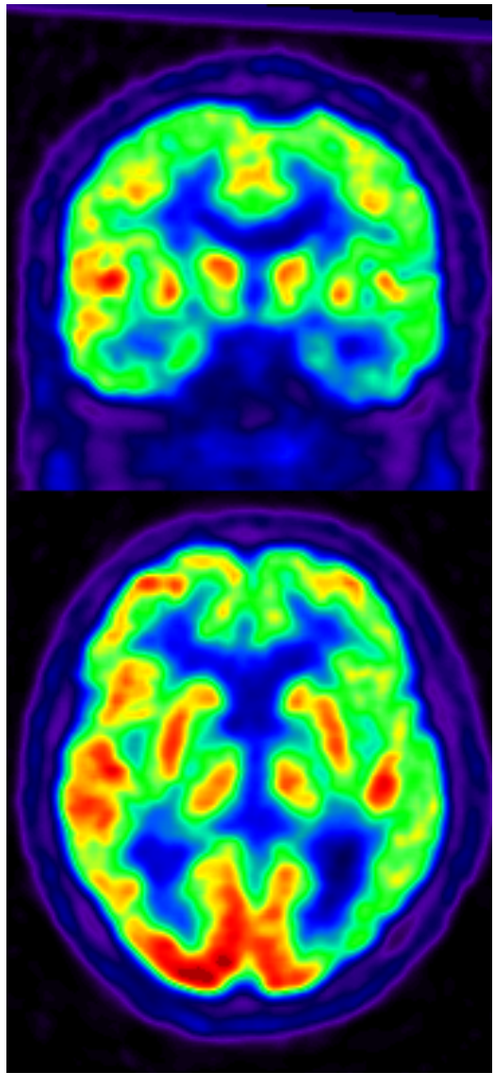
- FDG PET



Normal Control



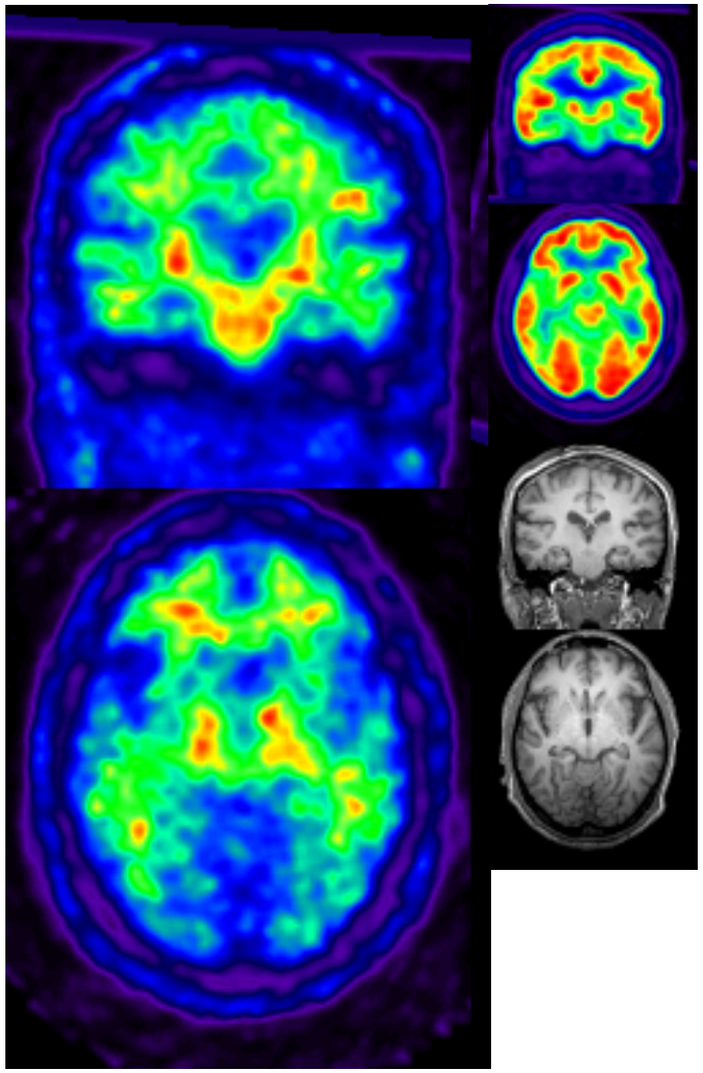
Mild Cognitive Impairment



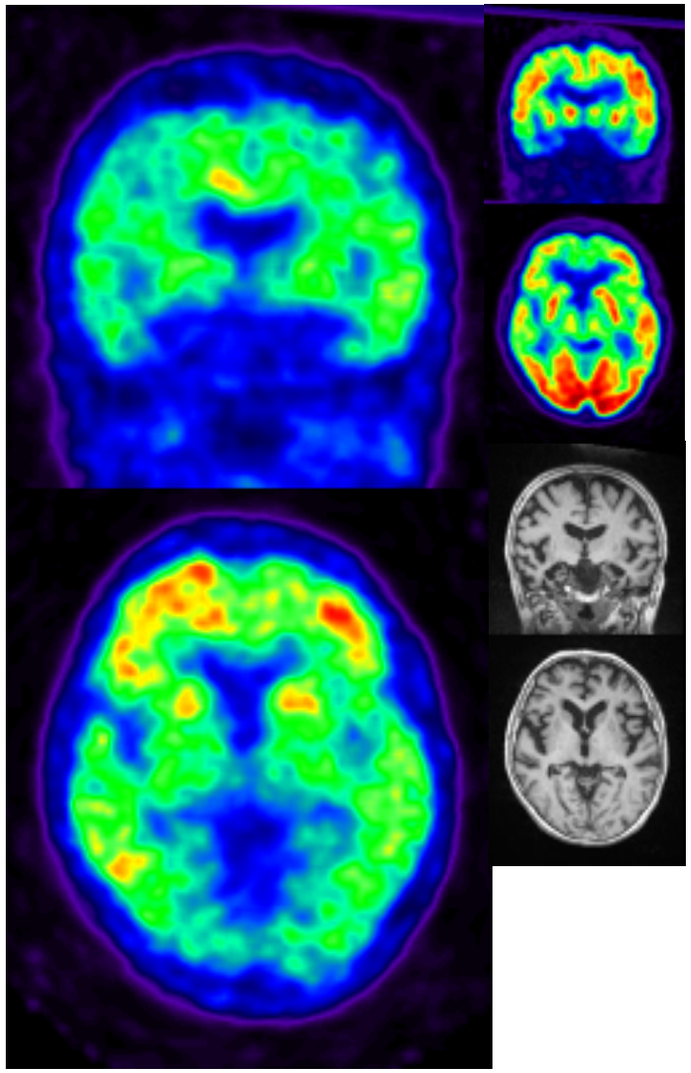
Alzheimer's disease

Positron Emission Tomography (PET)

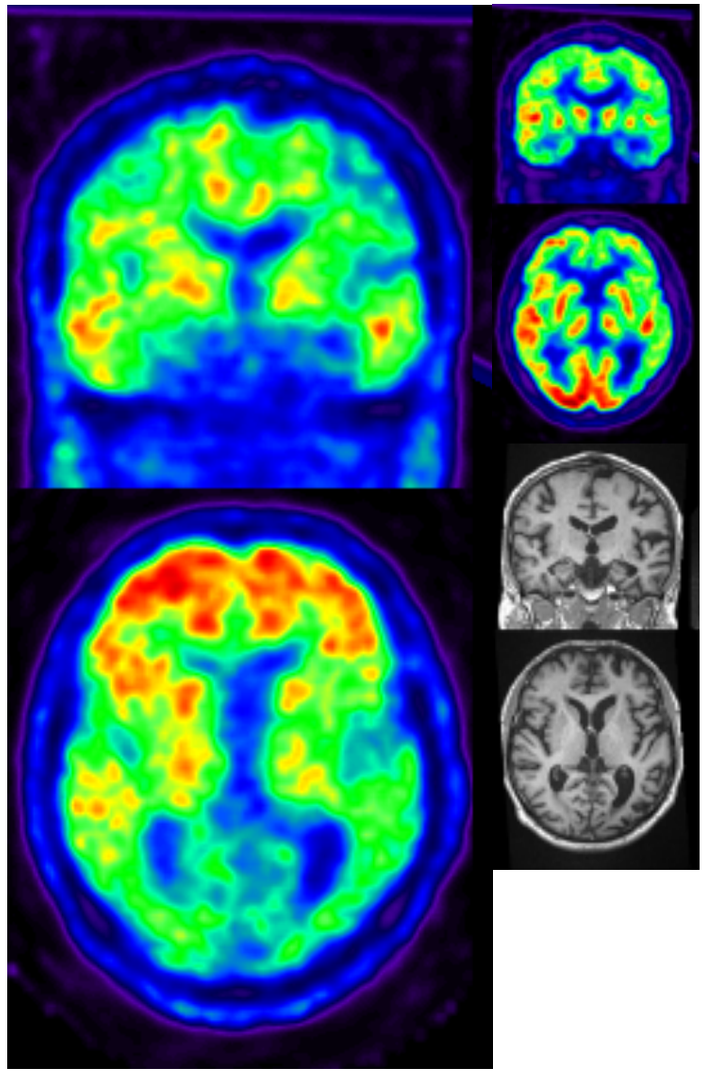
- PIB PET



Normal Control



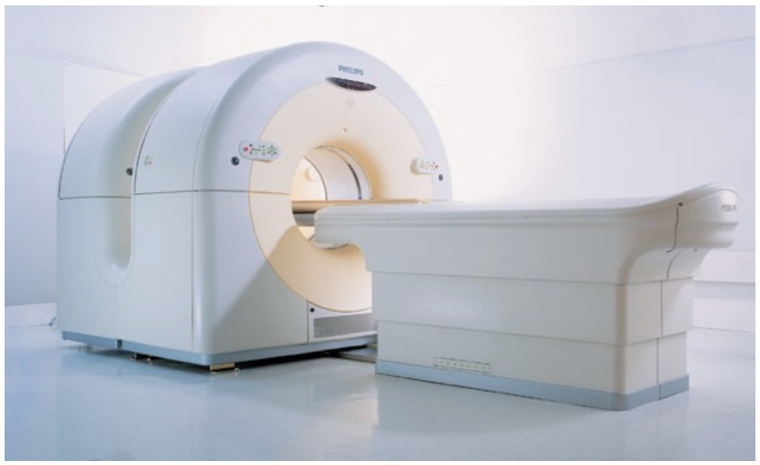
Mild Cognitive Impairment

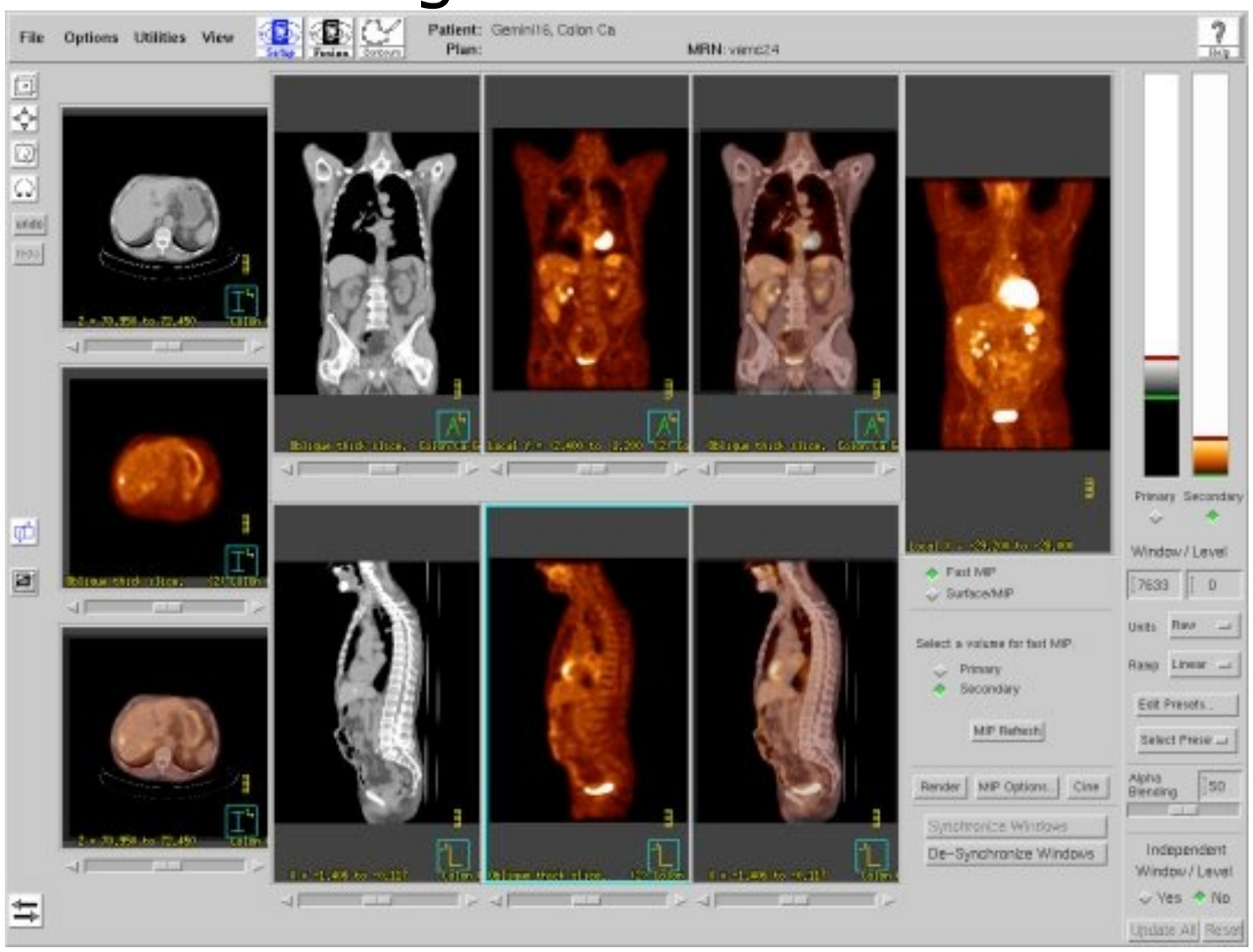


Alzheimer's disease

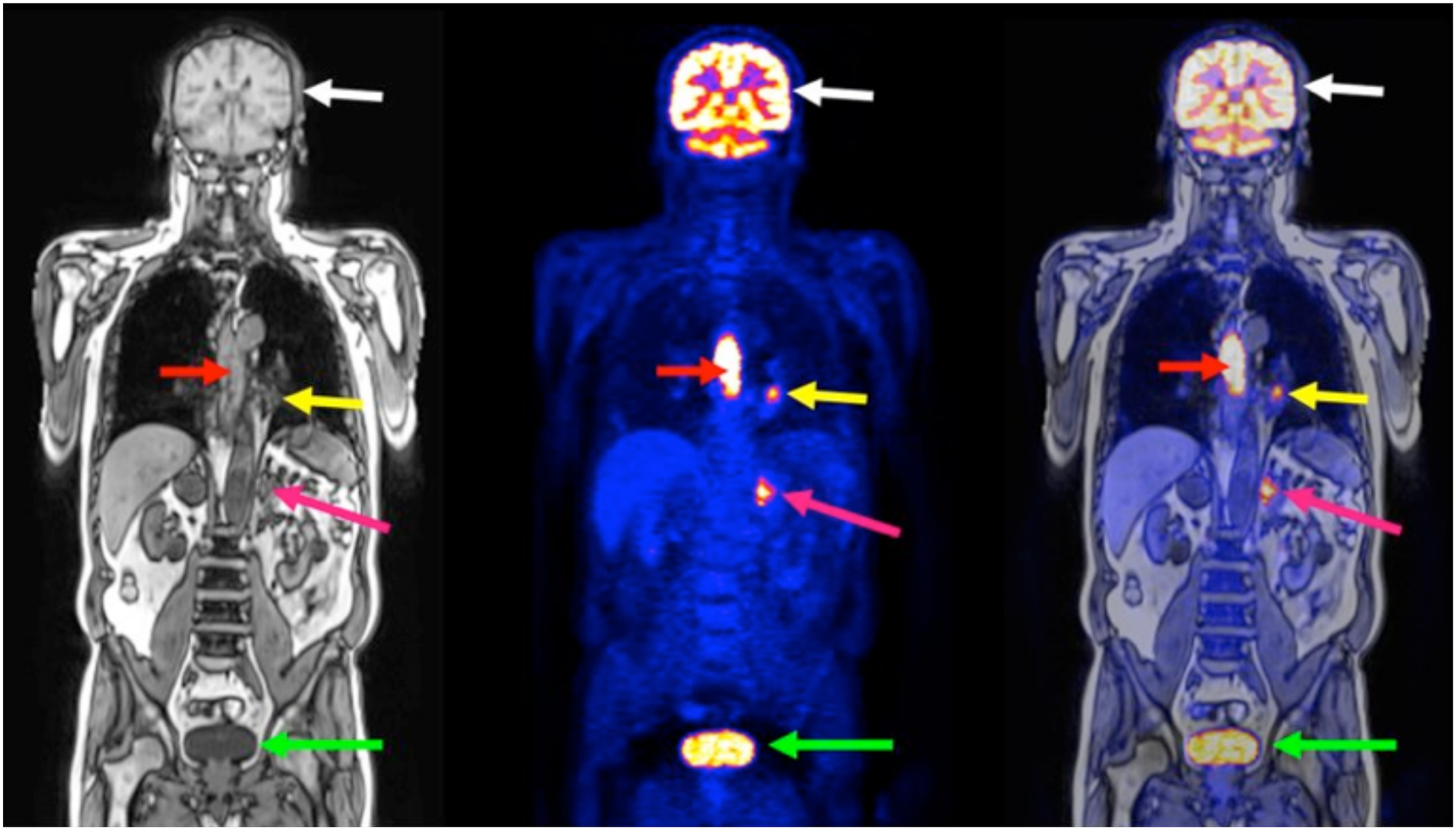
Combined PET-CT

- Combining Structure and Function has many diagnosis and screening advantages

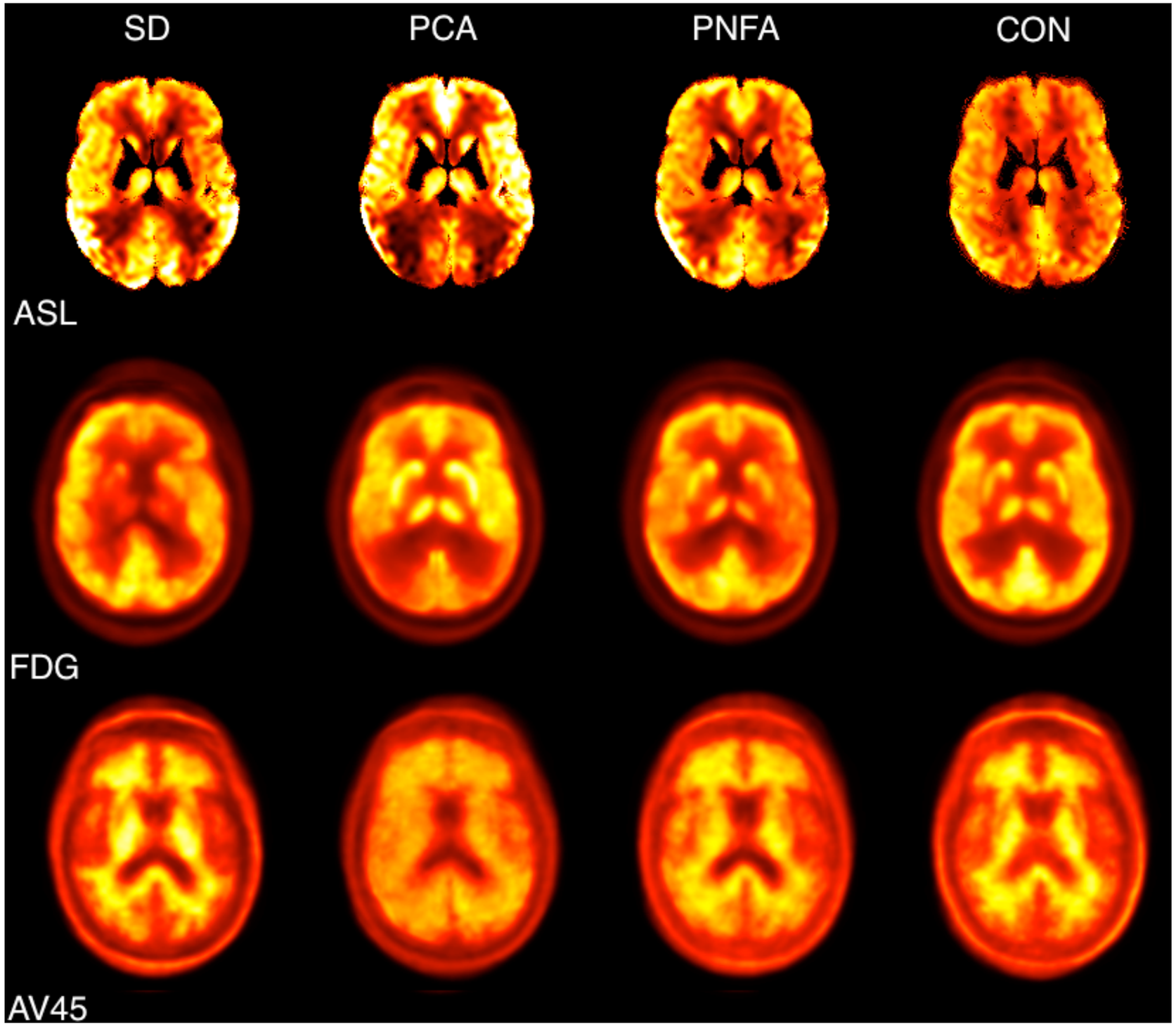




Combined PET-MR



Combined PET-MR



Clinical Applications

	Chest	Abdomen	Head
X-Ray/ CT	+ widely used + CT	– needs contrast + CT - excellent	+ X-ray - is good for bone – CT - bleeding trauma
Ultrasound	– Mostly heart	+ excellent – problems with gas	– poor
Nuclear	+ extensive use in heart	Merge with CT	+ PET
MR	+ growing cardiac applications	+ minor role	+ standard

Clinical Applications

	Cardiovascular	**Skeletal / Muscular**
X-Ray/ CT	+ X-ray – Excellent, with catheter-injected contrast	+ strong for skeletal system
Ultrasound	+ real-time + non-invasive + cheap – but, poorer images	– not used
Nuclear	+ functional information on perfusion	+ functional - bone marrow
MR	+ getting better High resolution Myocardium viability	+ excellent

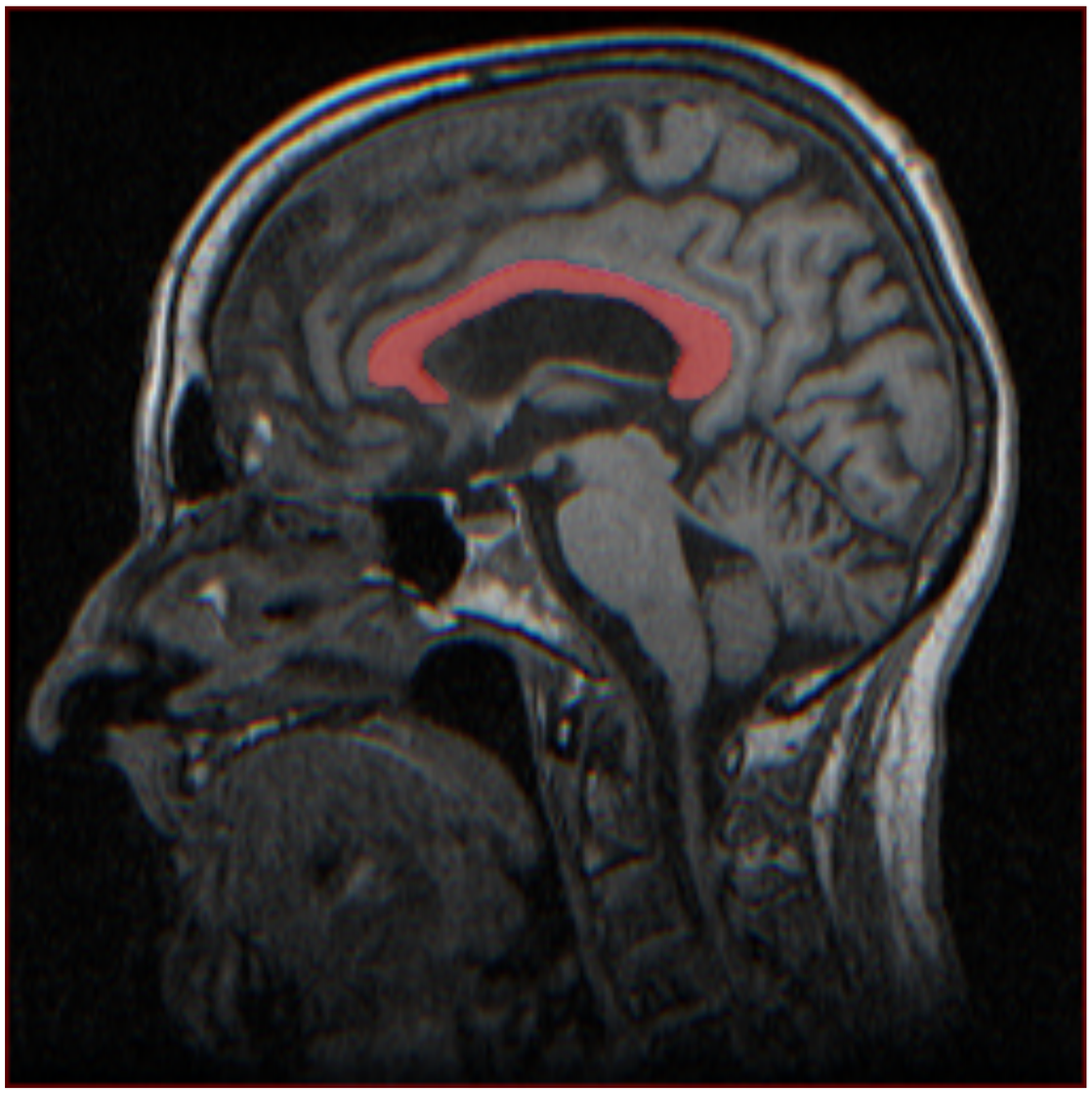
Methods

What is segmentation?

- "Delineating and assigning a label to a biological structure"

A wide variety of techniques have been proposed

No magic segmentation for all images

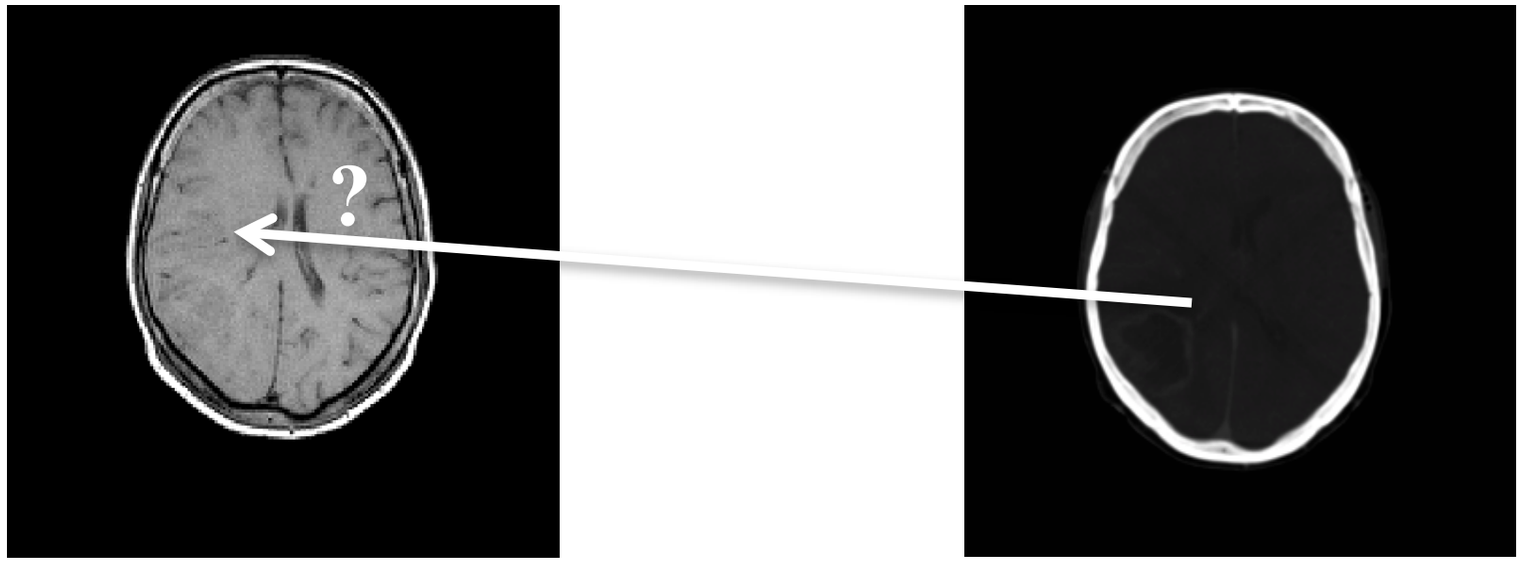


Segmentation: Matrix Classification

	Pixel-based	Region-based	Model-based
Structural	Thresholding Edge-based	Watershed	Graph-searching
Statistical	Clustering	Markov Random Fields Split and Merge	Histogram-based
Hybrid	Statistical Atlas	Region Growing	Deformable Model Atlas Warping

What is registration?

- "Registration is the process of mapping between coordinates in one space and those in another, to achieve biological, anatomical or functional correspondence".



Why do we need registration?

- Quantitatively compare scans of the same subjects done at different times or with different modalities.
- Pre-/Post- surgery/treatment.
- Compare MR/CT/PET/SPECT.
- Correct for patient motion in dynamic imaging.
- Estimate change over time (tumour progression, atrophy).

- Quantitatively compare scans of different subjects.
- Compare normal subjects with abnormal subjects.
- Construct population models of anatomical variation.
- Fit generic models to individual subjects.

A taxonomy of reg. algorithms

Parametric

Rigid

Affine

Thin-plate Spline

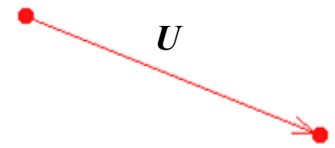
DCT

Free form deformation

Non-Parametric

Optical flow

Daemons



Log Demons

Diffusion

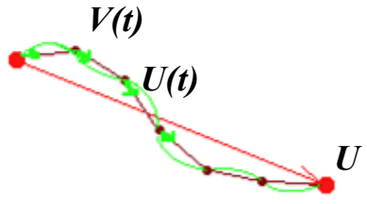
Dartel

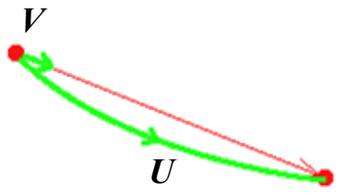
Elastic

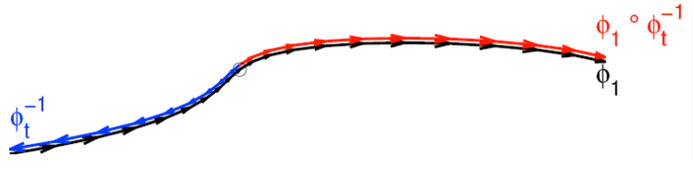
Curvature

Fluid

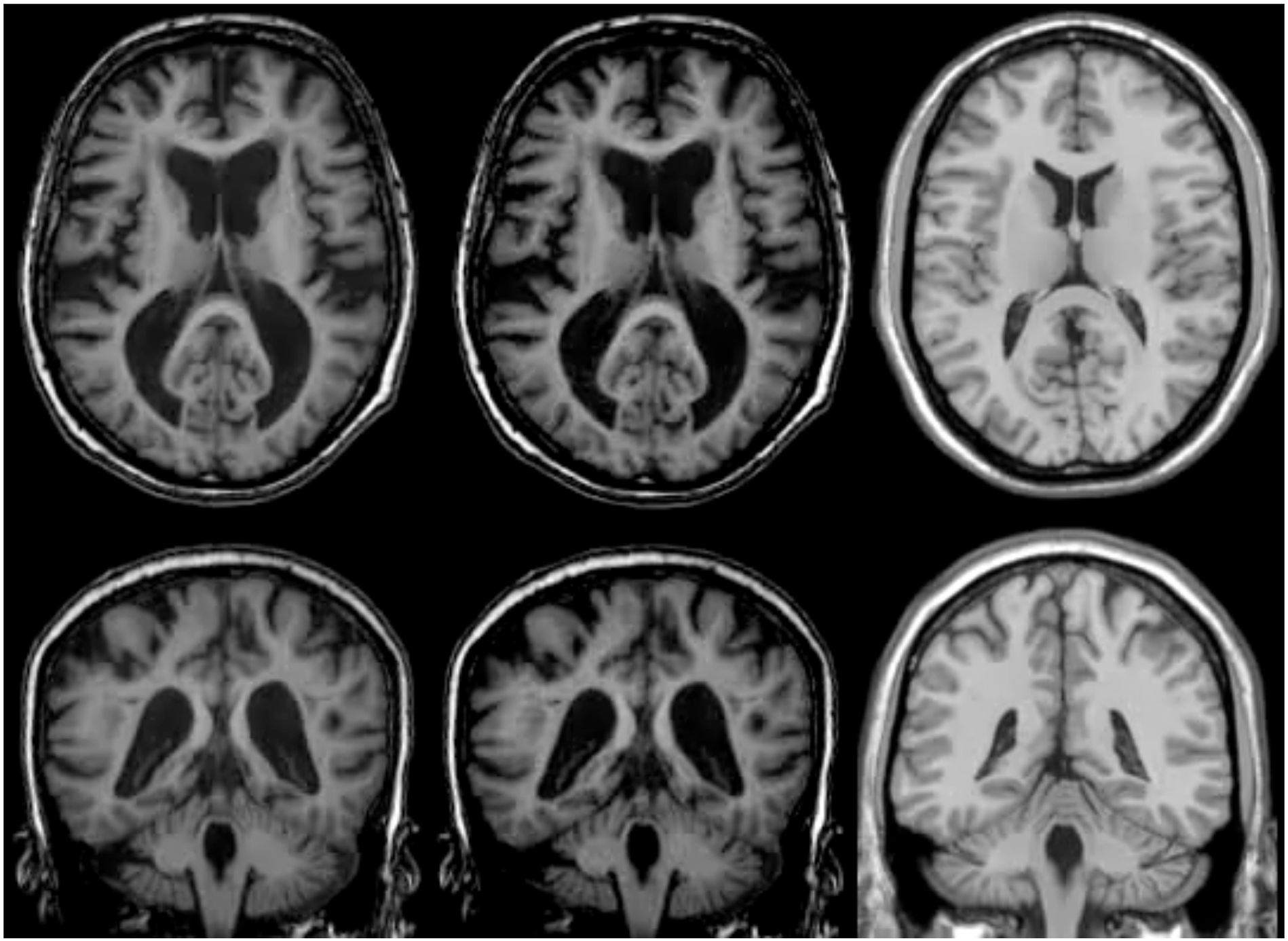
LDDMM



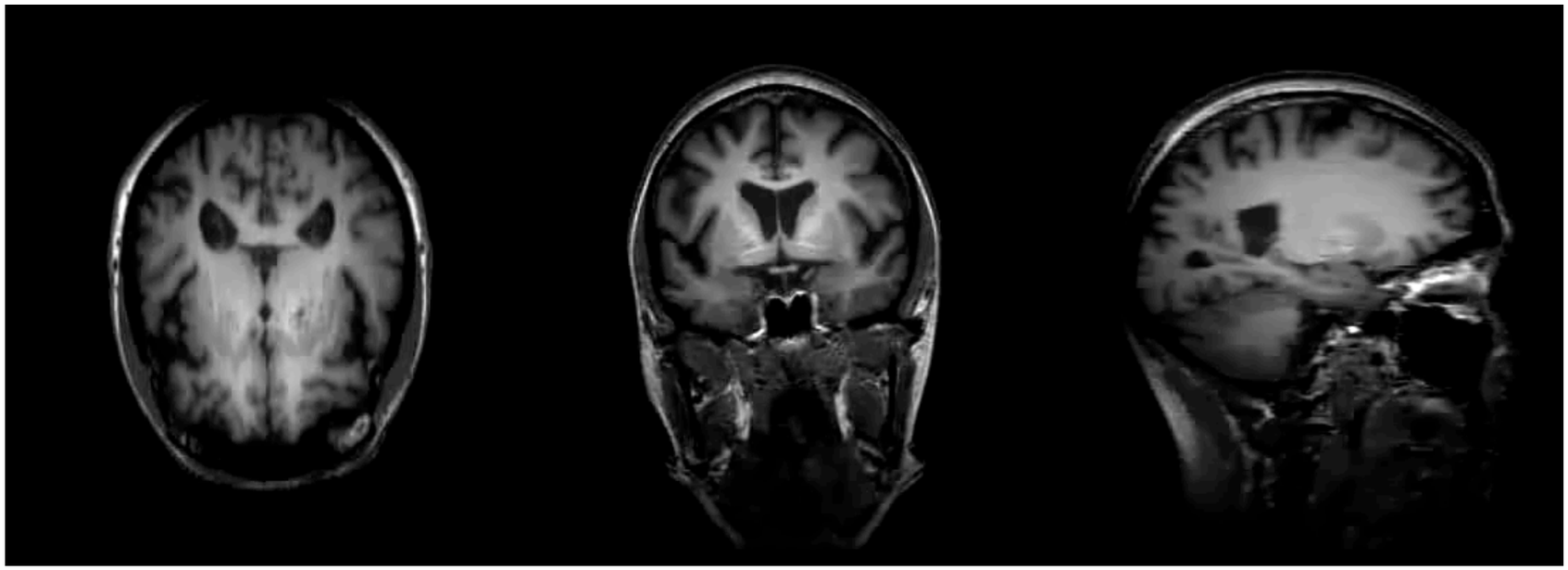




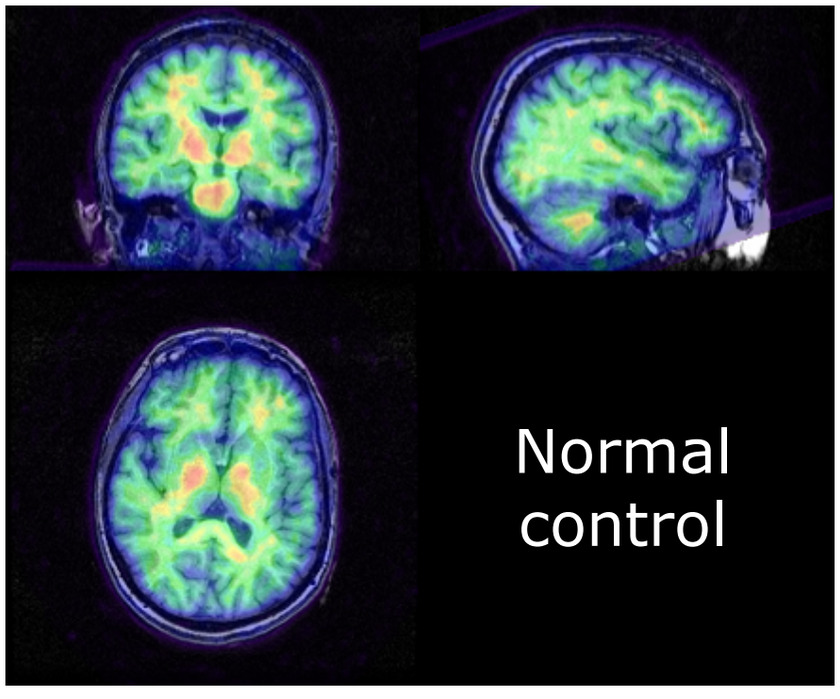
Registration example

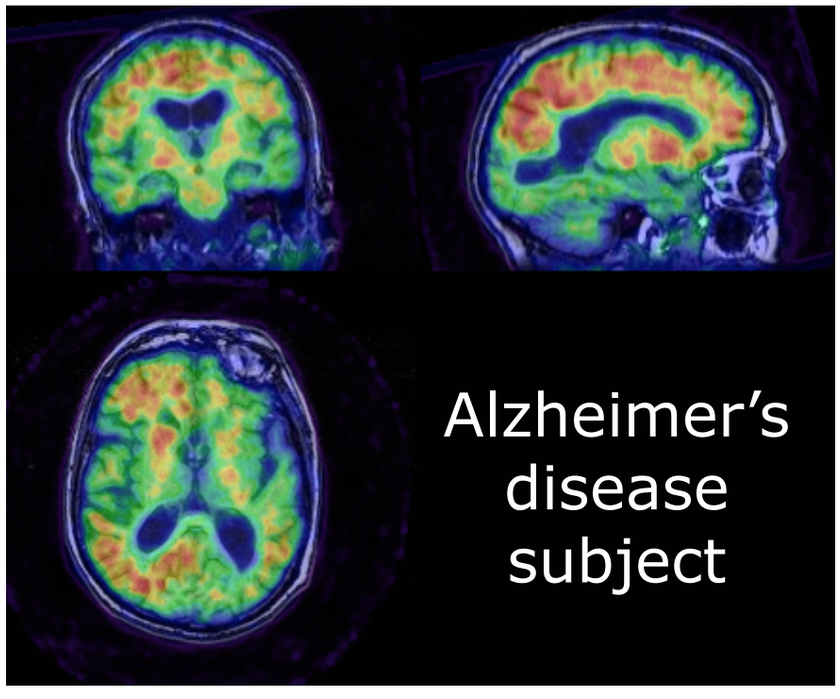


Registration example



Registration process of PET and MR of the same patient





Registration application examples

- Some (of many) clinical applications
  - Measurement of atrophy in Alzheimer's disease
  - Measurement of lesion volume in Multiple Sclerosis
  - MRI-US for surgery image guidance
  - Intraoperative MRI
  - Tumour growth modelling
  - Breathing motion modelling for radiotherapy guidance
  - MRI-US prostate biopsy guidance
  - Motion correction in contrast enhanced MRI
  - Preterm imaging
  - Genotype-Phenotype imaging
  - Research software at CMIC

Alzheimer's Disease: the most common cause of dementia

- Alzheimer's disease (AD) affects more than 18 million people worldwide

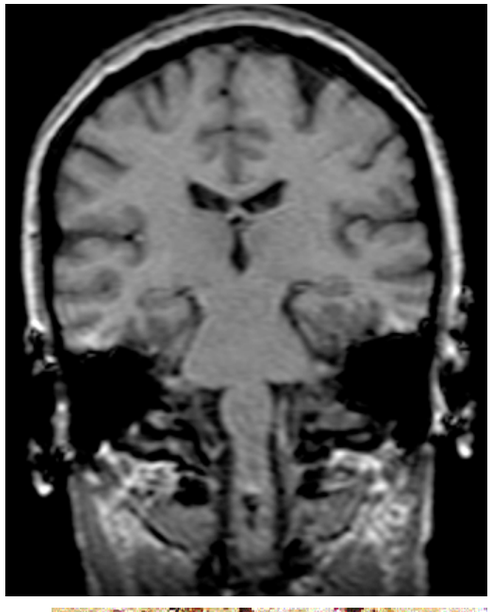
- If onset was delayed by 5 years, the number of cases worldwide would be halved

- According to the Amyloid cascade hypothesis, accumulation of Aβ in the brain is the primary influence driving AD pathogenesis (Hardy, Science'92)

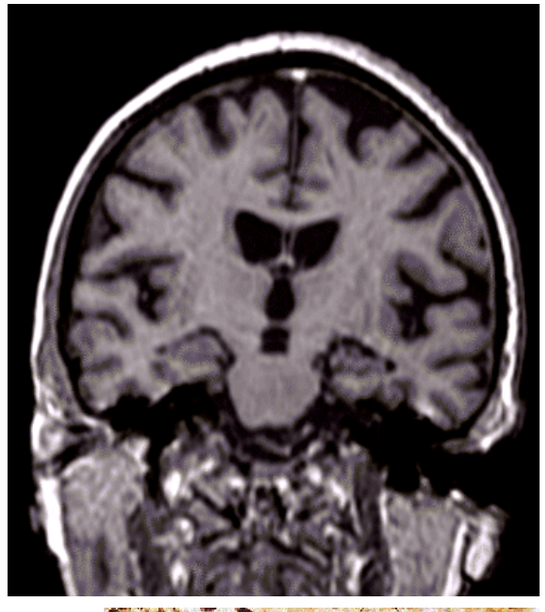
- Early detection of abnormal Amyloid deposit could help detect AD before neurons death and cognitive decline

Alzheimer's Disease: the most common cause of dementia

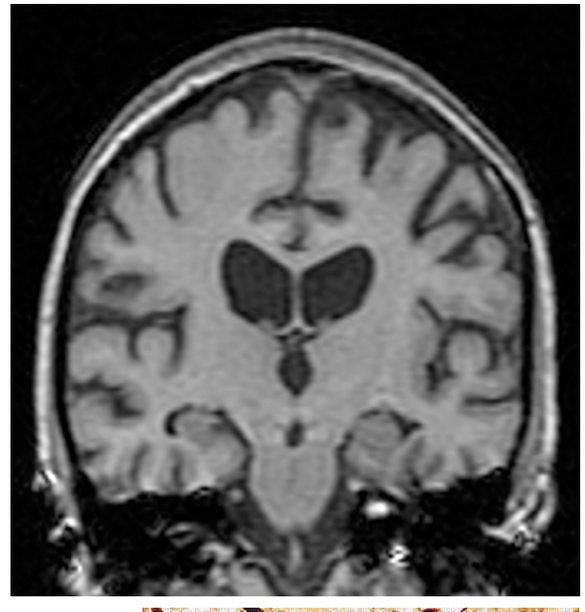
- Changes at a cellular level have macroscopic consequences that might be detectable with Magnetic Resonance Images (MRIs).



Pre-symptomatic



Diagnosis

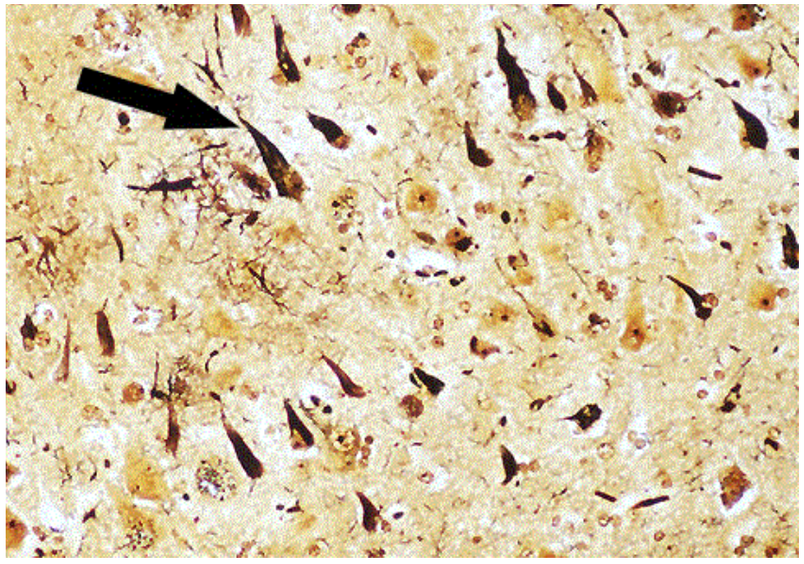


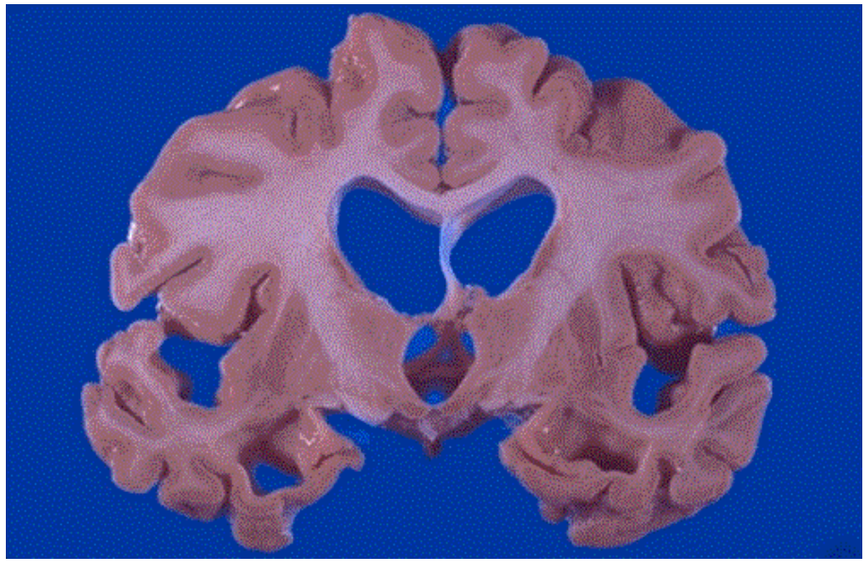
Dementia

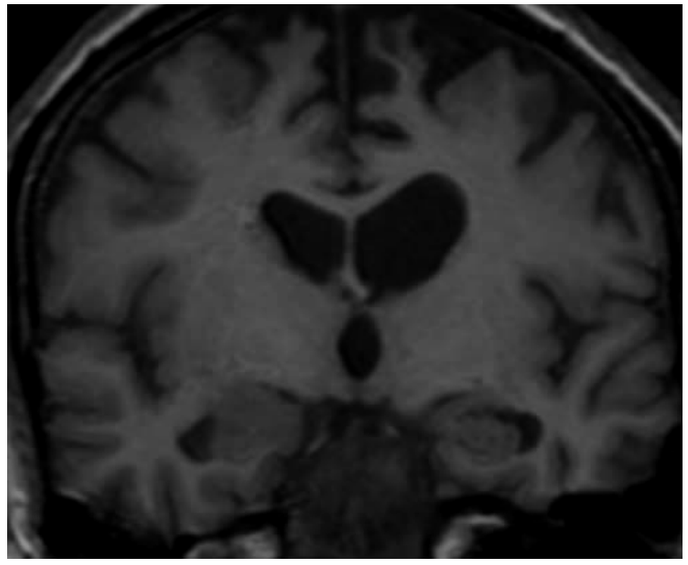
Cerebral atrophy

- AD = amyloid plaques, neurofibrillary tangles, synaptic, dendritic, neuronal & axonal loss… and atrophy

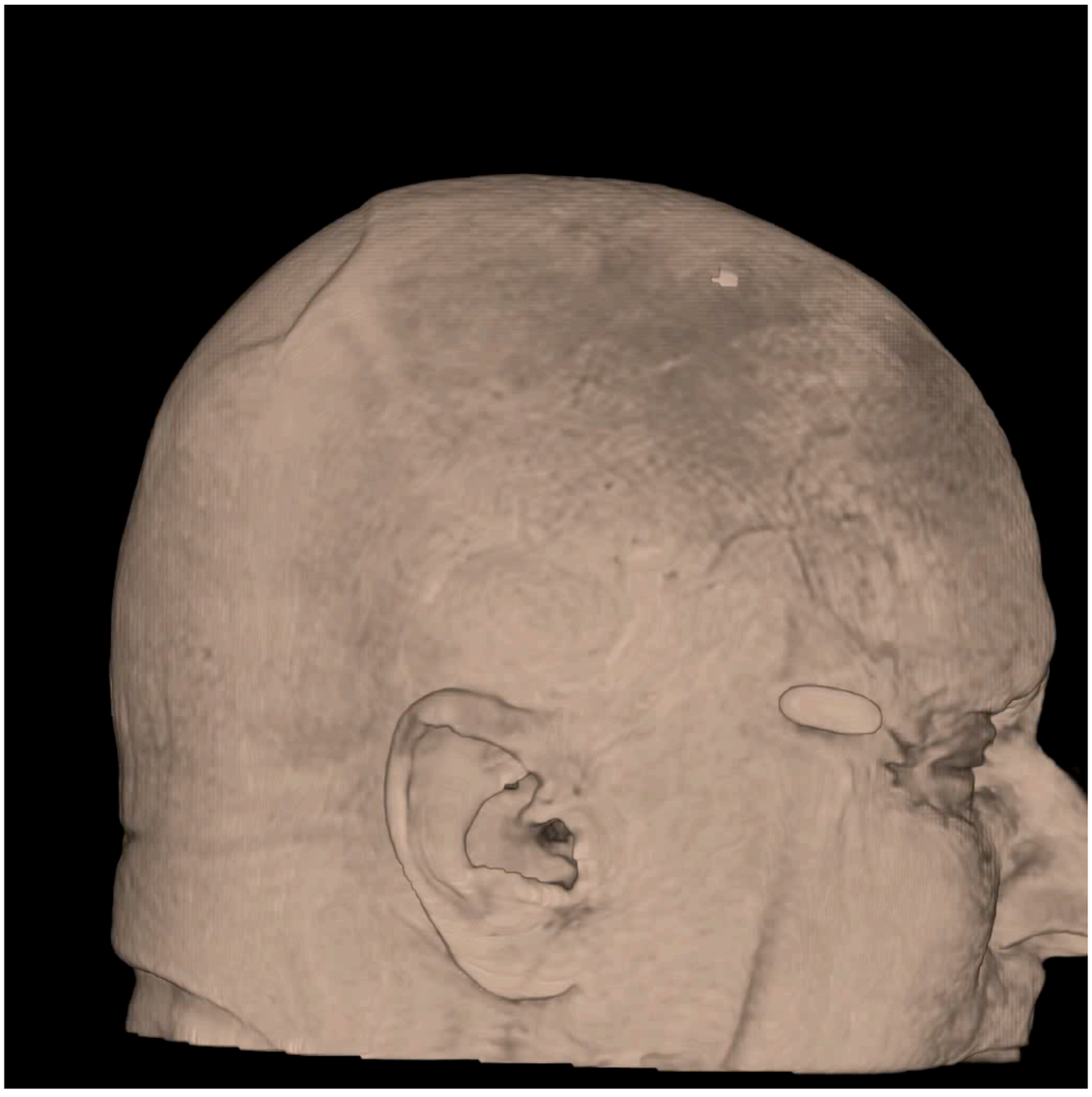
- Can we measure atrophy using MRI?
  Using 4D MRI: 3D MRI + time







Cerebral atrophy



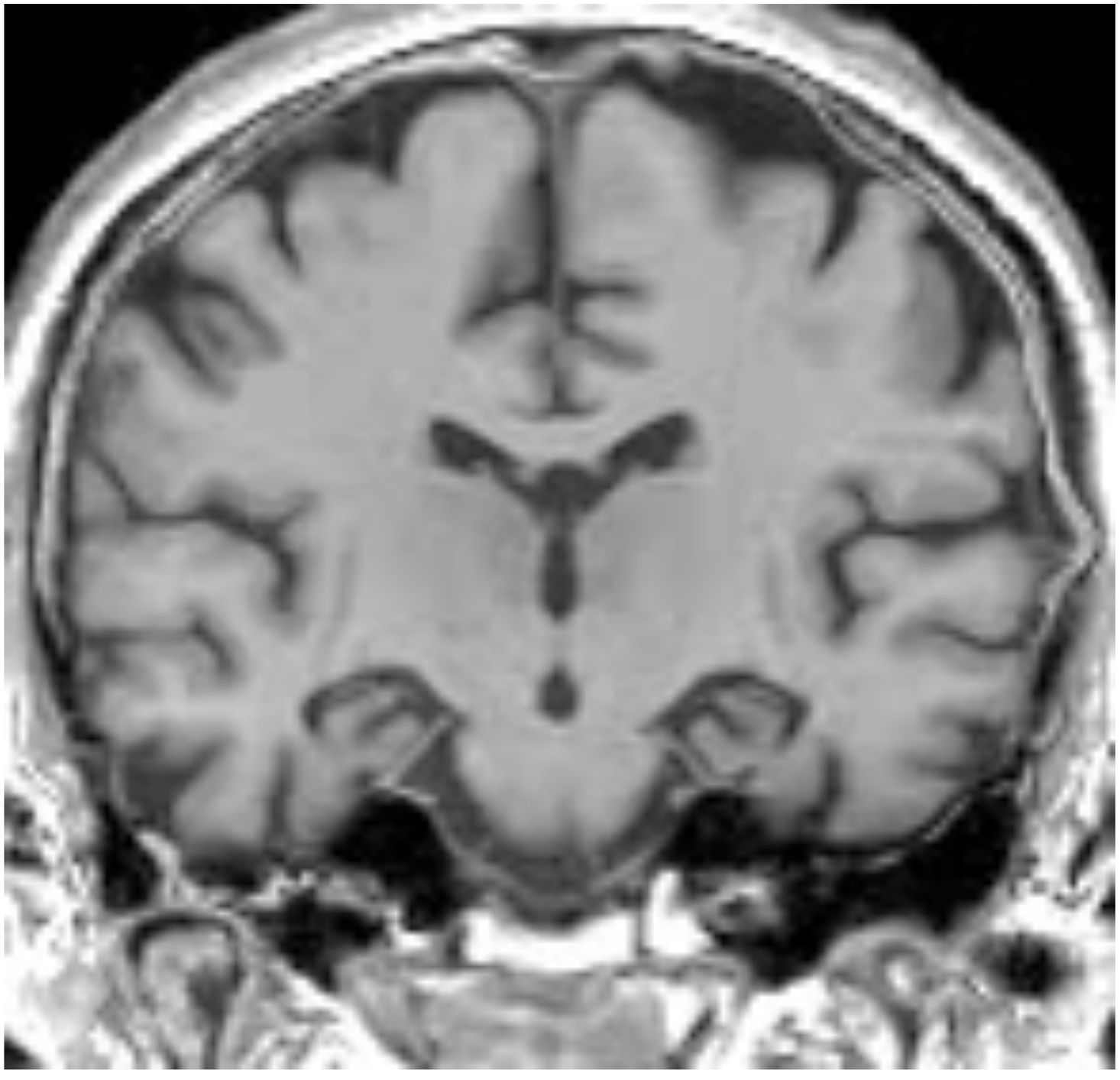
Volume changes occurring over two years

Simulated using two T1-weighted MRIs
Baseline and 2 year follow-up

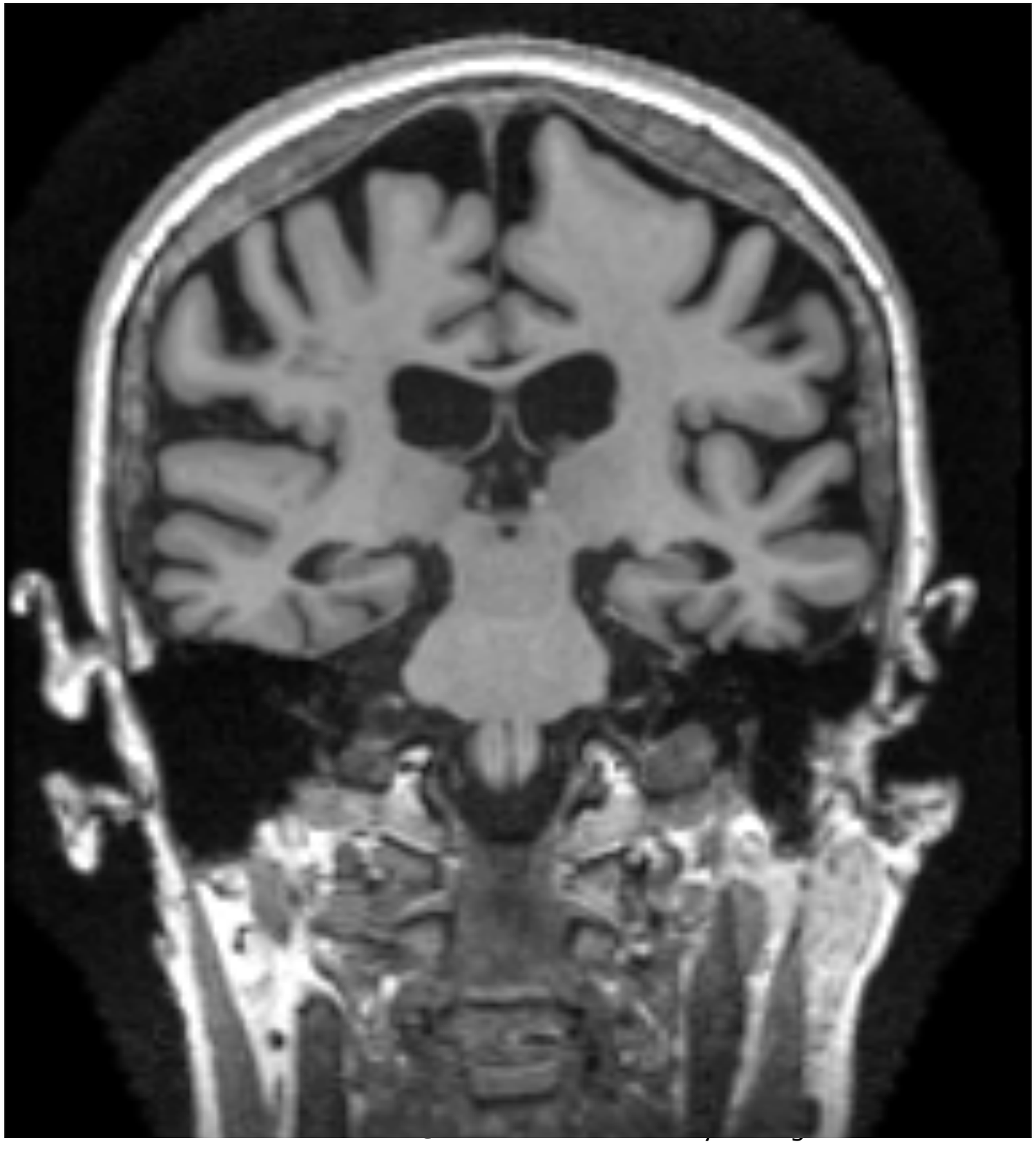
Male - 68 years old at baseline
Alzheimer's disease diagnosed

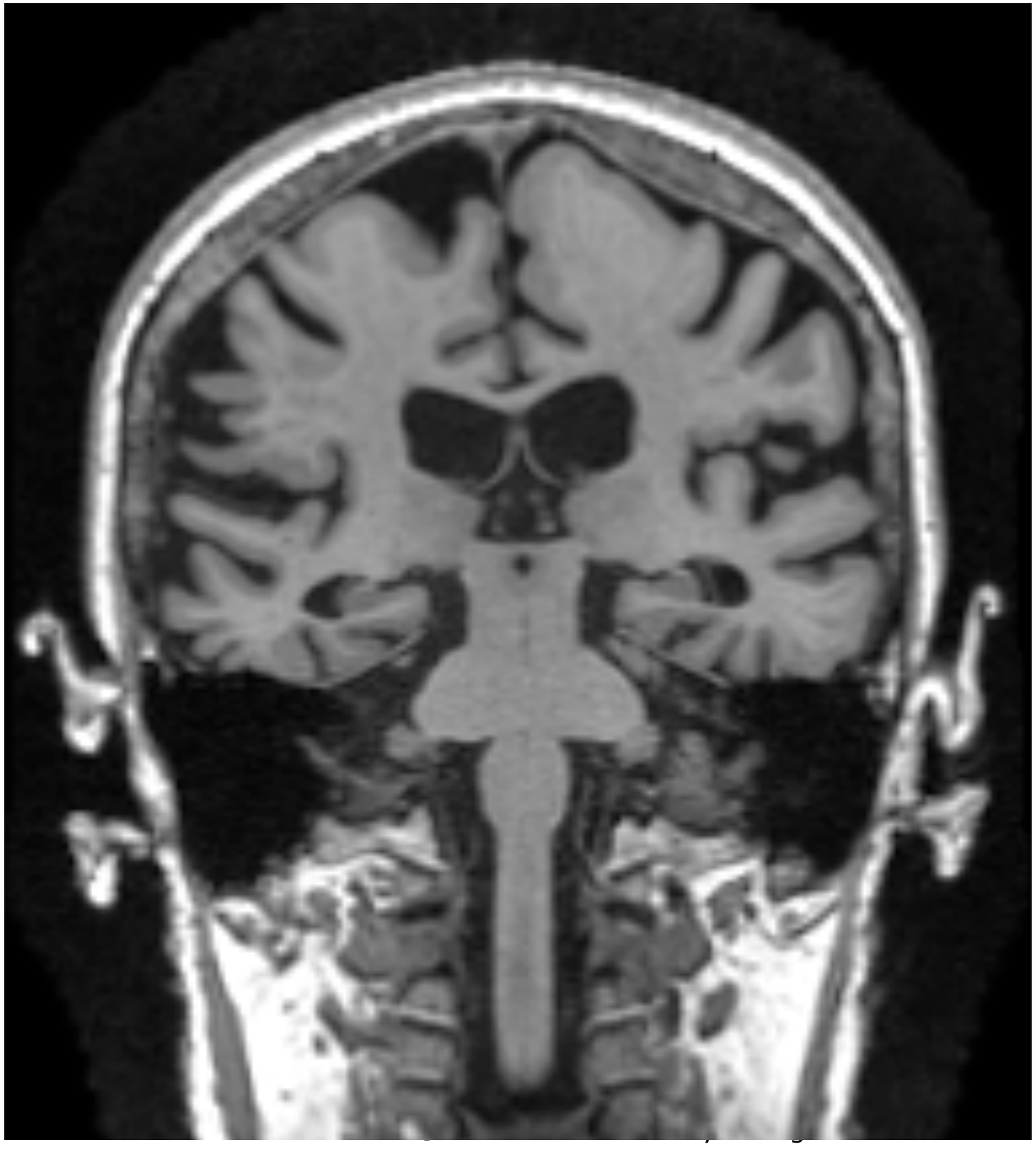
Subject from the ADNI databse

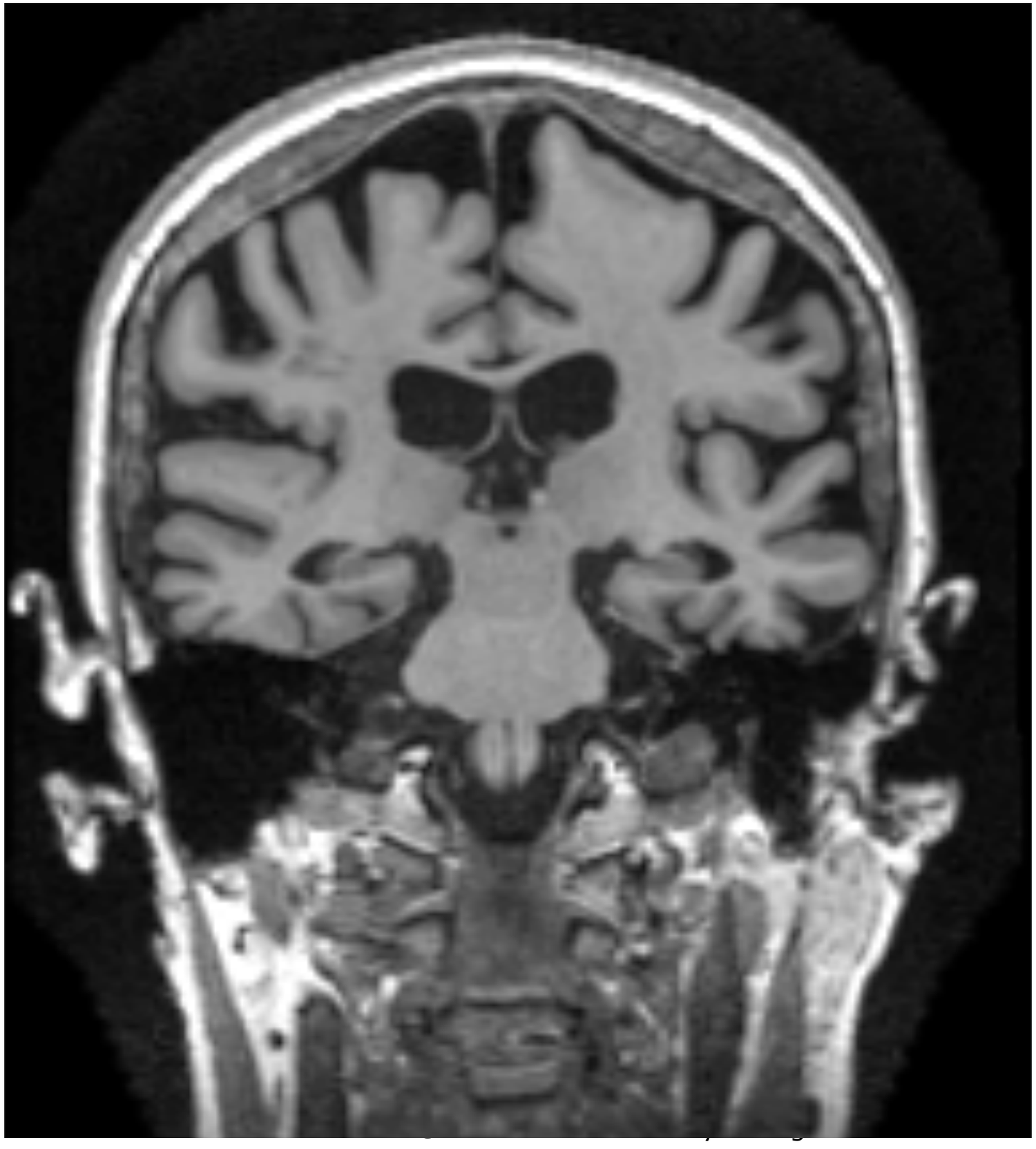
Cerebral atrophy

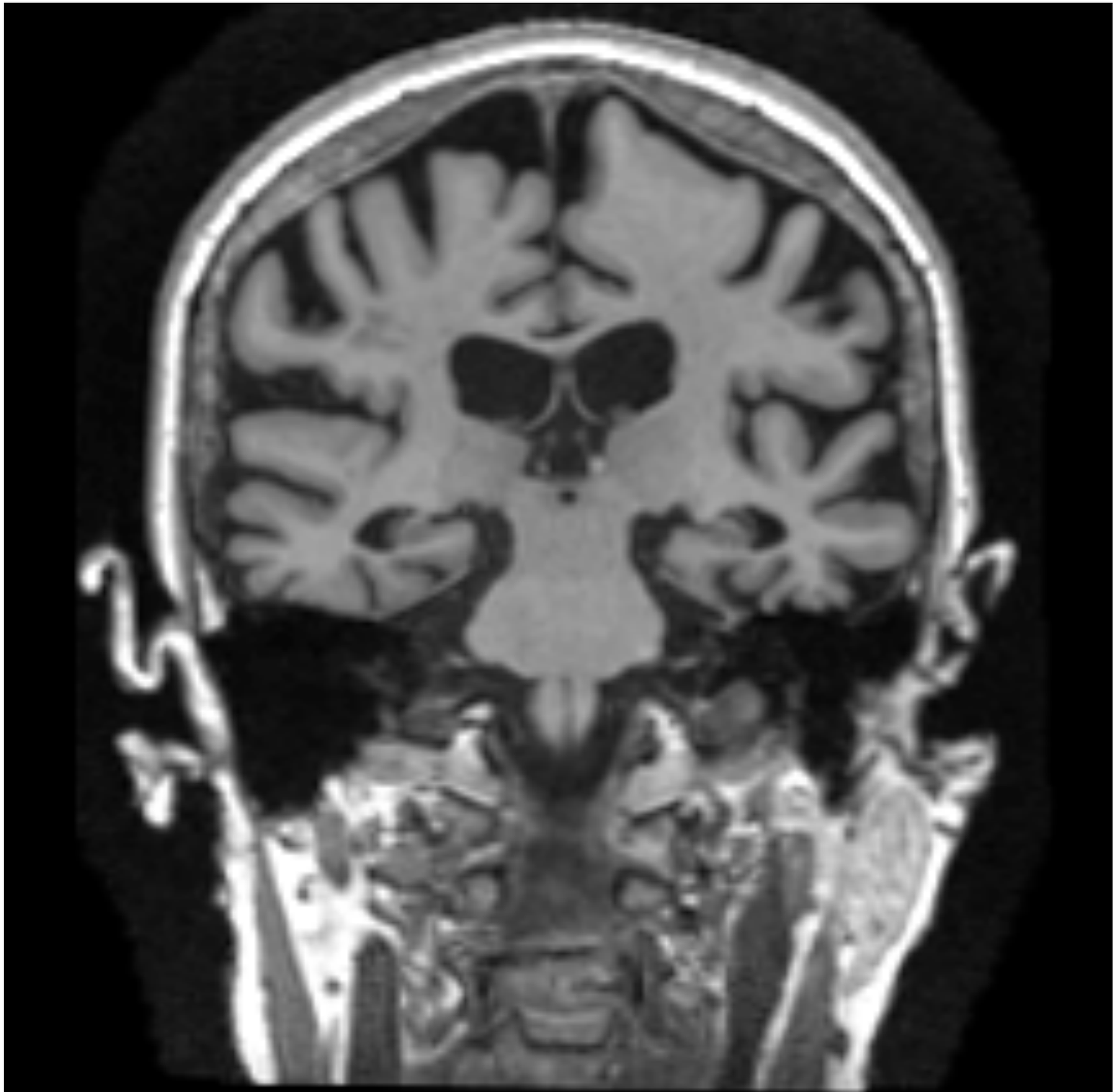


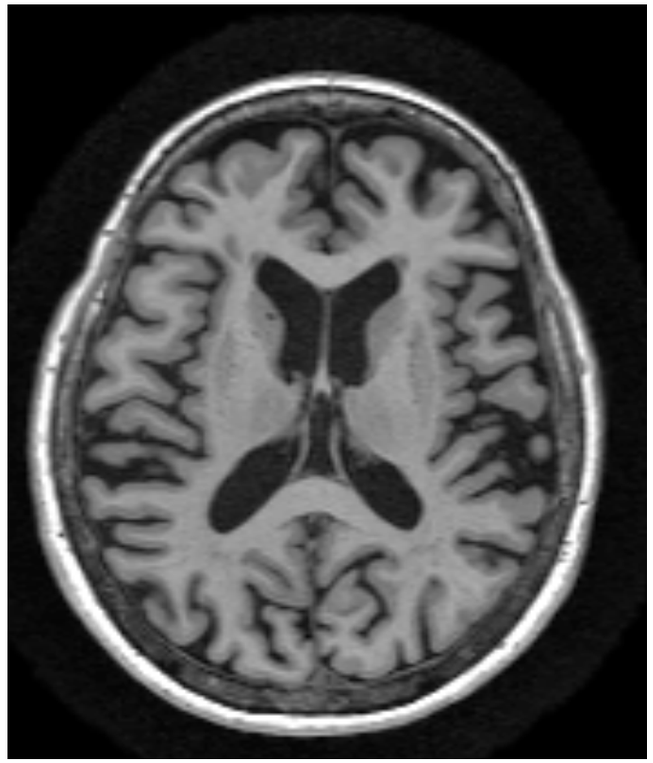
Brain evolution over 12 years (2000-2012)

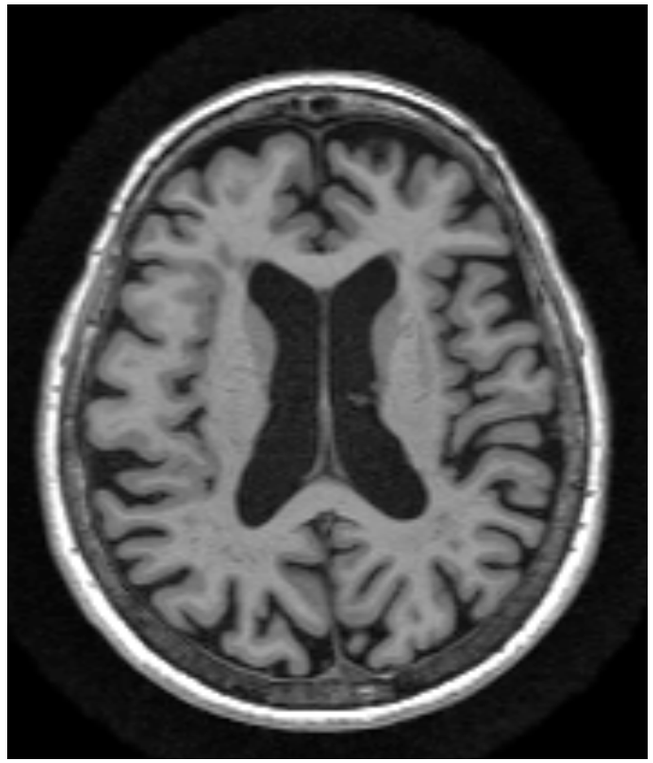


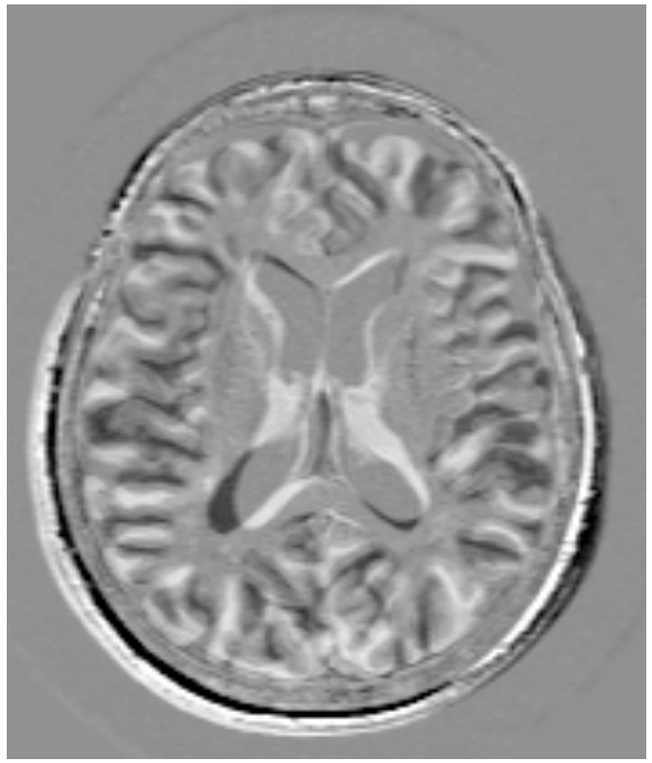


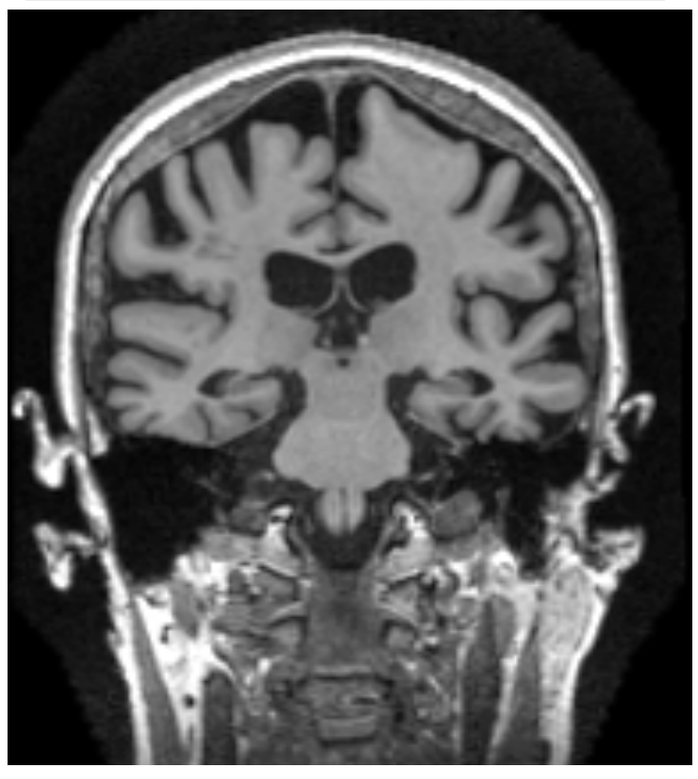


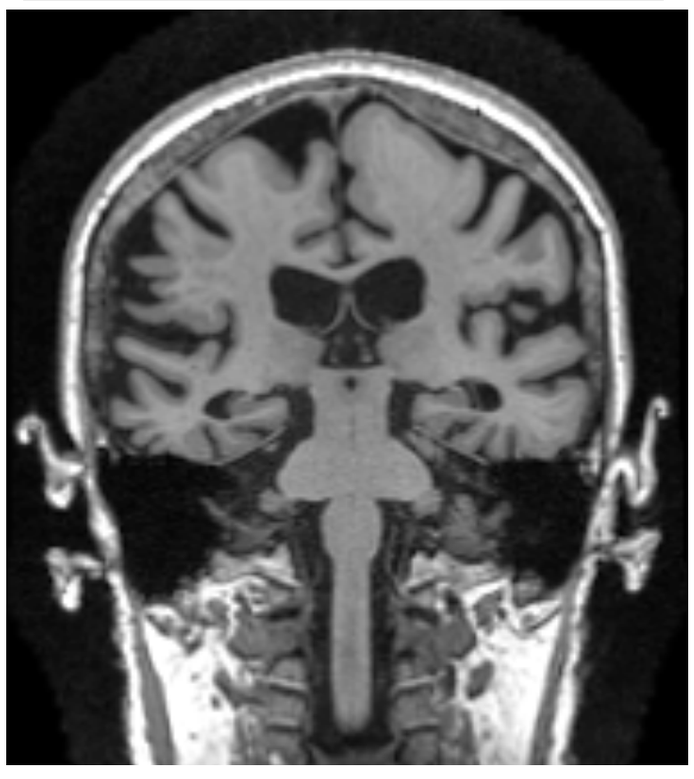


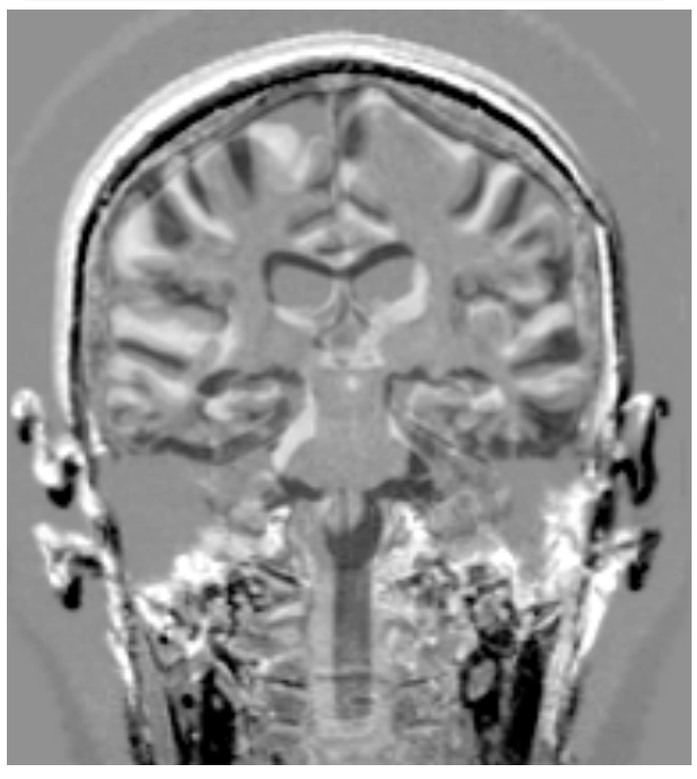








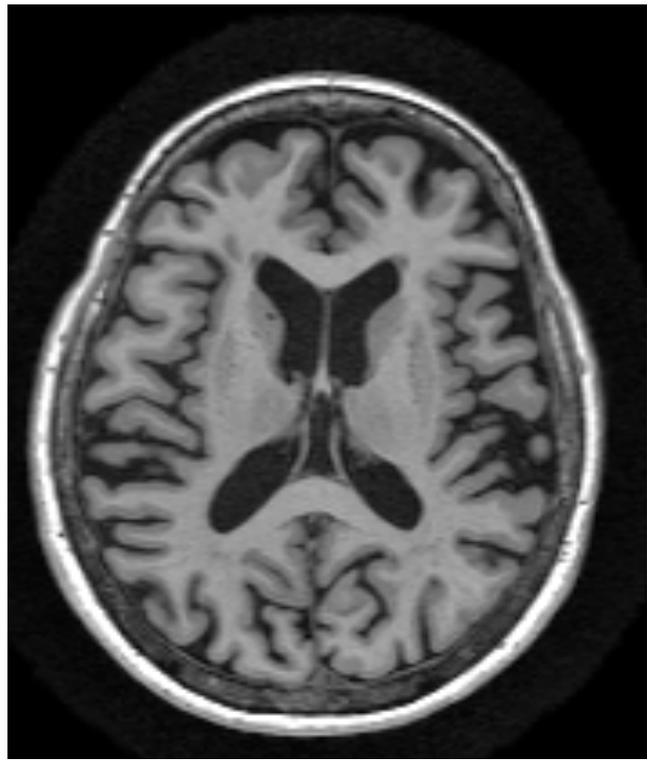




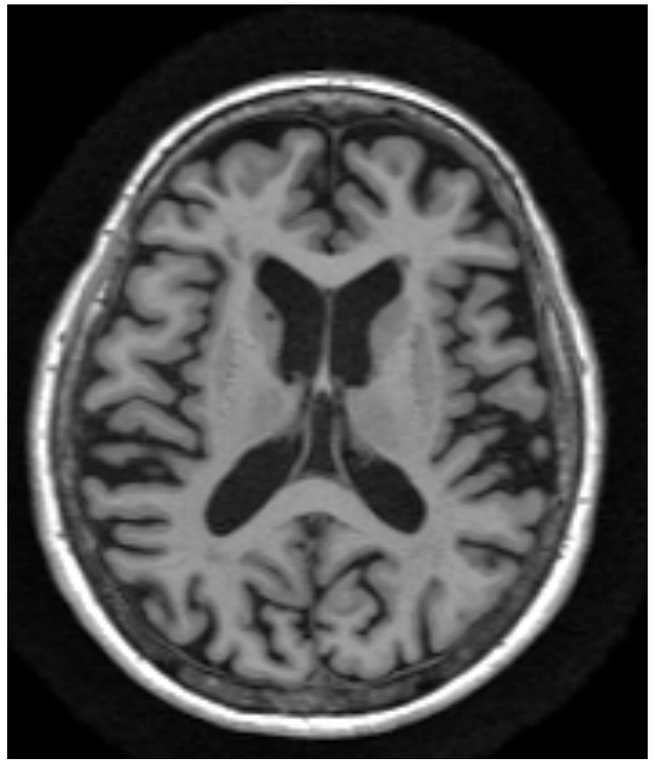
Baseline scan

Follow-up scan

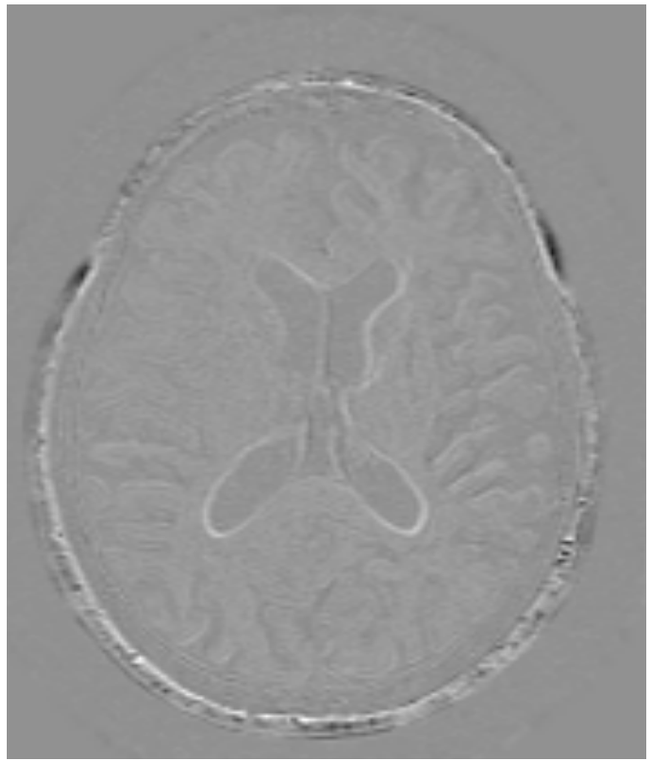
Difference image



Baseline scan

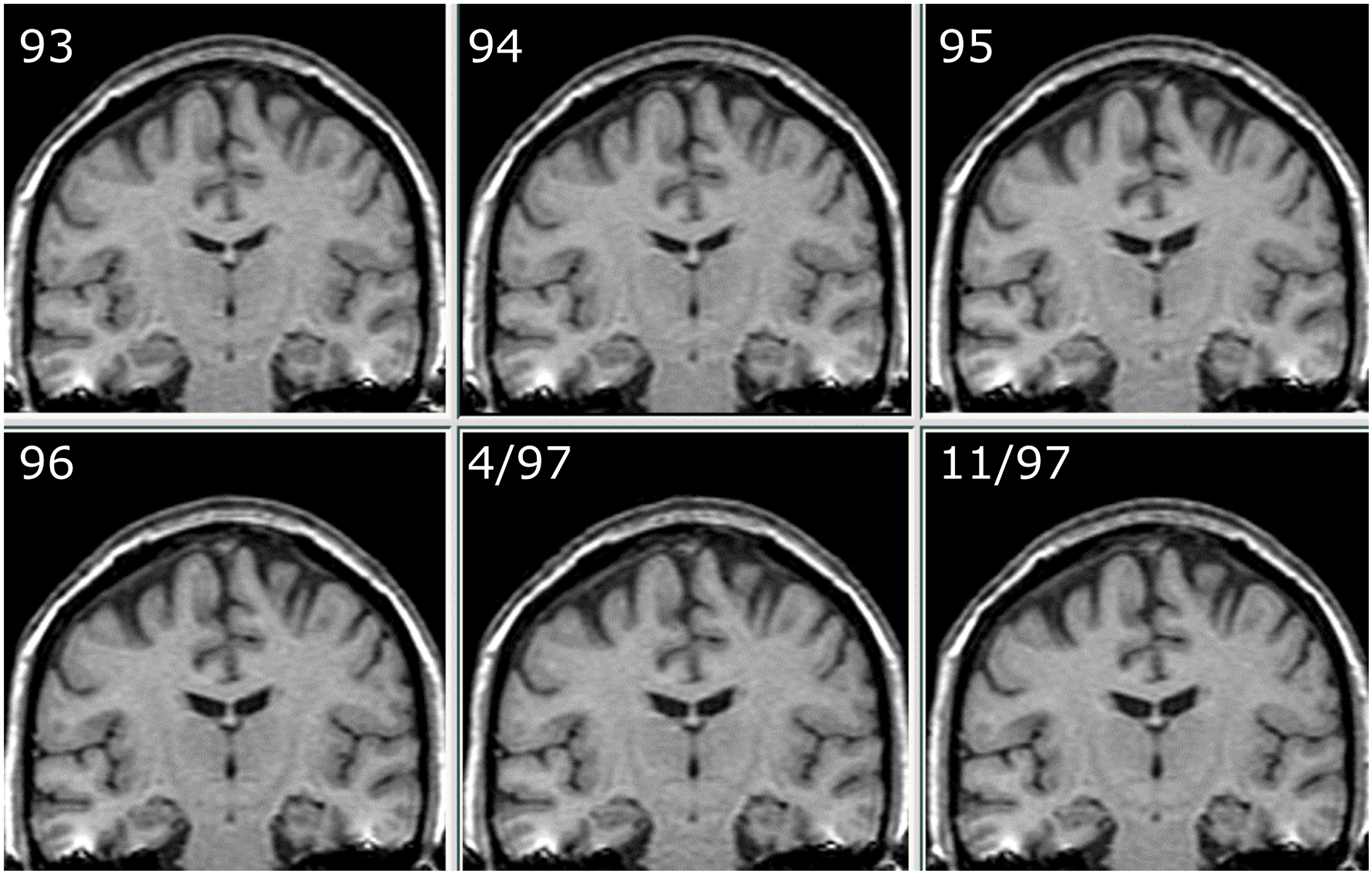


Follow-up scan



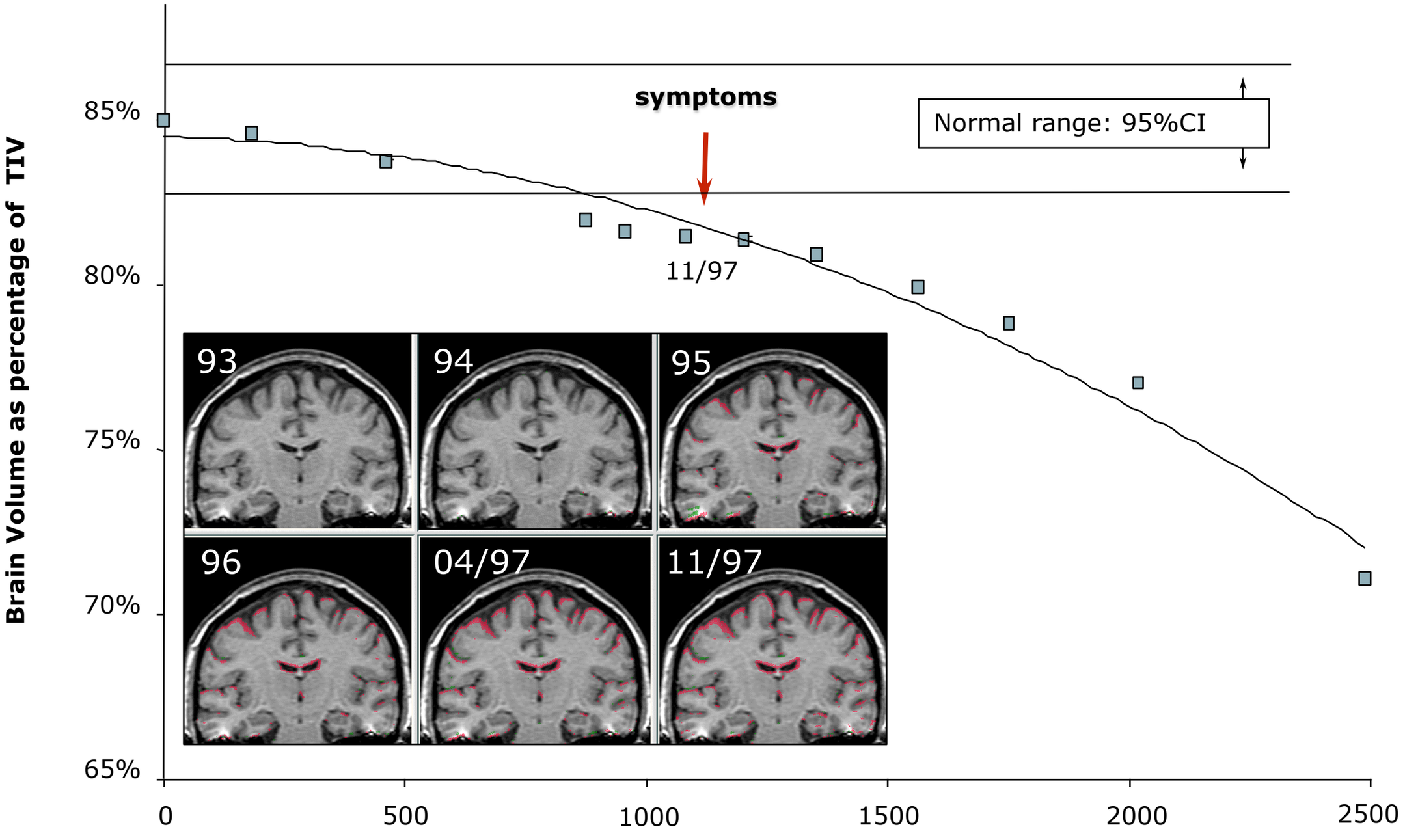
Difference image

Brain atrophy - 4-year longitudinal study



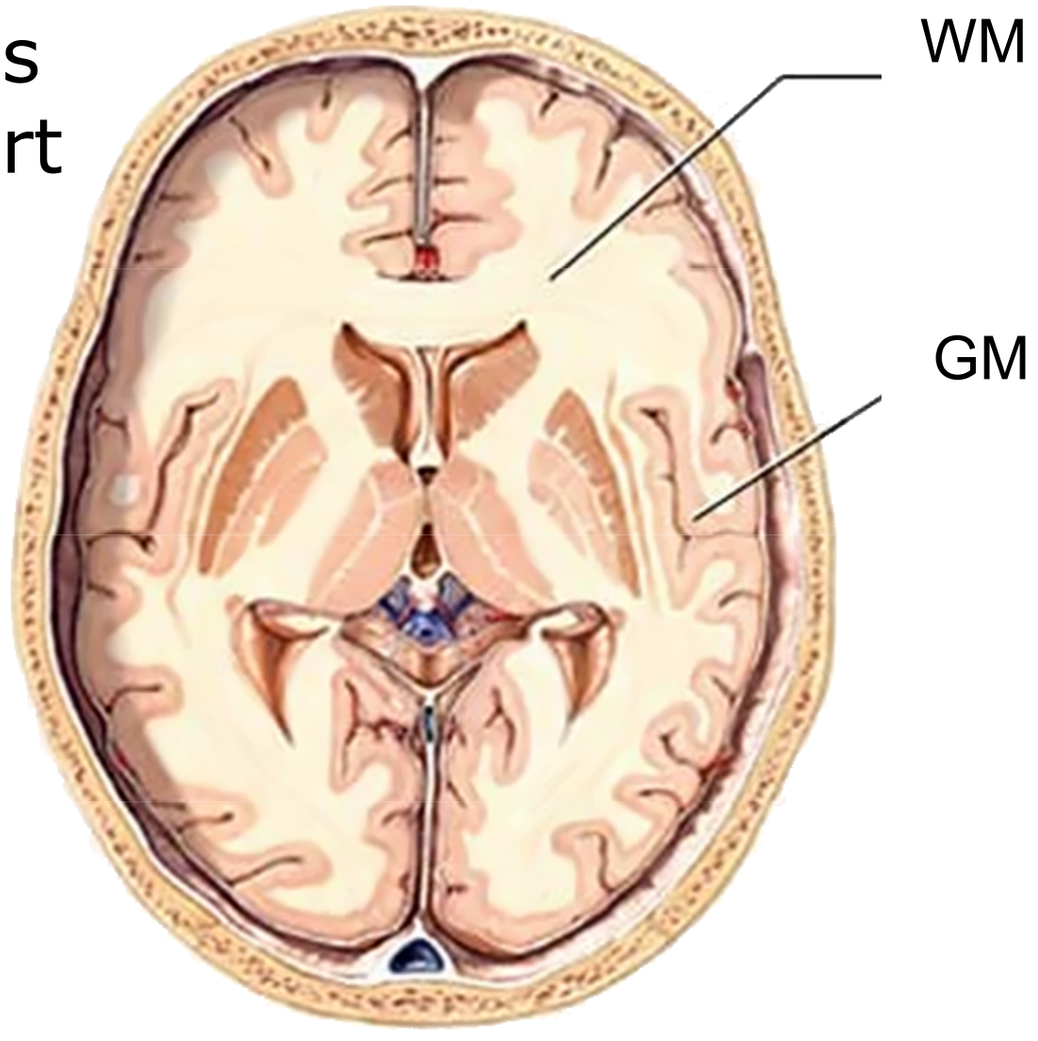
AD: At risk subject - serial scans registered to 1993 baseline

Brain atrophy
Detect changes before clinical symptoms



Cortical thickness

- Cortical thickness is at promising biomarkers for neurodegenerative disease progression.
- Leading to:
  - Earlier and more robust diagnosis
  - Reduction in the size of the cohort for the same statistical power in clinical studies



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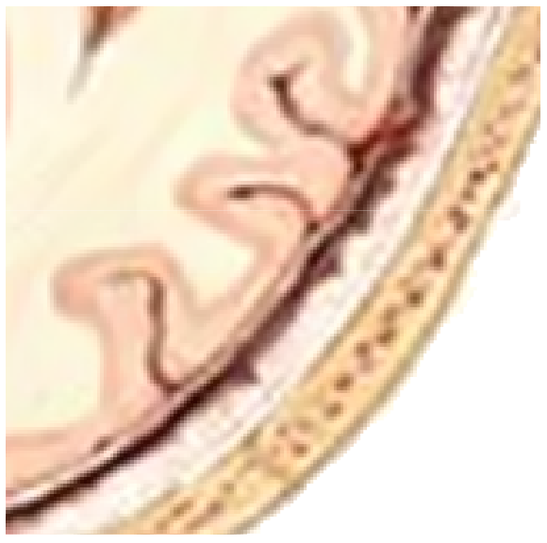

Cortical thickness

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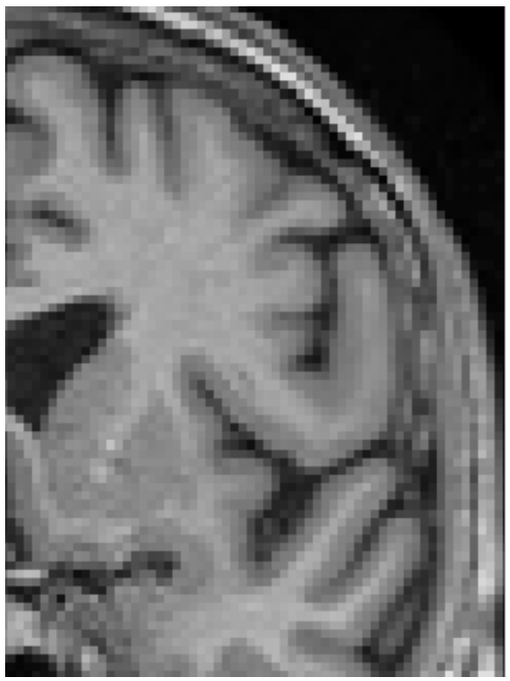
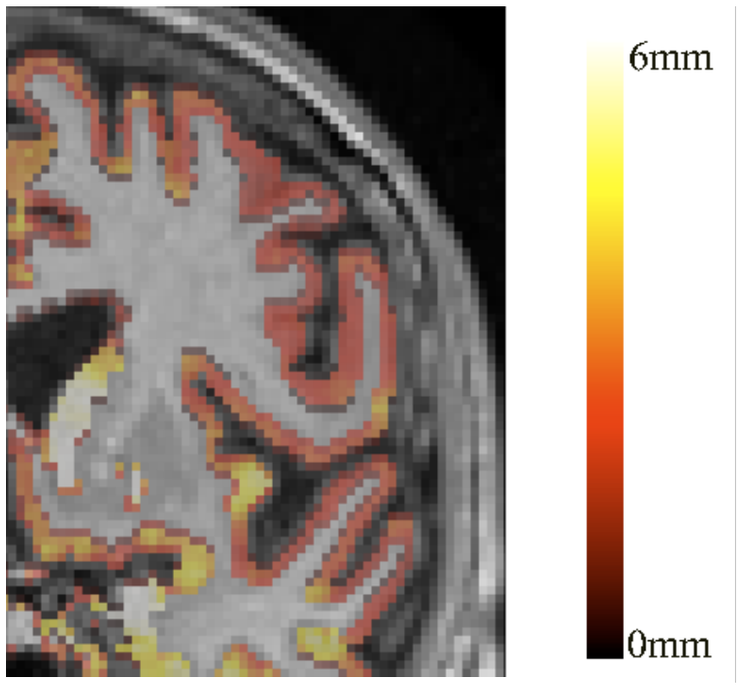
Cortical thickness

- Segmentation of the cortex
  - Very convoluted surfaces
  - Differentiate at least three kinds of tissues (GM, WM, CSF)
  - Inhomogeneities in intensity (bias field correction)
- Estimation of the cortex thickness



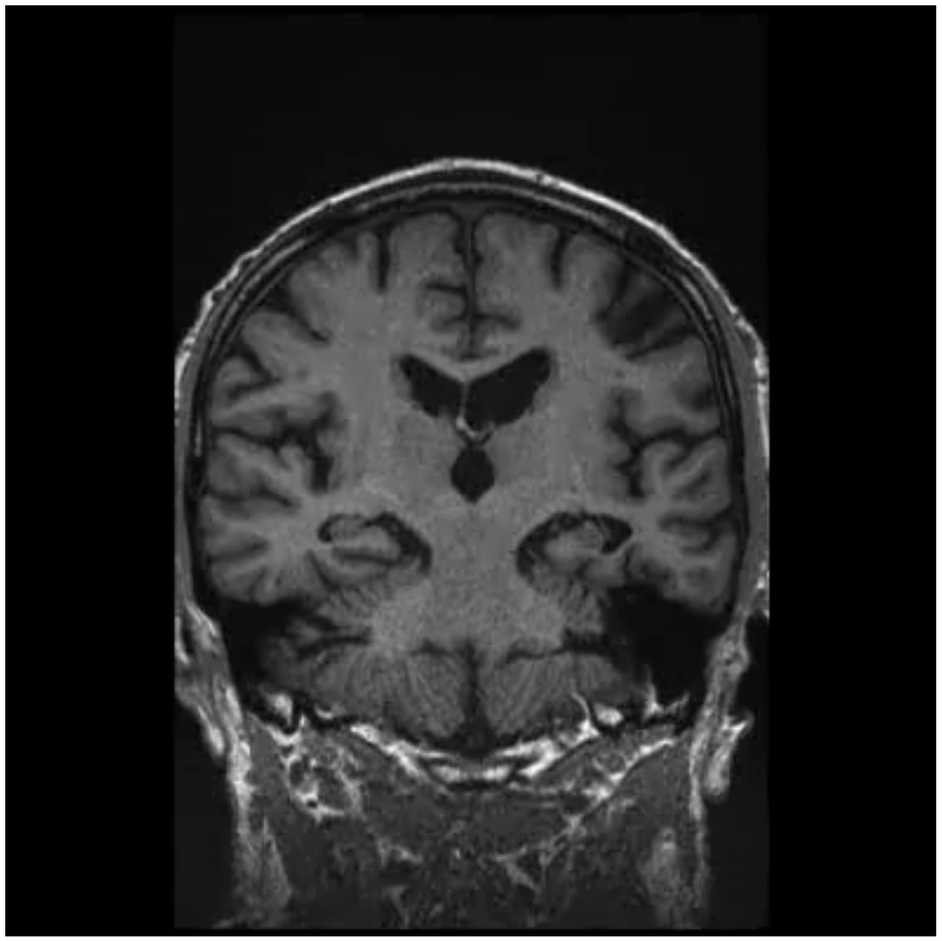
Original MRI

Segmentation

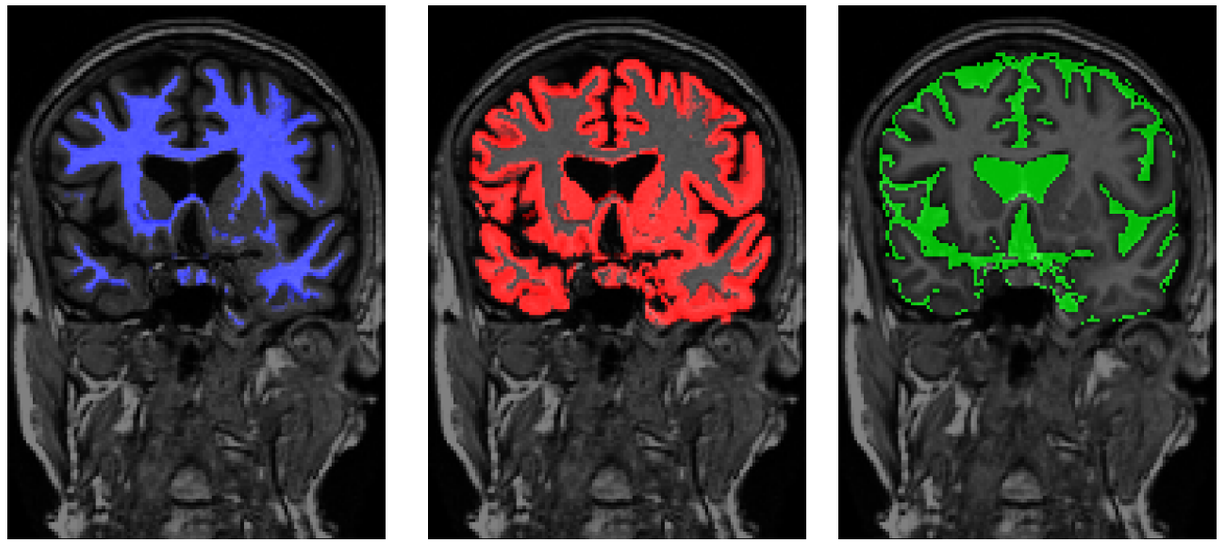


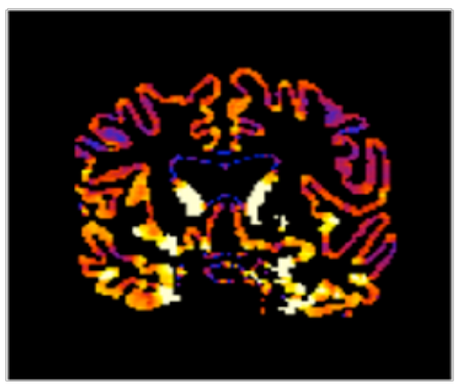
Cortical thickness estimation

Brain tissue segmentation

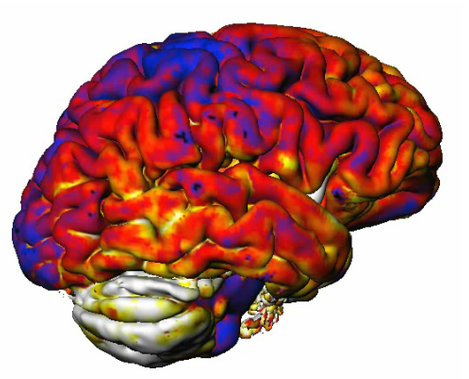


Evolution/convergence of an Expectation Maximisation (EM) algorithm for brain tissue segmentation





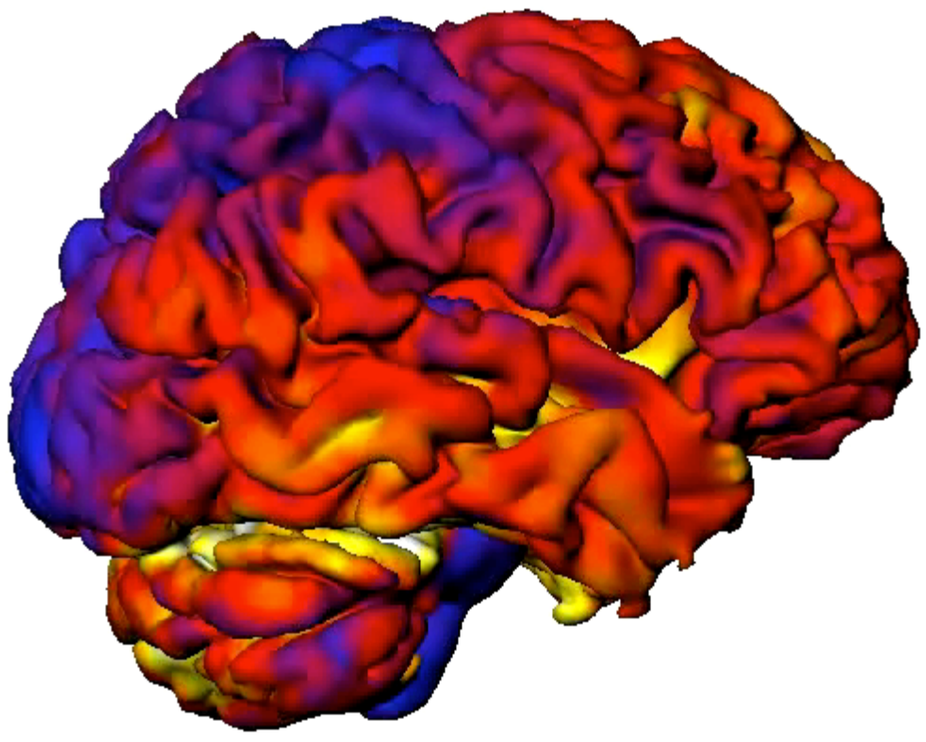
GM thickness map



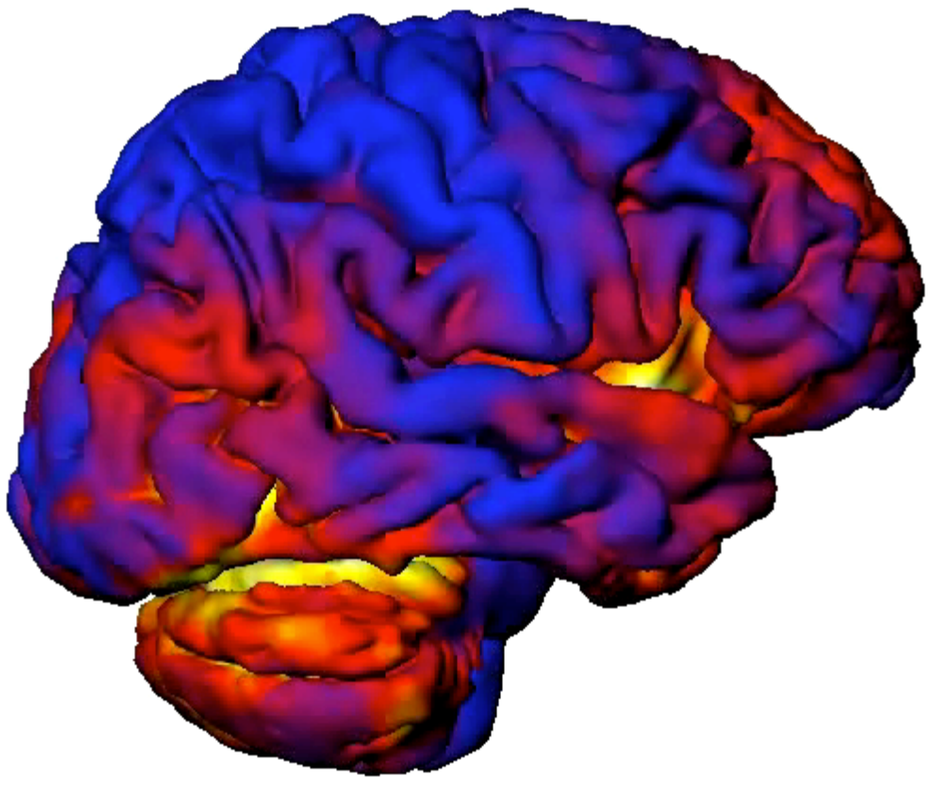
3D representation

Brain tissue segmentation

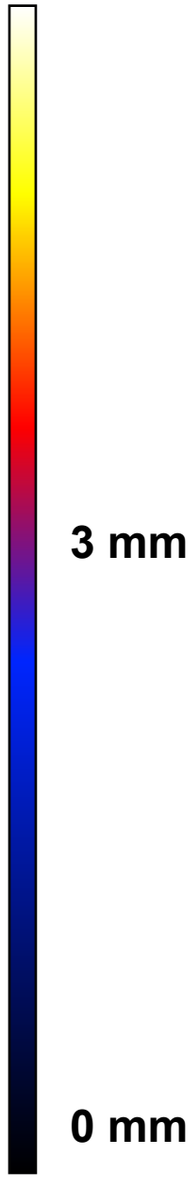
- Significant differences between AD and NC in the temporal, parietal and occipital



70 Years old normal control

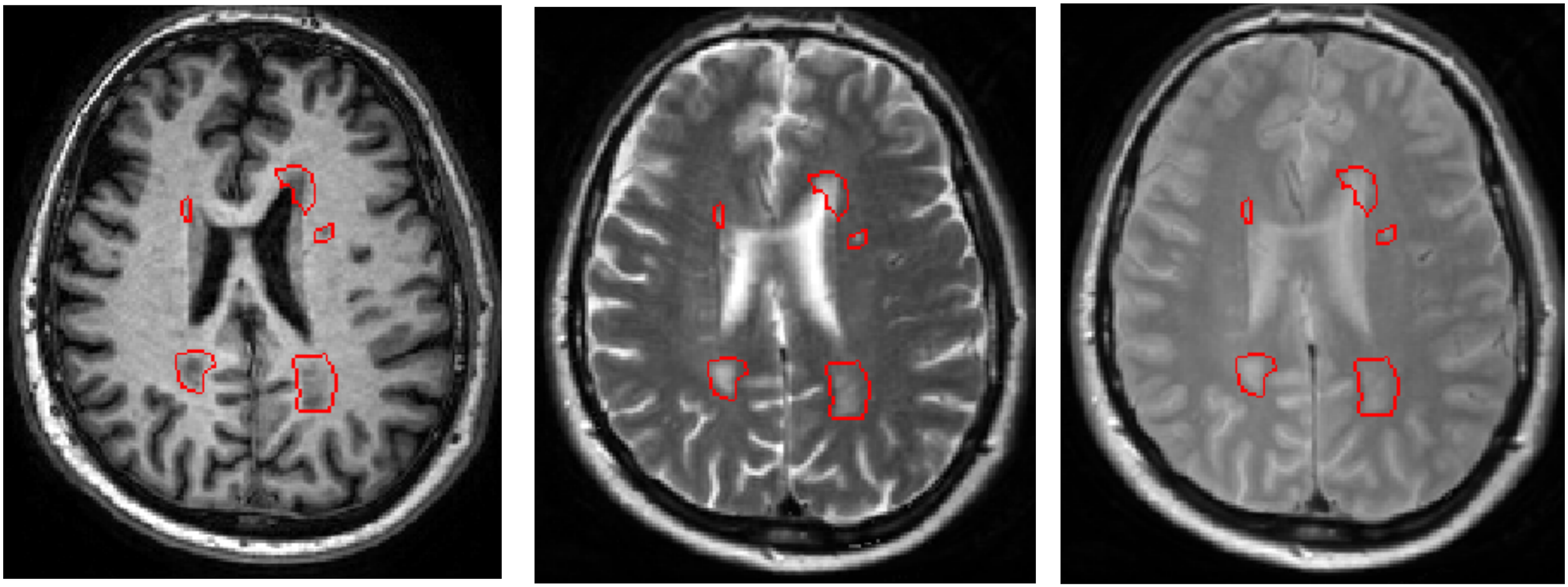


70 Years old Alzheimer's disease subject

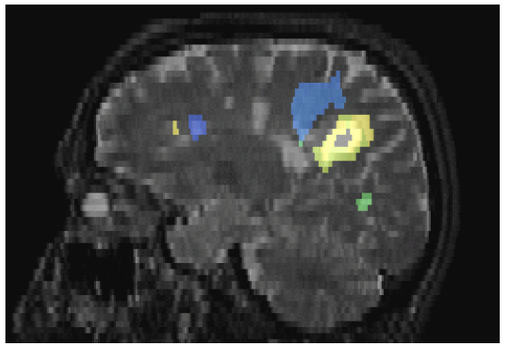


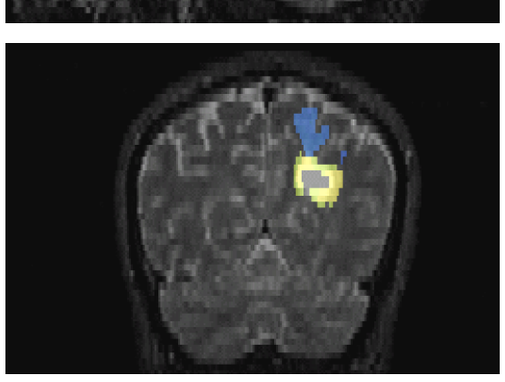
Multiple Sclerosis

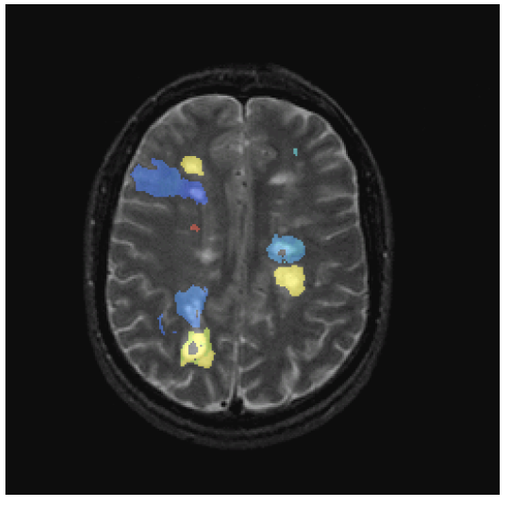
- Examples of white matter lesions visible on MRI

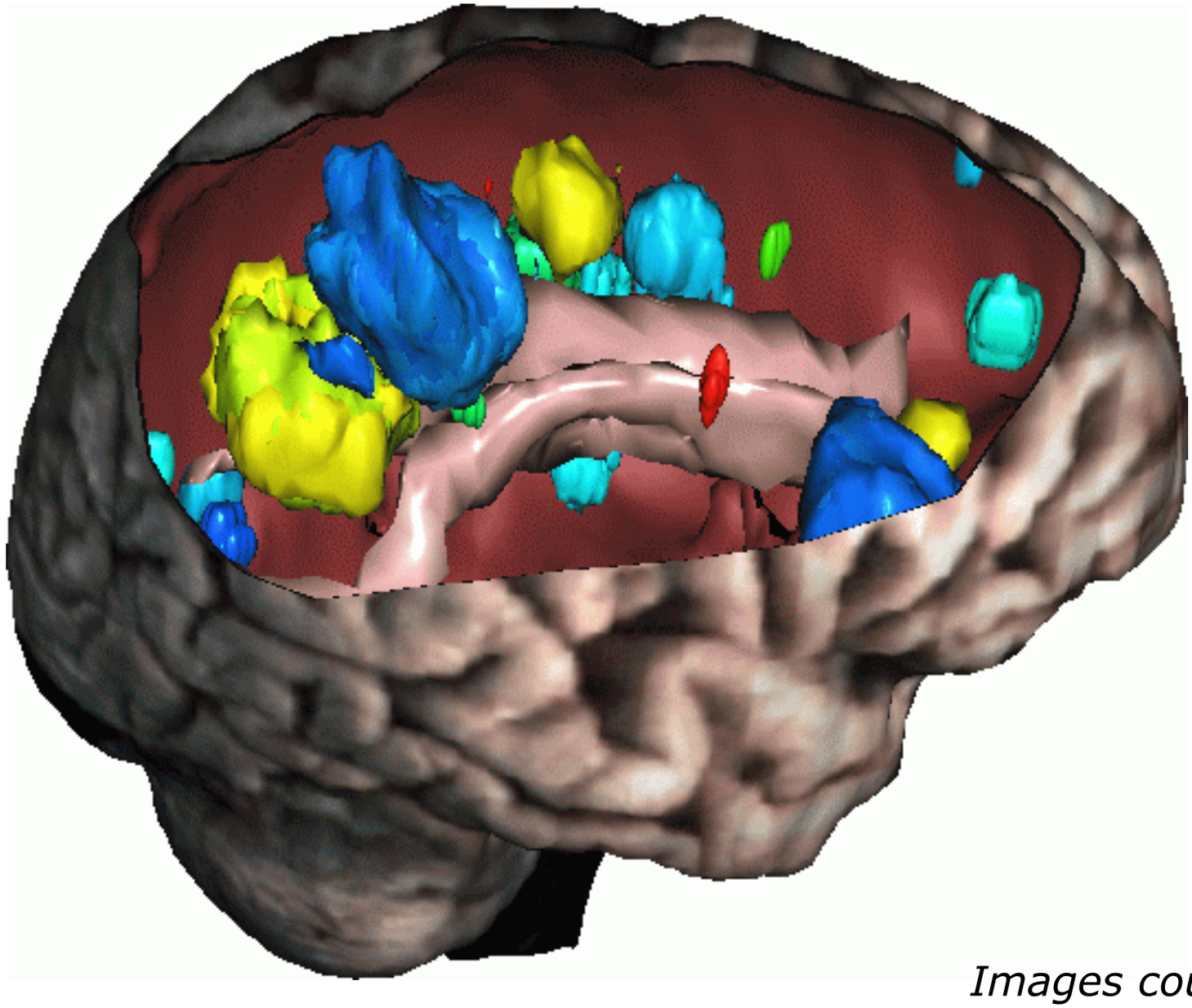


Temporal evolution of multiple Sclerosis





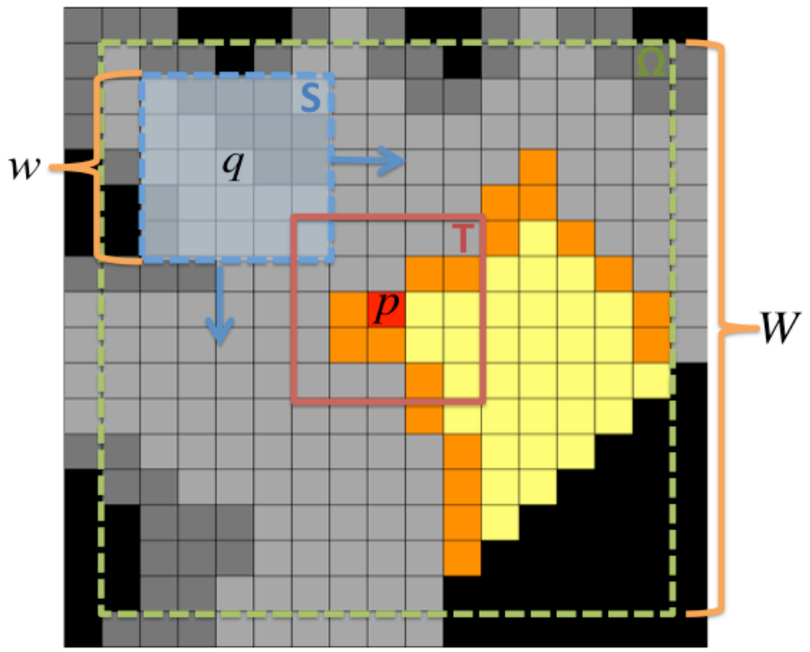


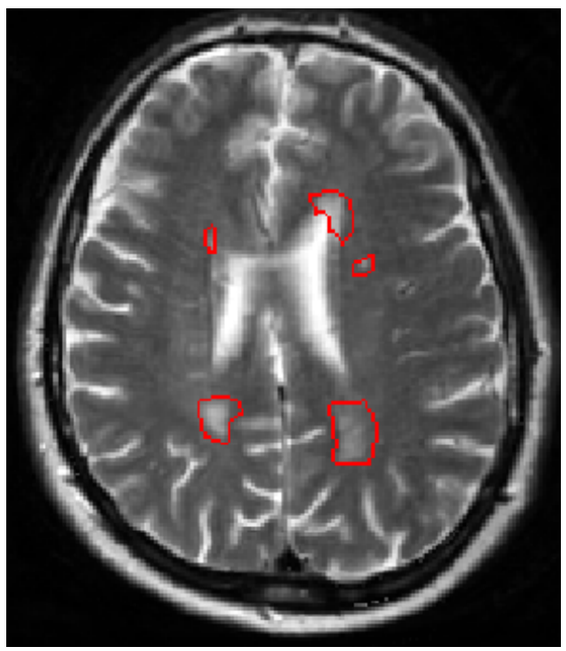


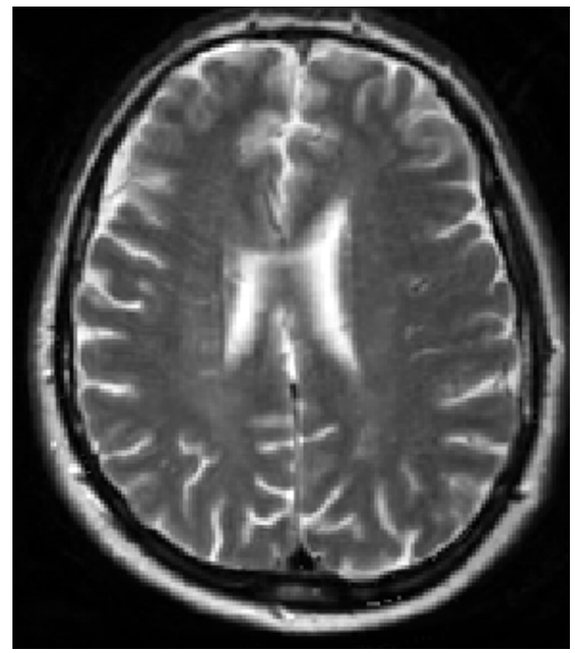
Images courtesy of INRIA

Multiple Sclerosis

- Lesions can have an impact on processing pipeline using for example registration or segmentation







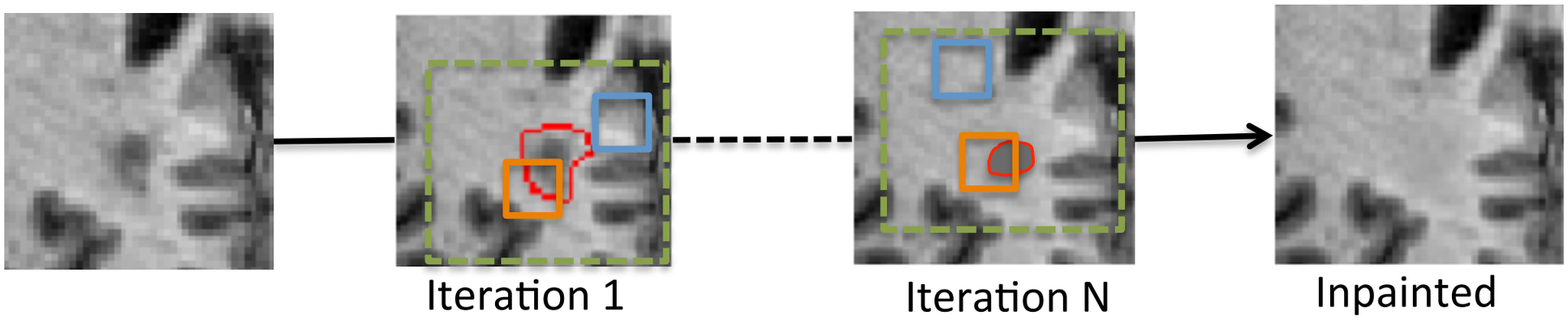
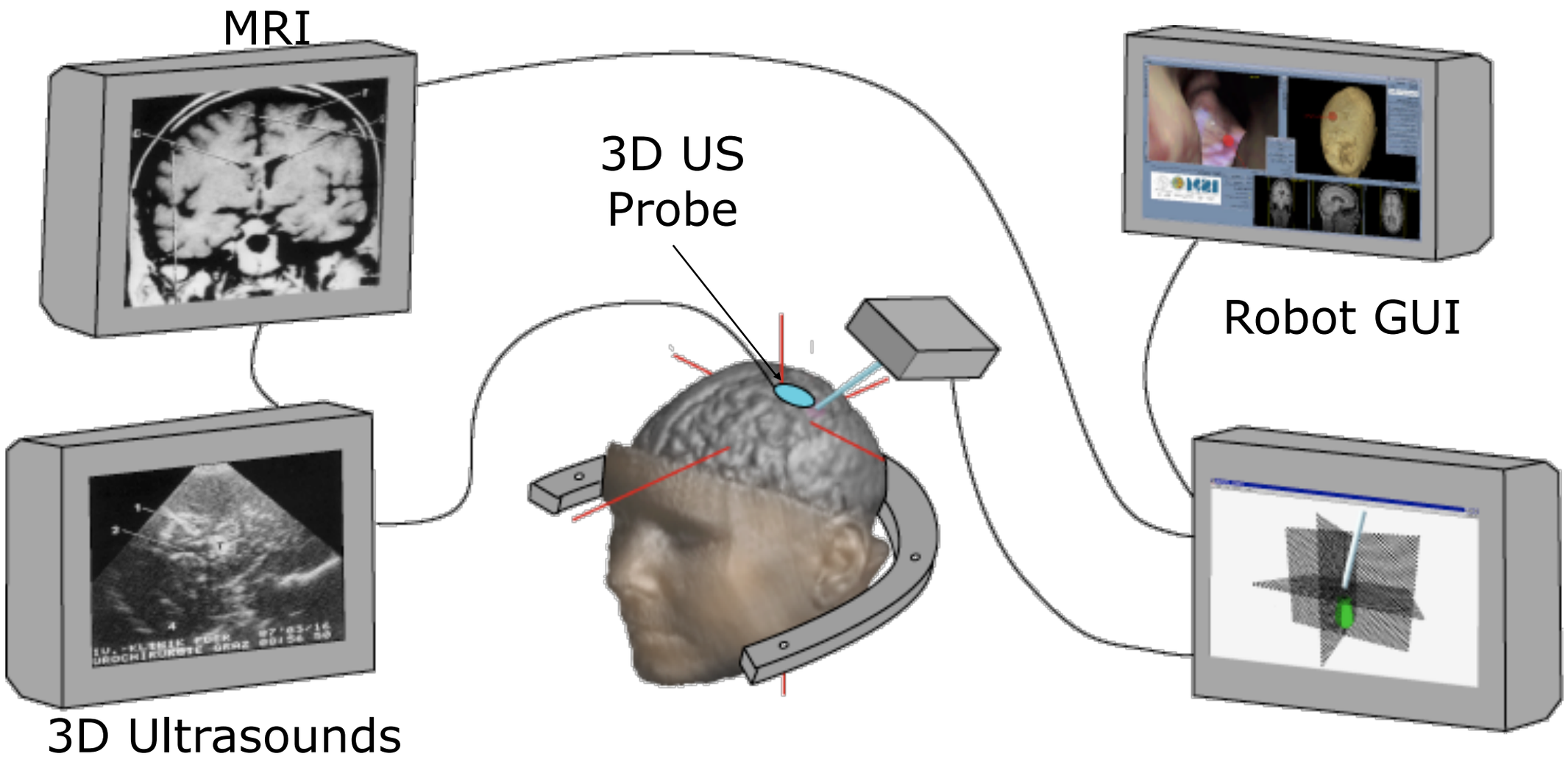


Image guided neurosurgery - MRI/US

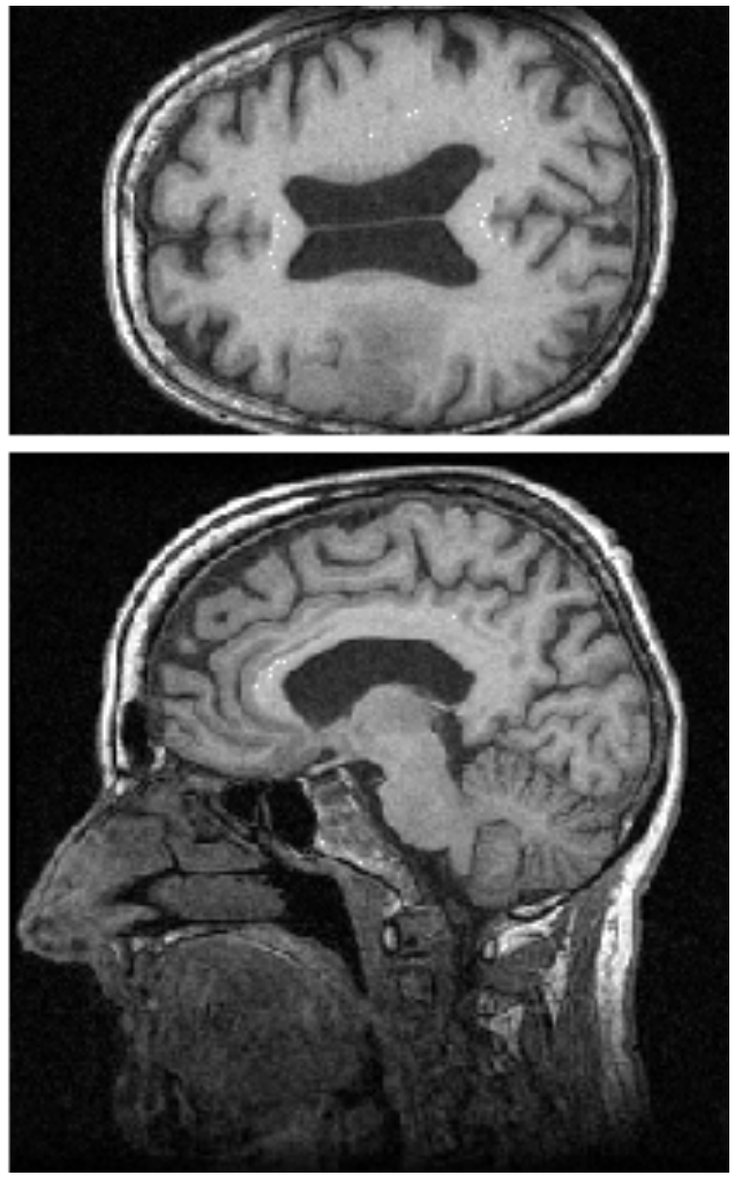
- Endoscopic Neurosurgery assisted by robotics and images



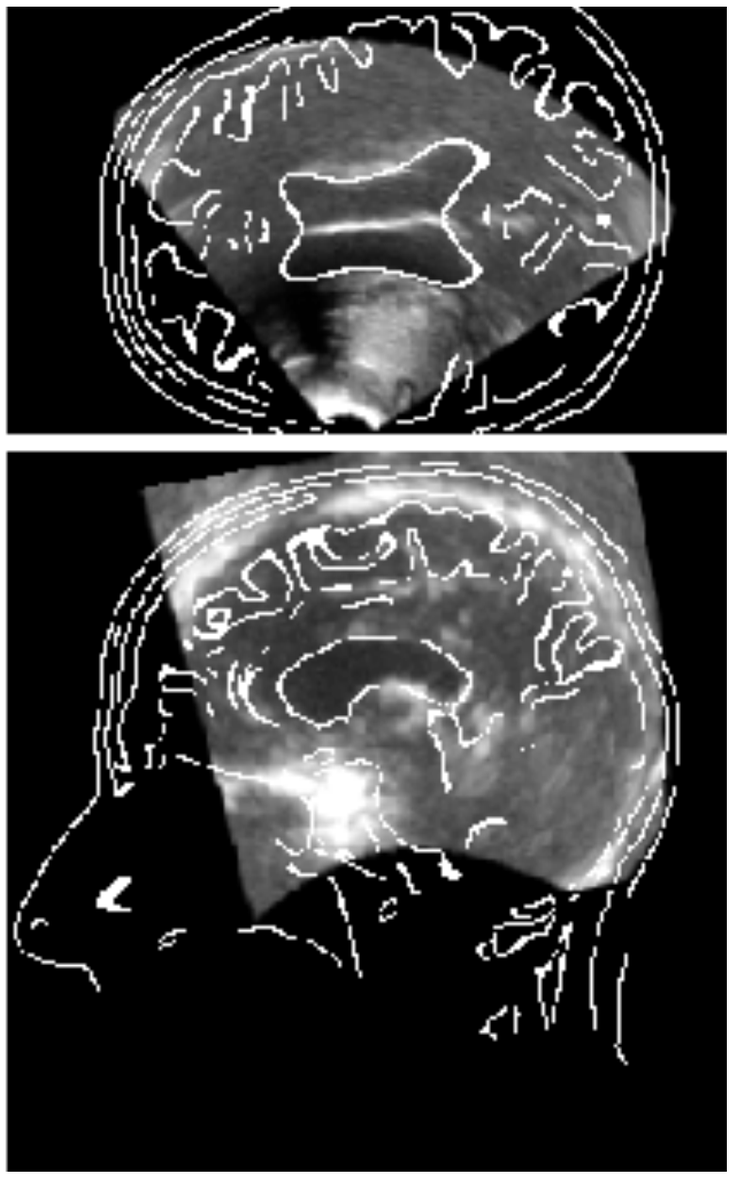
Courtesy Brian Davies

Image guided neurosurgery - MRI/US

Pre-operative MRI



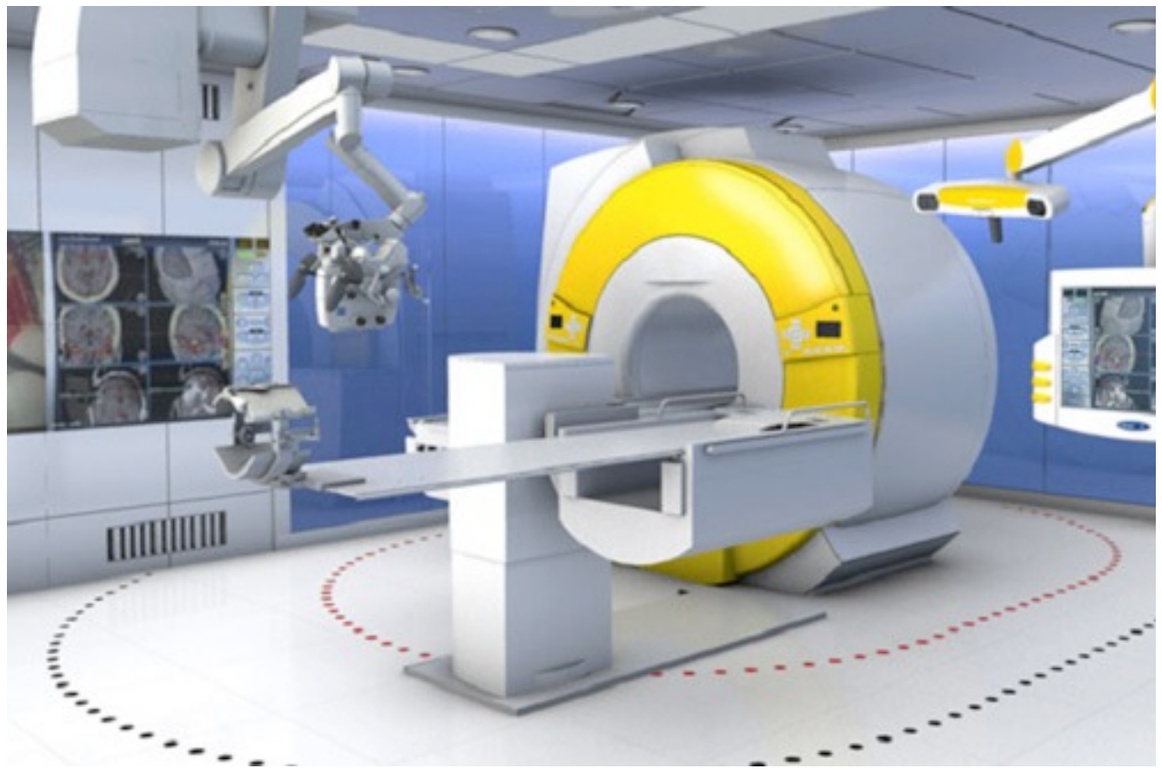
Registered MRI-US



Interventional MRI facility at Queen's Square, IoN, UCL

- Standard 1.5T MRI scanner with 8-element array coil capable of full diagnostic imaging.

- BrainLAB VectorVision Sky with Cranial navigation



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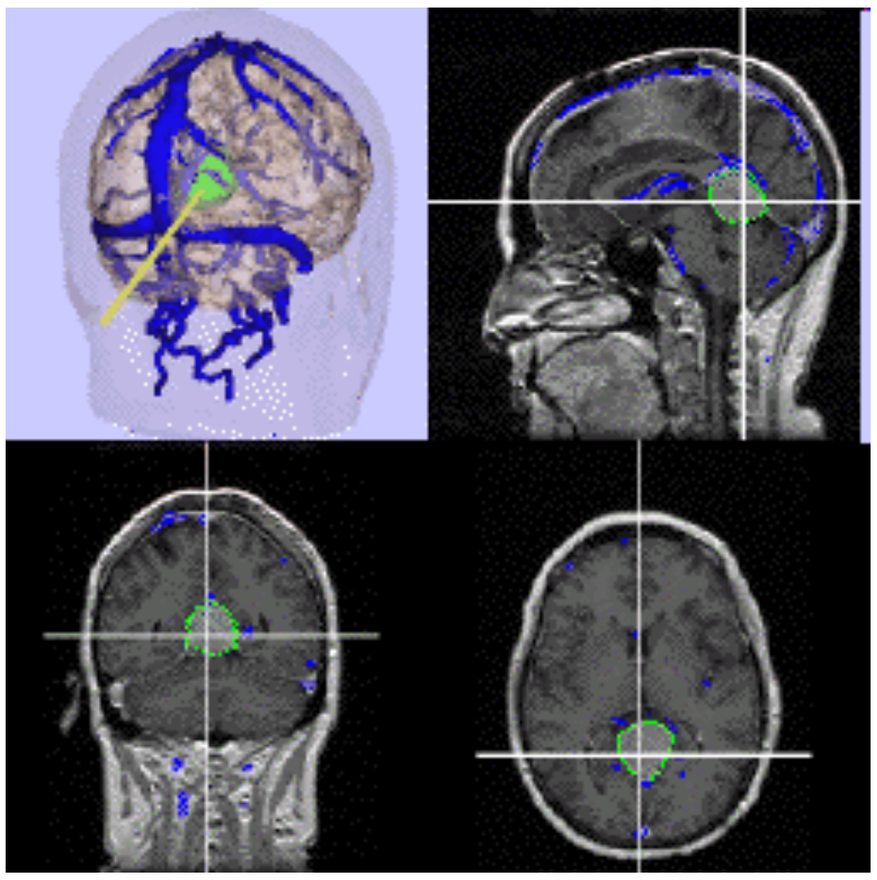
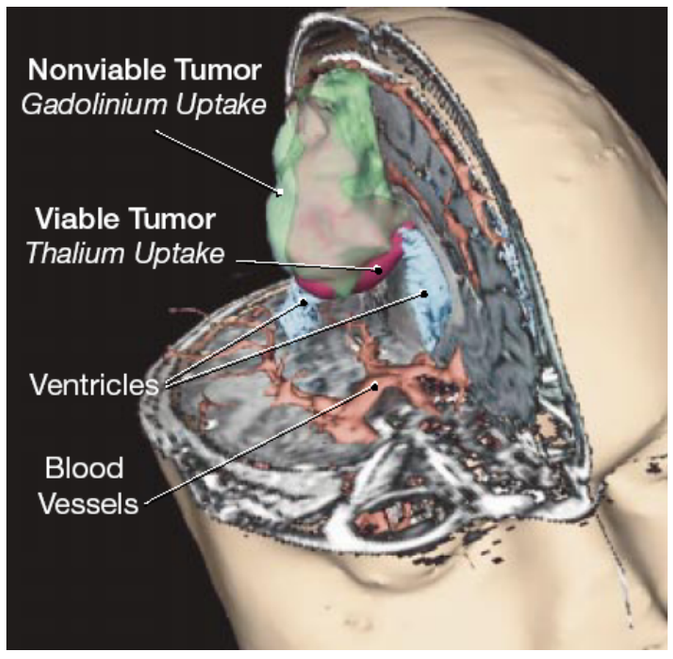
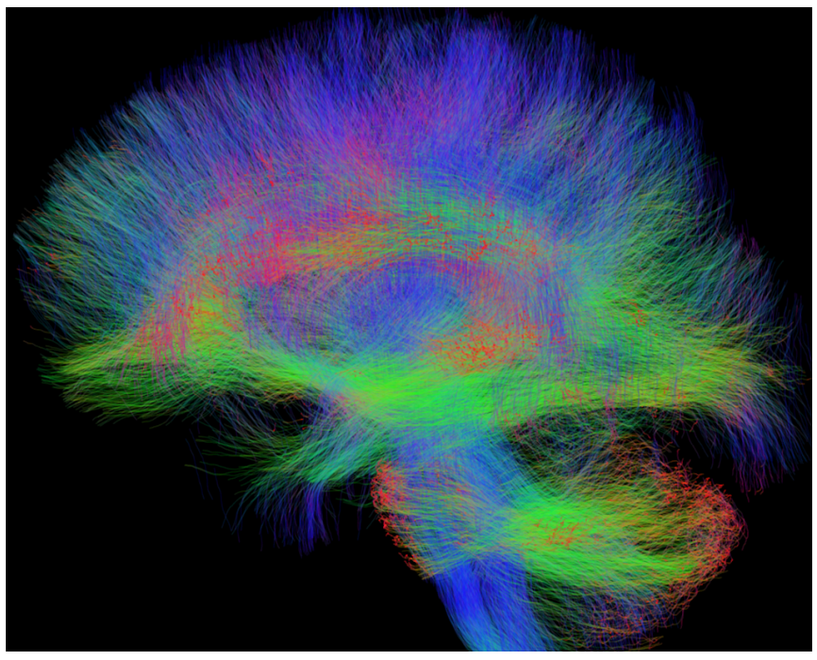
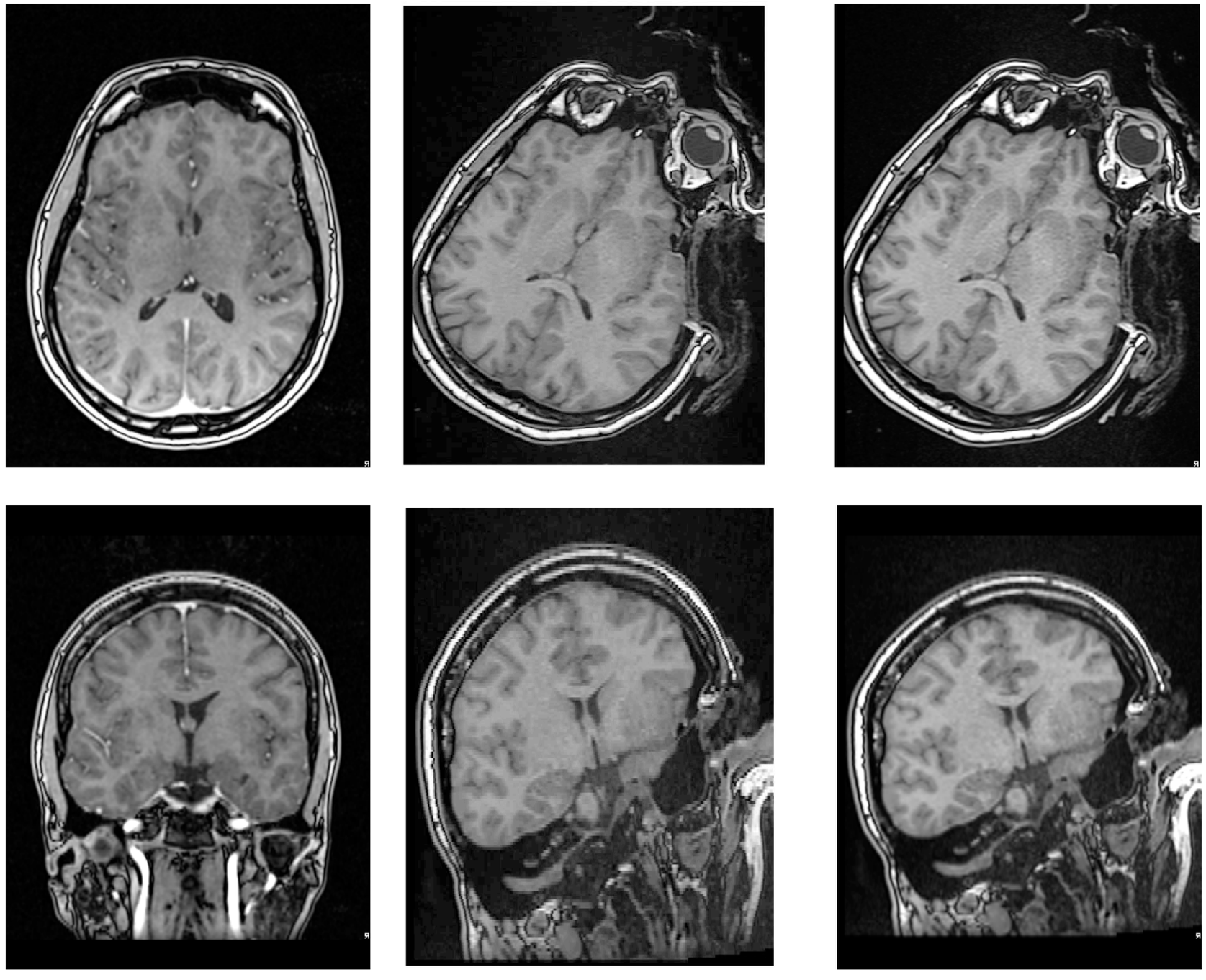






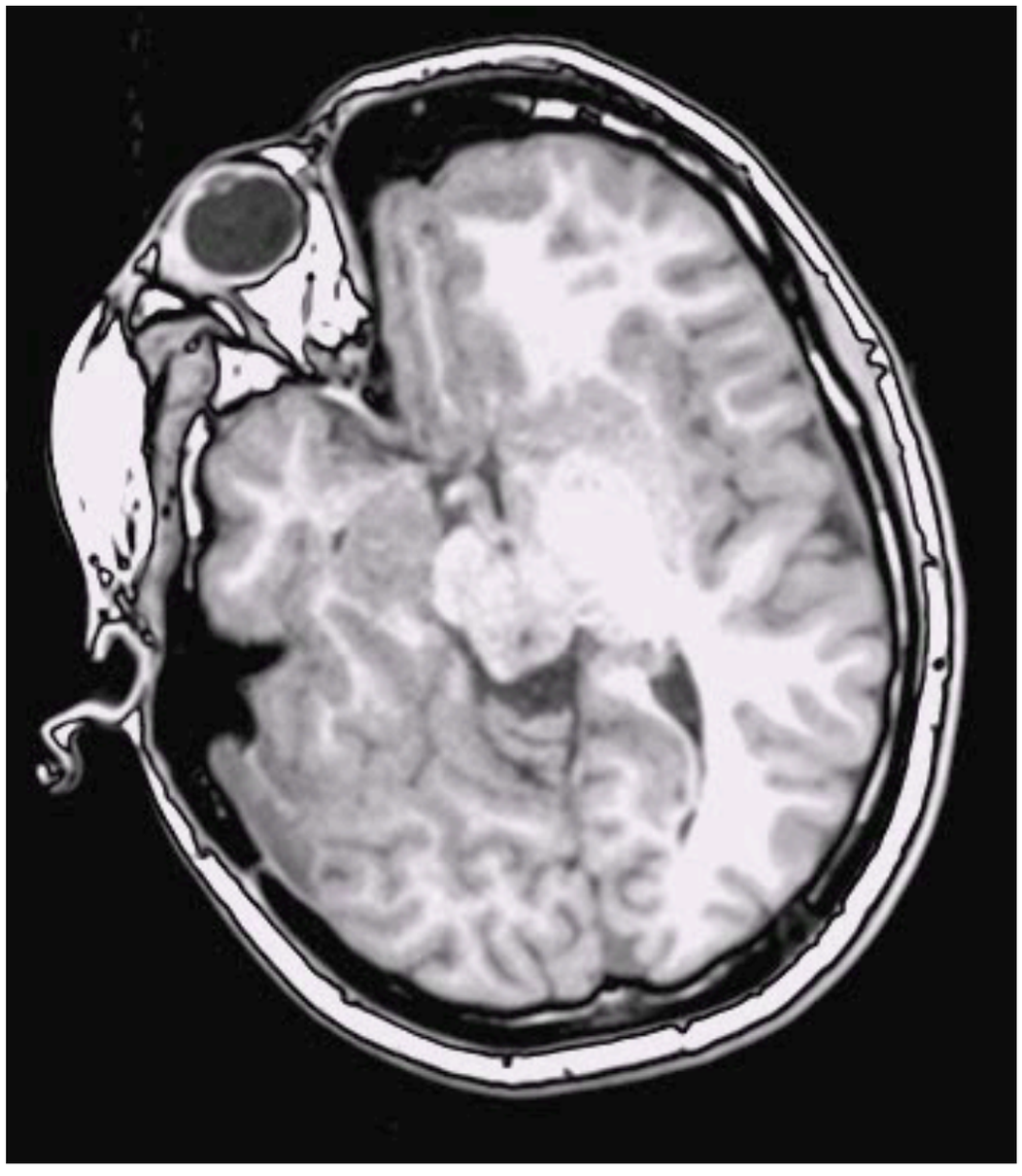
Updating Surgical Planing during the intervention

- Brain Shift correction



Updating Surgical Planing during the intervention

- Optic Radiation tracking (first intra-op scan)



Updating Surgical Planing during the intervention

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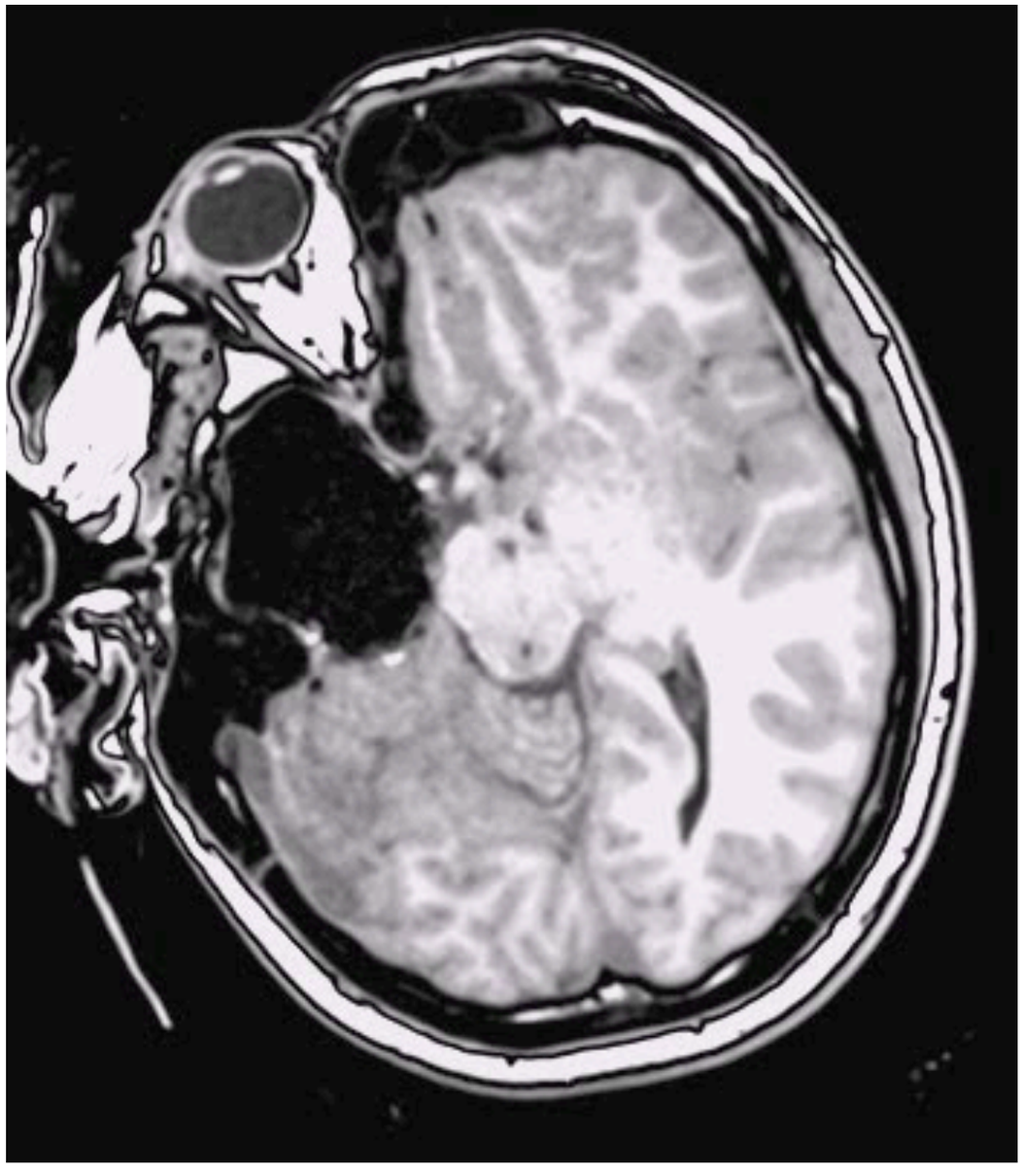
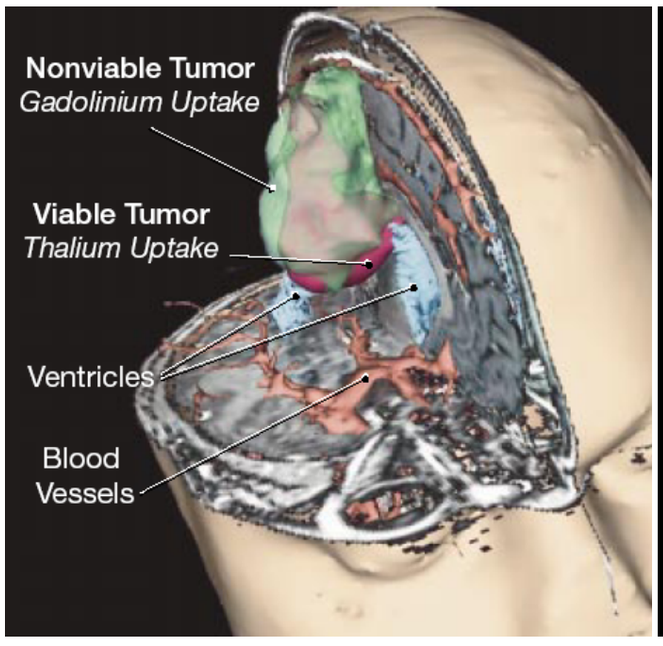
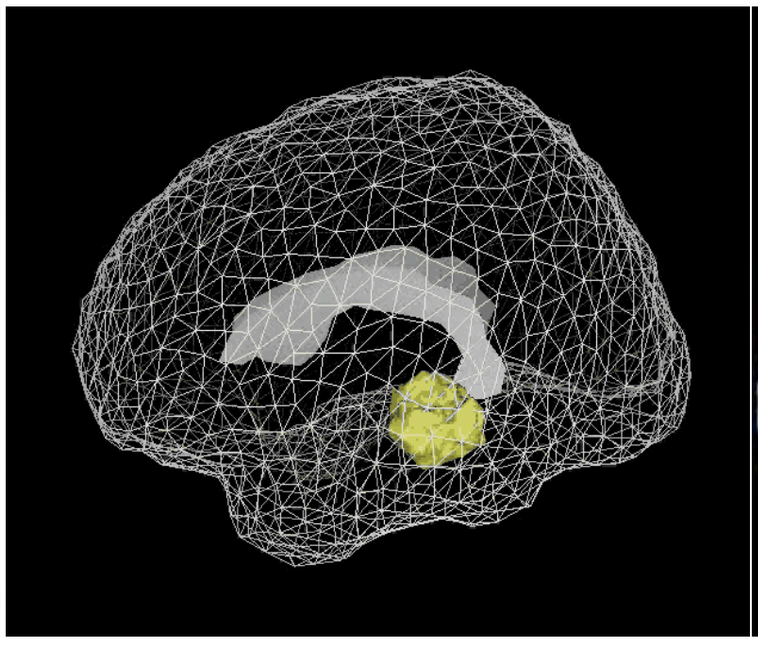
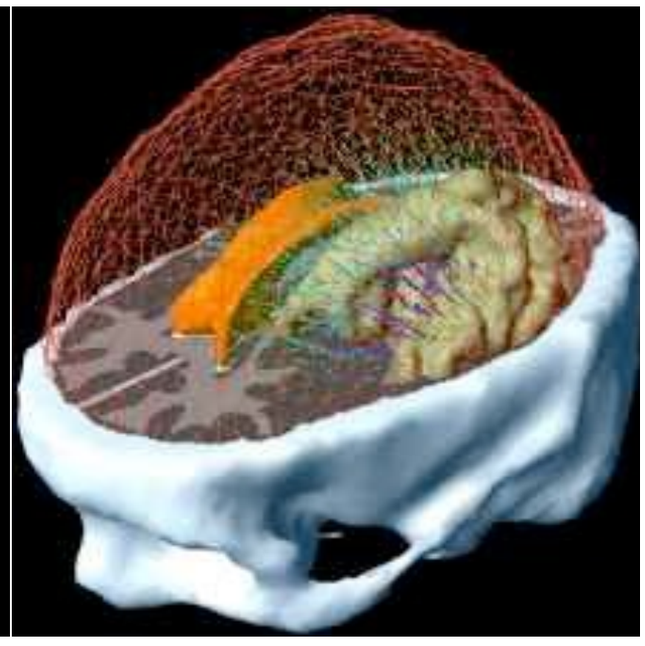
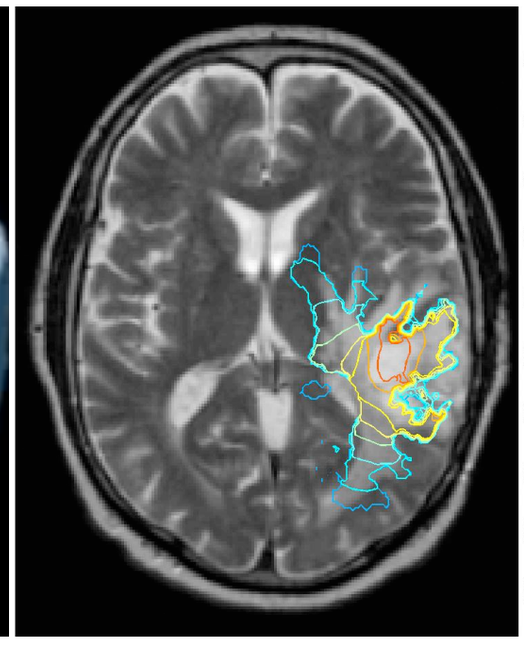


Creation of Body Double Patient Specific Biomechanical Model and Growth evolution









Patient specific modelling

Courtesy of INRIA and Brigham & Women's Hospital

Cardiovascular application

- Measuring cardiac ejection fraction, wall motion
  - segmentation of ventricles and myocardium.

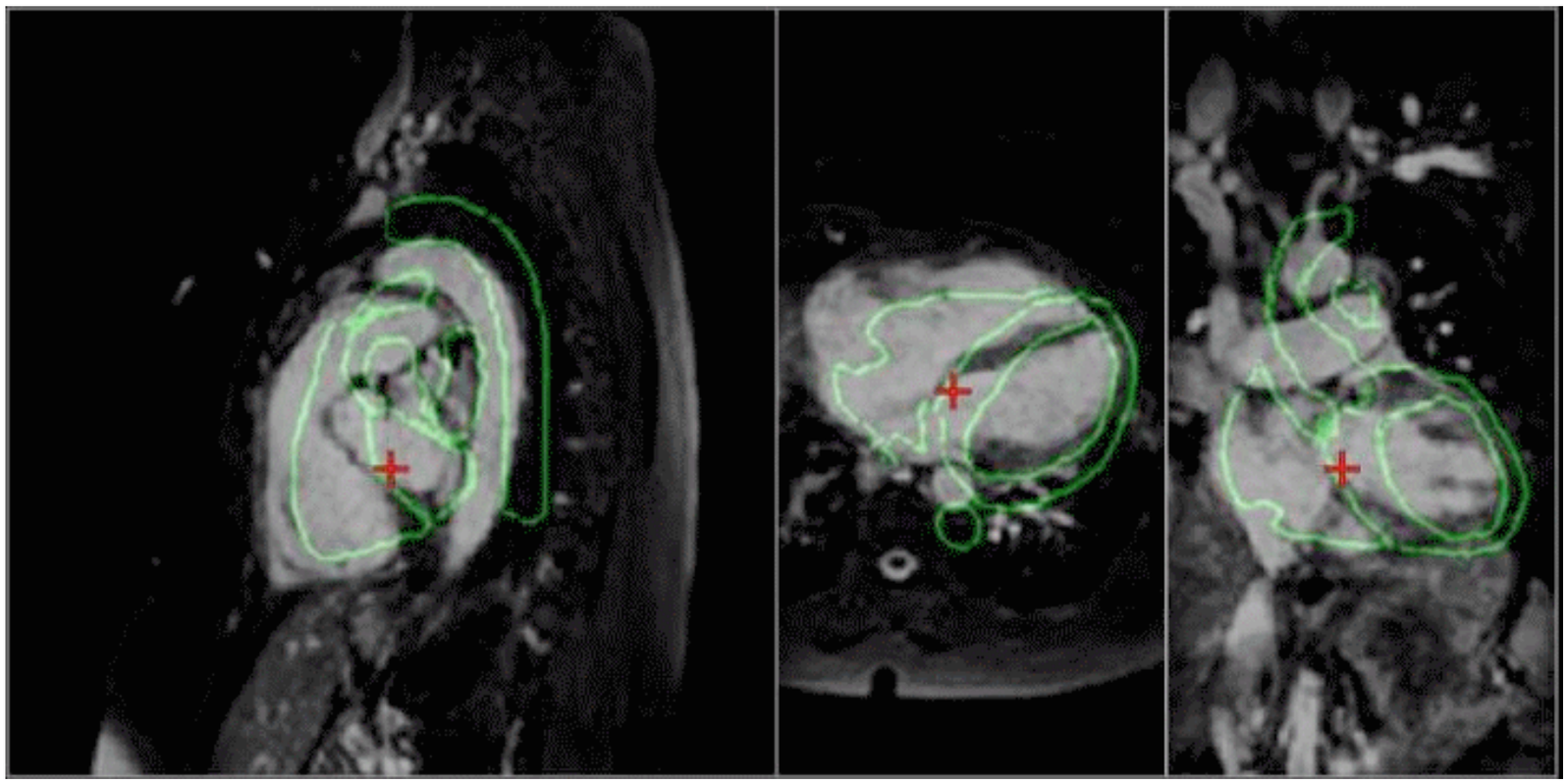
- Catheter-based Interventions
  - align x-ray images with pre-op images.

- Measuring blood flow & Quantifying fat
  - segmenting relevant tissue,
  - quantifying images.

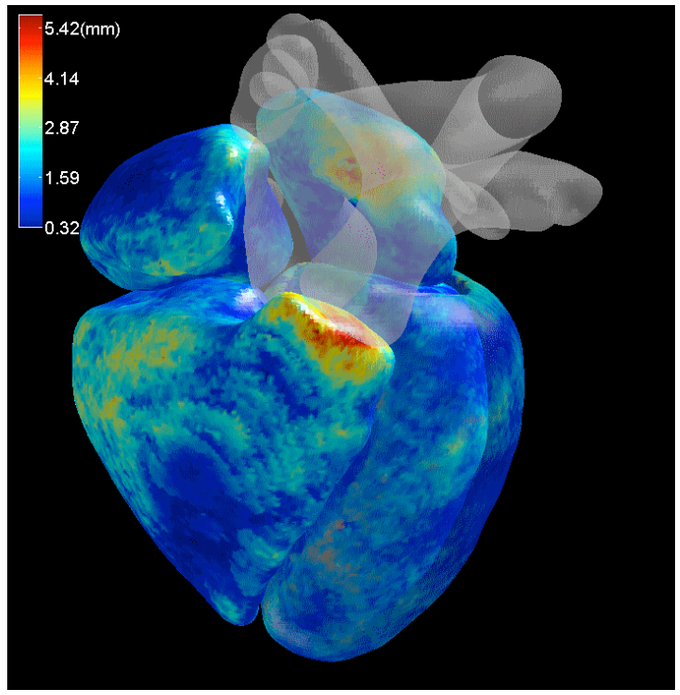
- Atherosclerosis
  - segmenting vessel walls, quantifying stenosis, characterising plaque.

Cardiovascular application

- Example of heart ventricle segmentation using registration



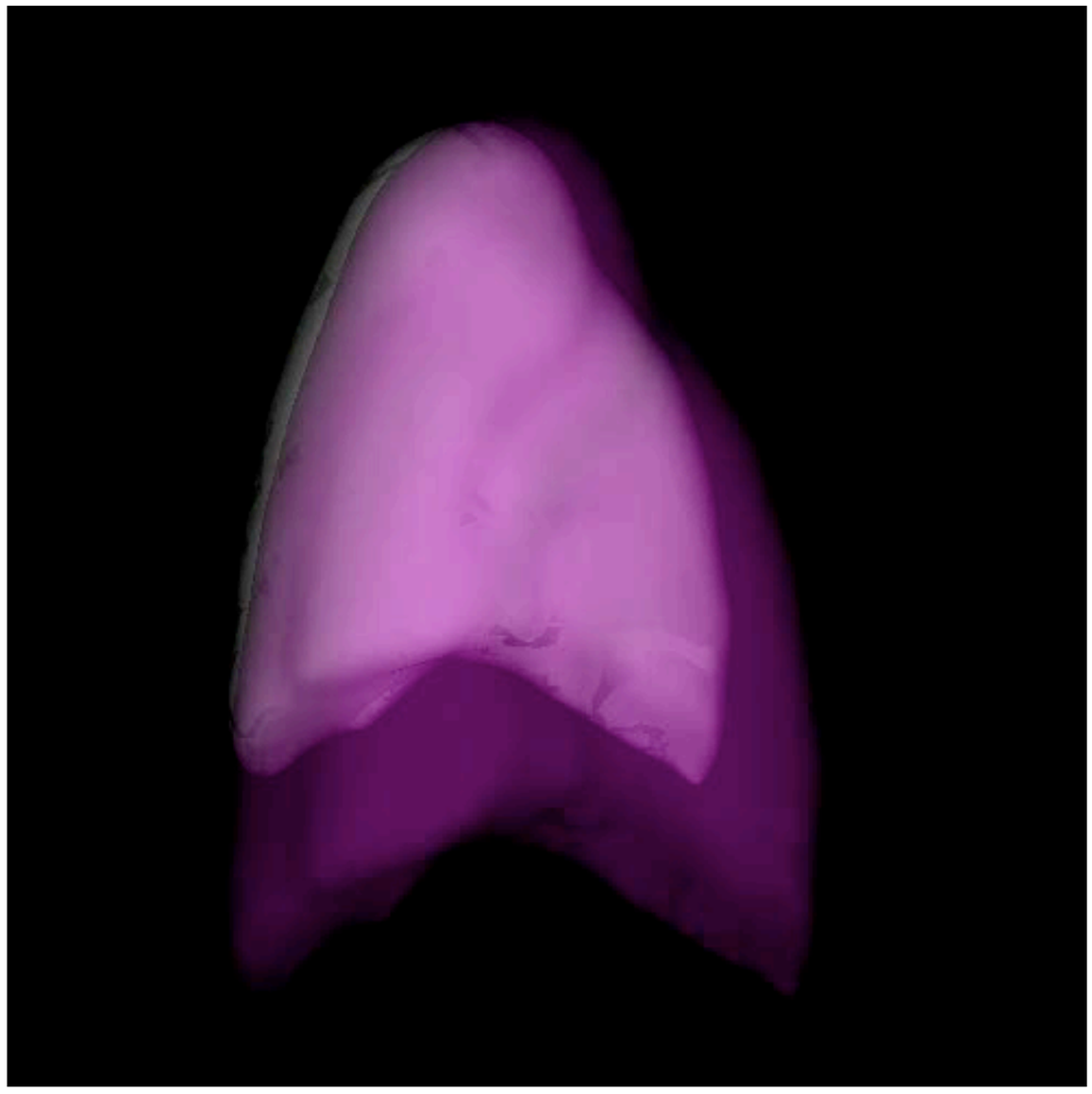
Whole heart segmentation using segmentation propagation



Error distribution

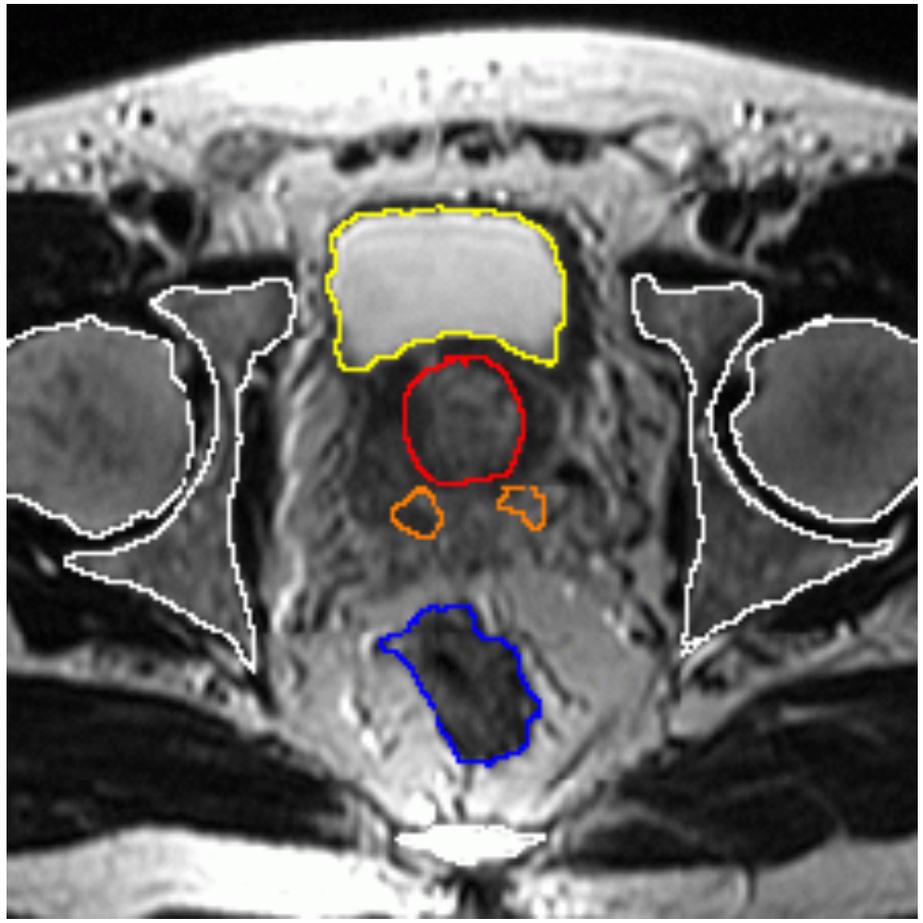
Image Targeted Radiotherapy in the lung

- Non-rigid registrations can be used to construct models of the respiratory motion.
- These can provide a better estimate of the true motion than 4DCT, and have many uses for the planning and delivery of RT.



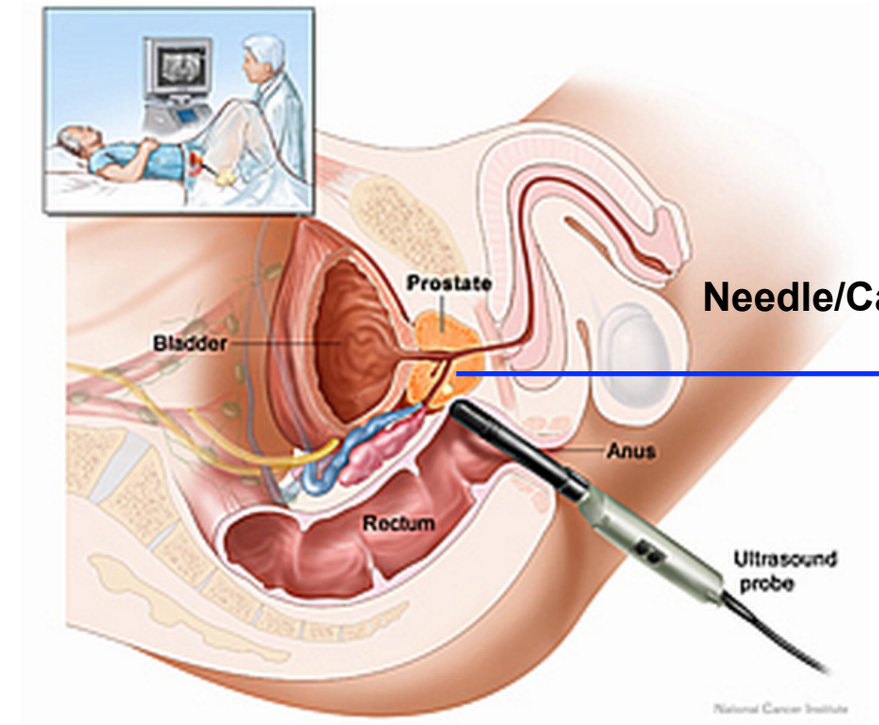
CT/MR fusion for radiotherapy

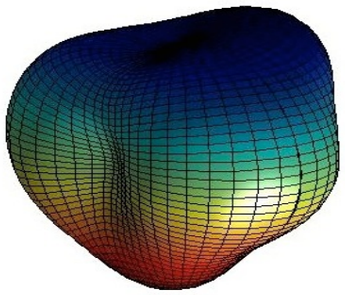
Tissular differenciation
between MR and CT.
Visualisation of the intra and
peri prostatic structures



Fusion CT / MR
(dosimetry / delineation)

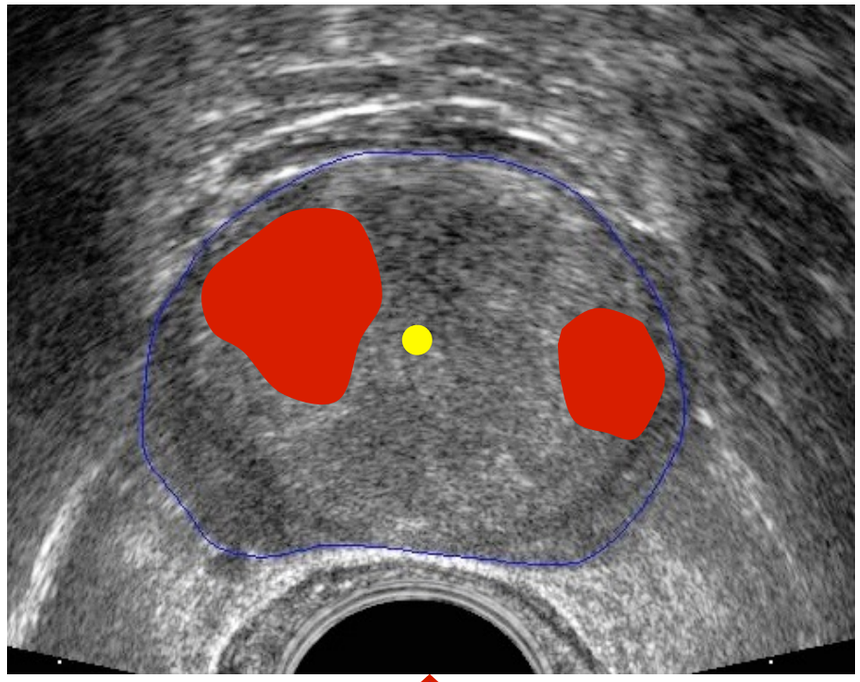
Transrectal ultrasound (TRUS) guidance

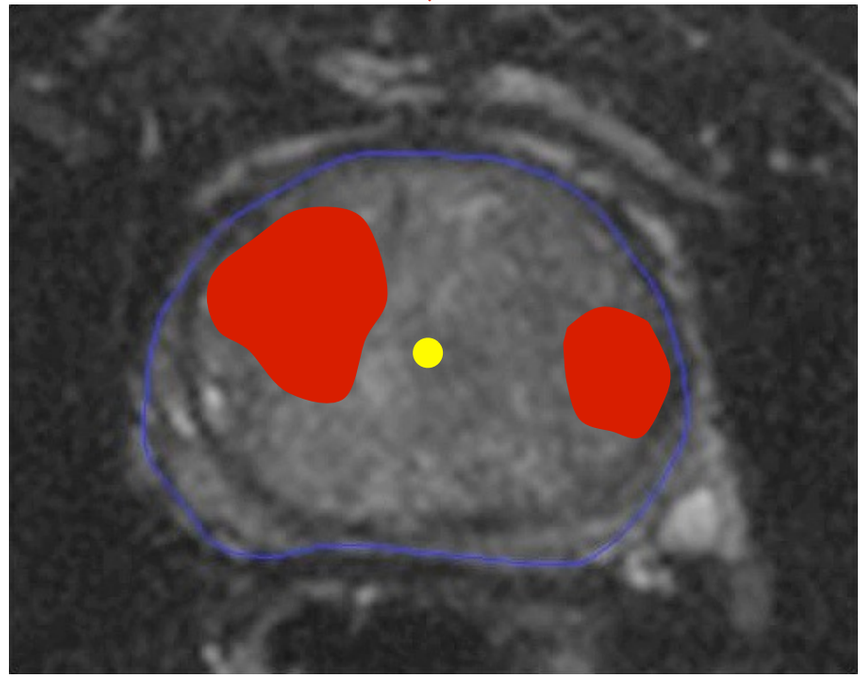




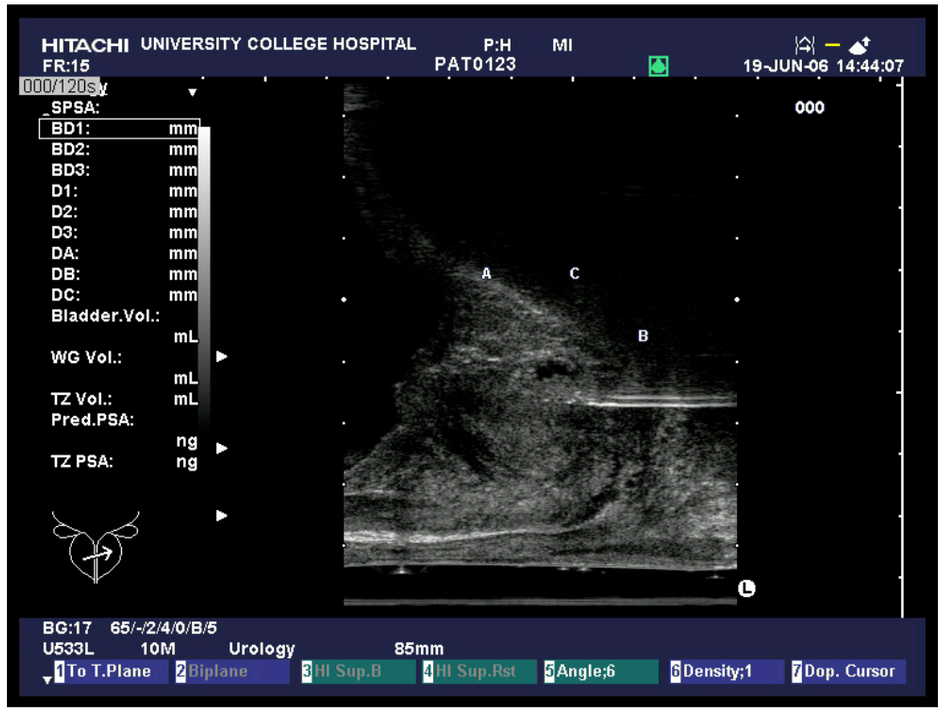
3D prostate model from MRI

TRUS



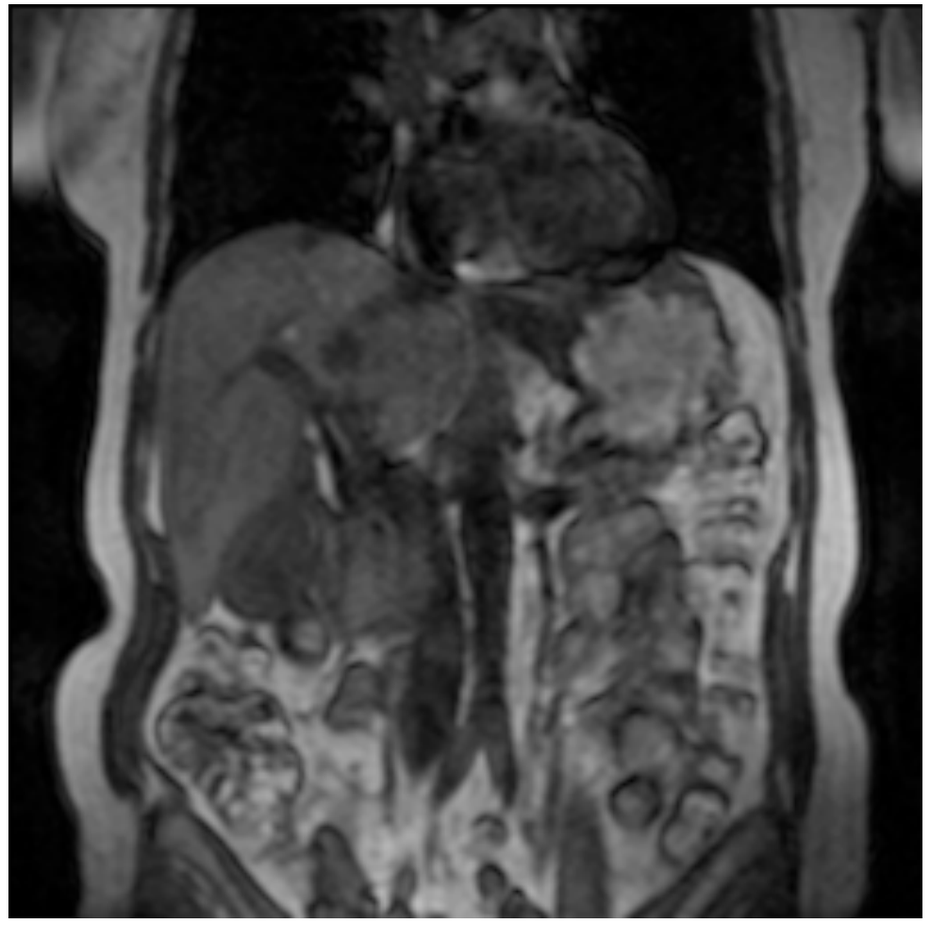


Preop. MR



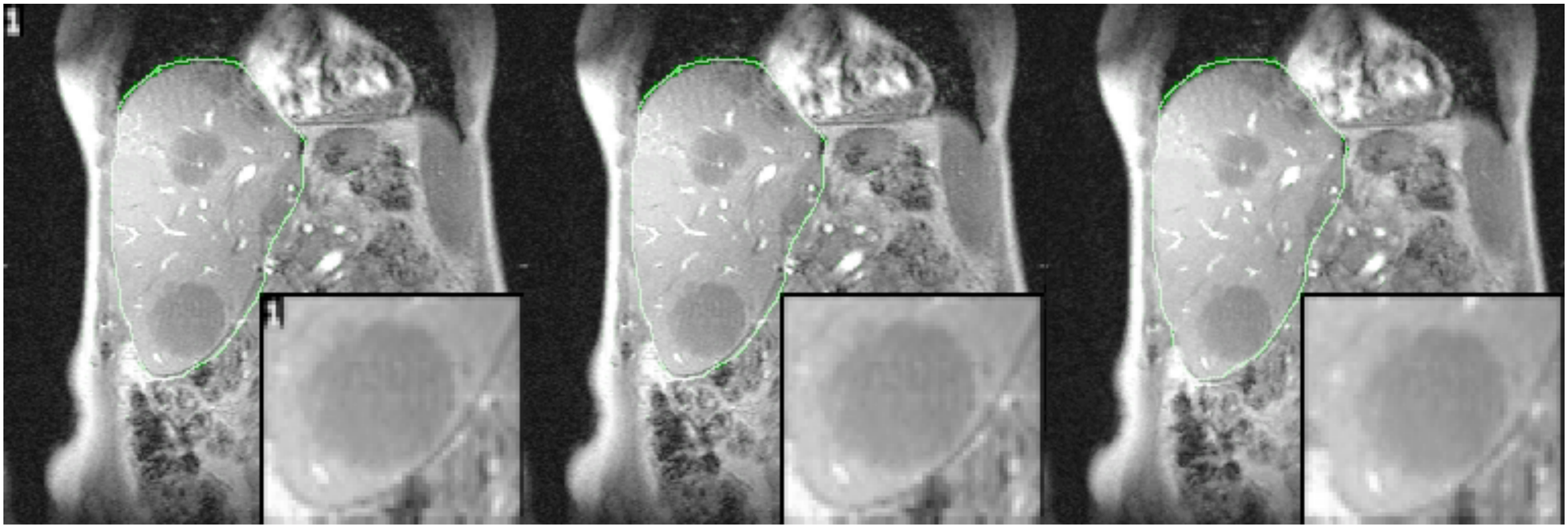
Motion correction for DCE-MRI

- Observing the passage and distribution (the pharmacokinetics) of contrast agent though organs allows analysis of the vascular status of organs or features.
- Dynamic Contrast-Enhanced MRI (DCE-MRI) monitors enhancement this can be used to provide extra information not possible in conventional MRI or X-ray CT



Motion correction for DCE-MRI

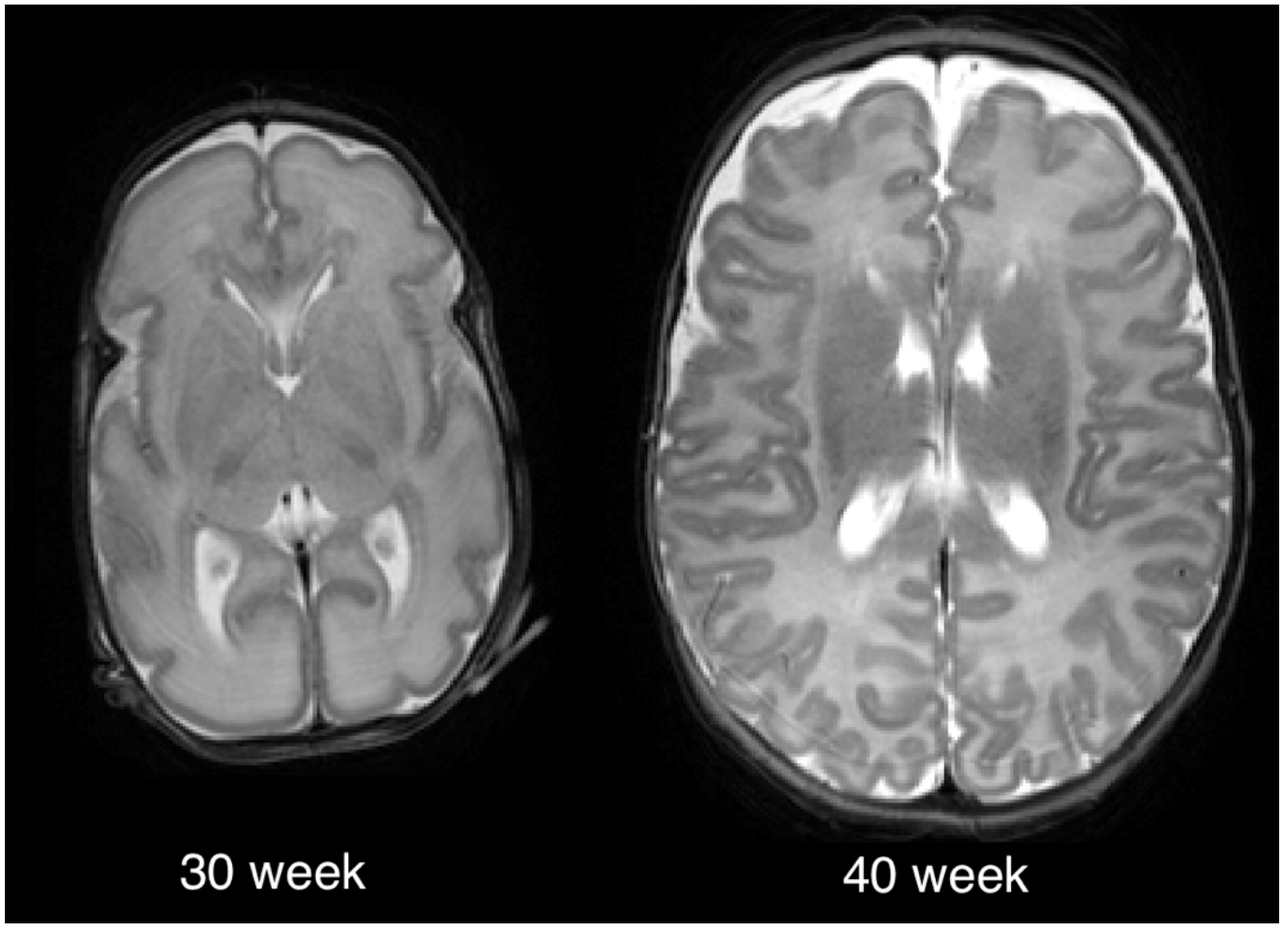
- Application to liver
  - Motion correction allows improved model-fitting and pharmacokinetic parameter estimation



Unregistered data | Non-specific registration algoritm | DCE-MRI specific registration algorithm

Pre-term imaging

- Birth at <32 weeks gestation is associated with increased risk of later developmental problems.
- MRI is used to investigate the neuro-developmental precursors to allow improved understanding or early intervention



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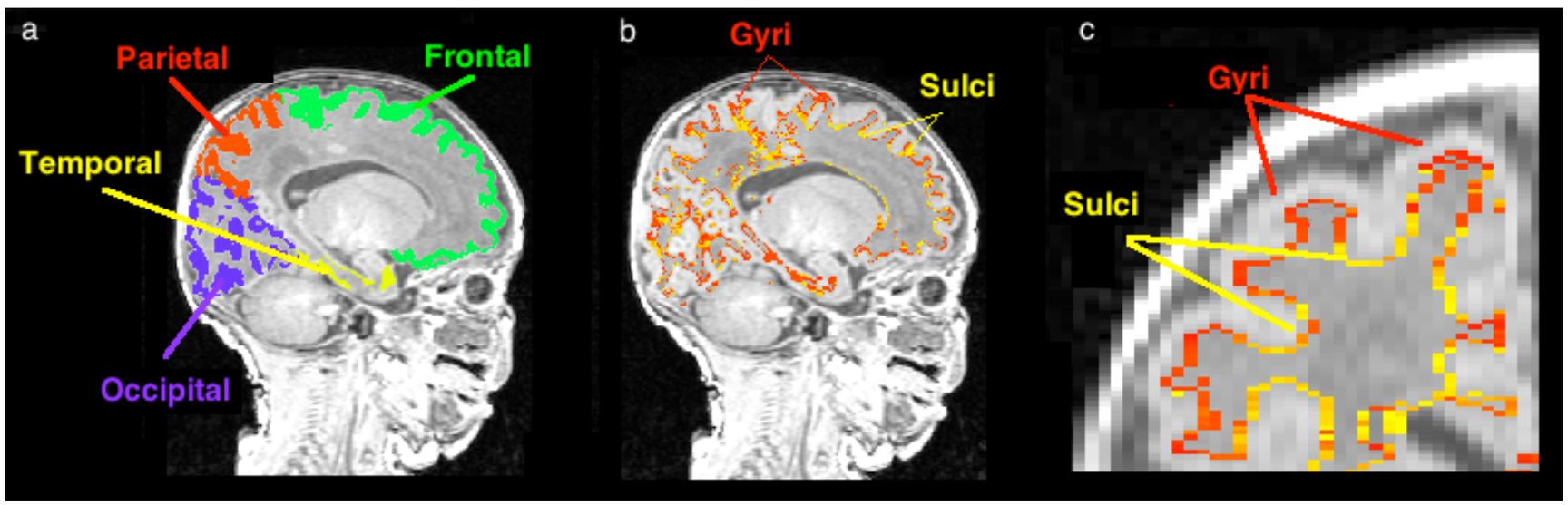
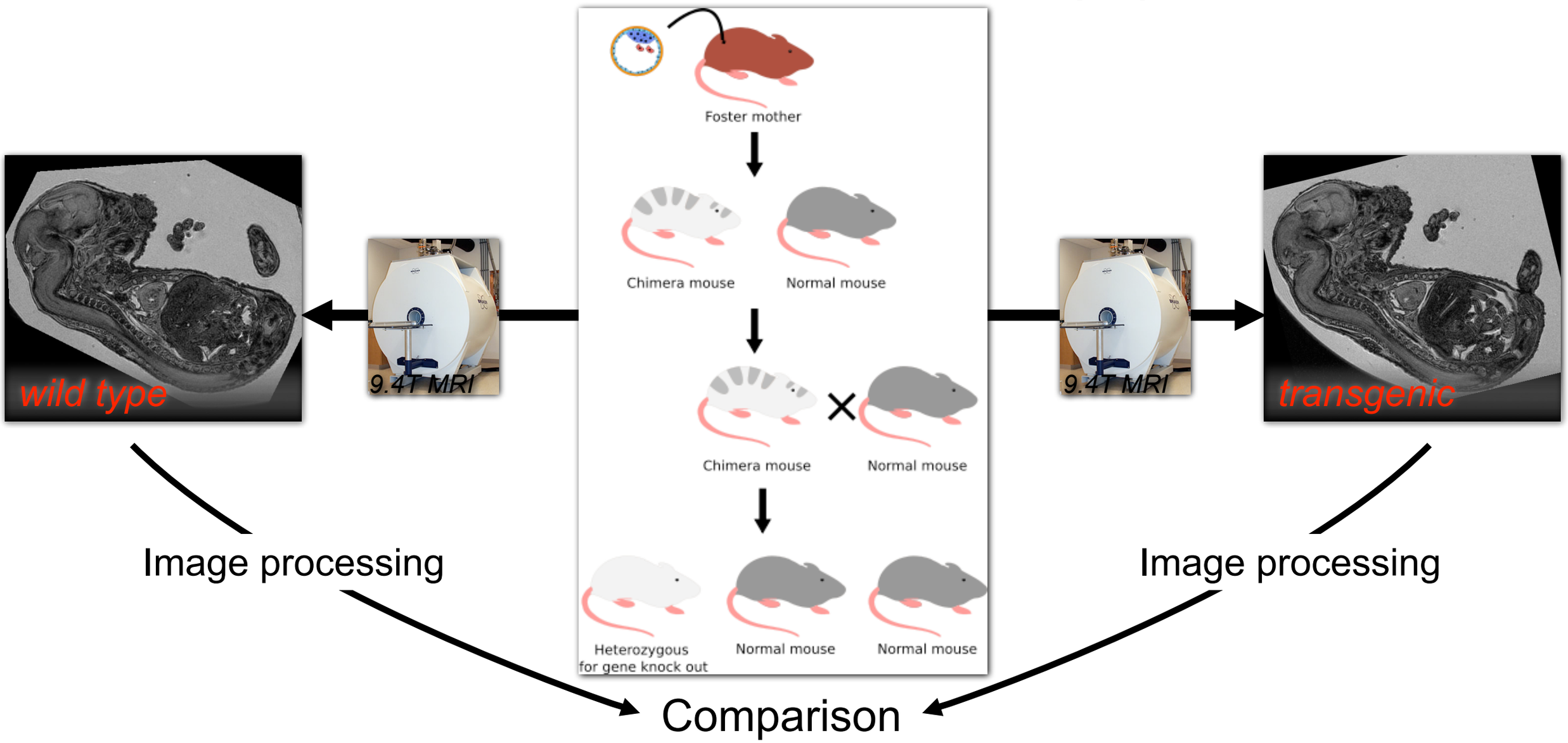
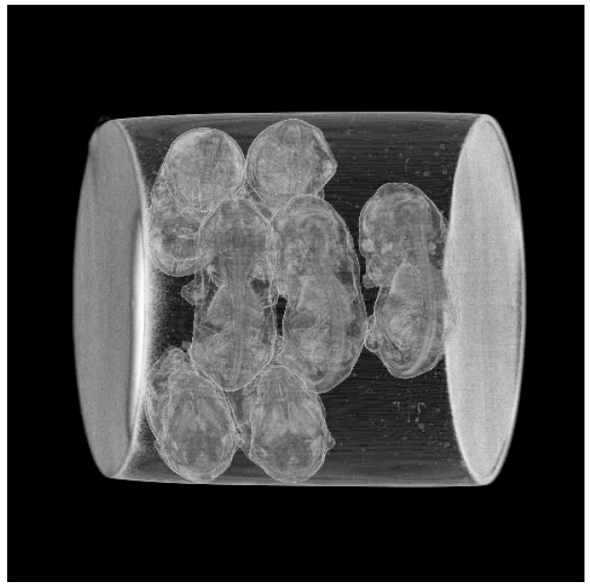


Mouse phenotyping

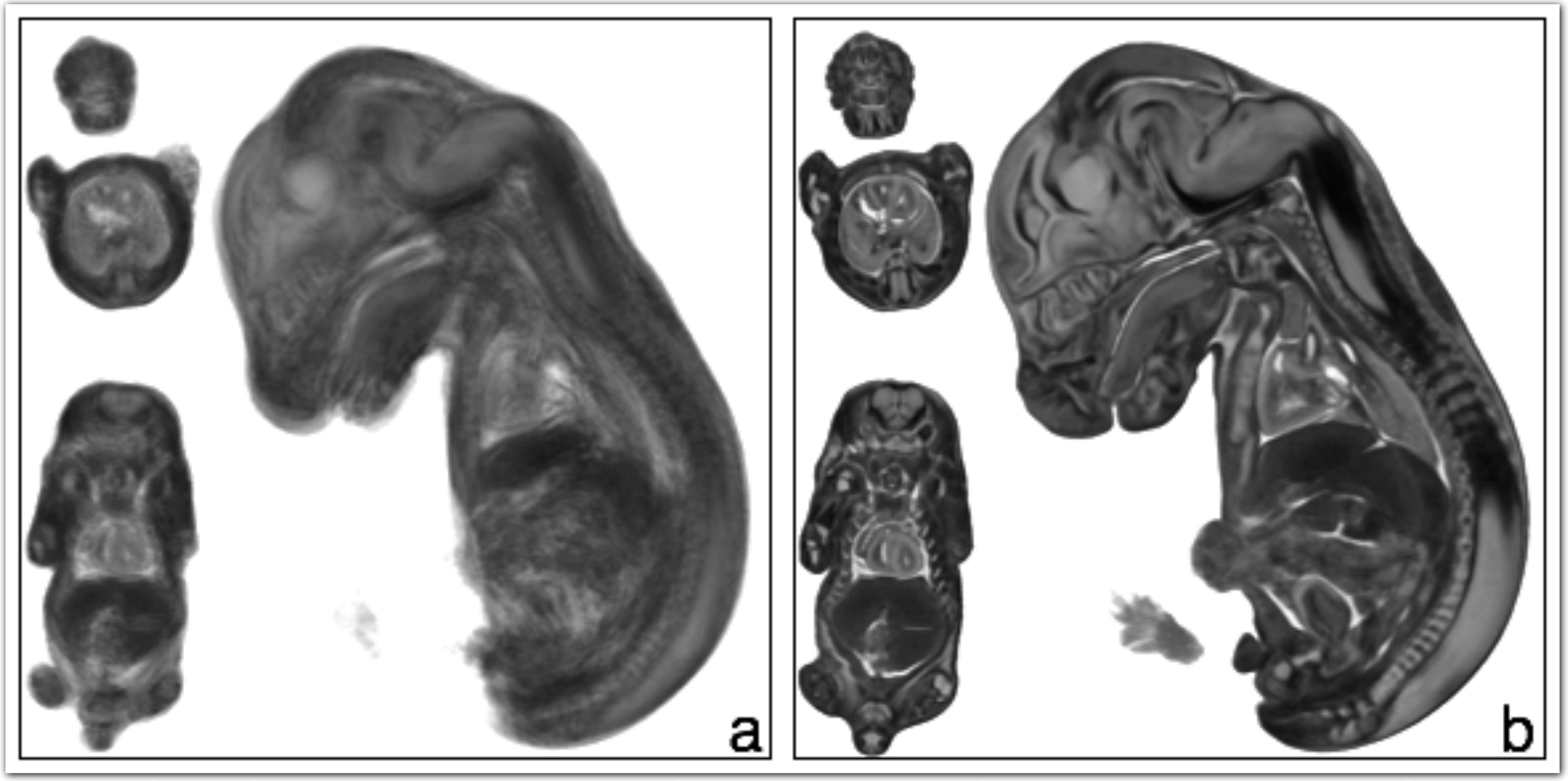
- Can we link a genotype to a phenotype?
- Can we detect difference between two populations?



Mouse phenotyping



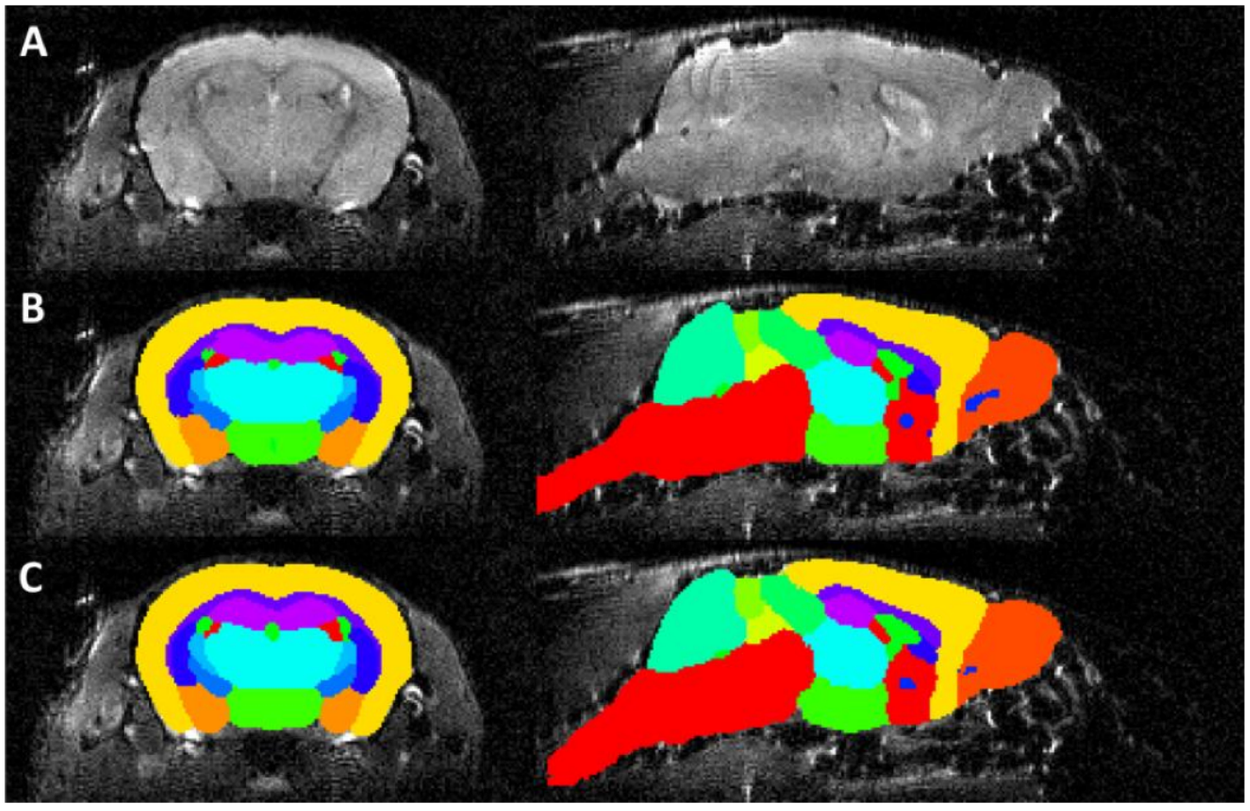
- Average atlas creation using registration



Global registration result Local registration result

Mouse phenotyping

- Parcelation



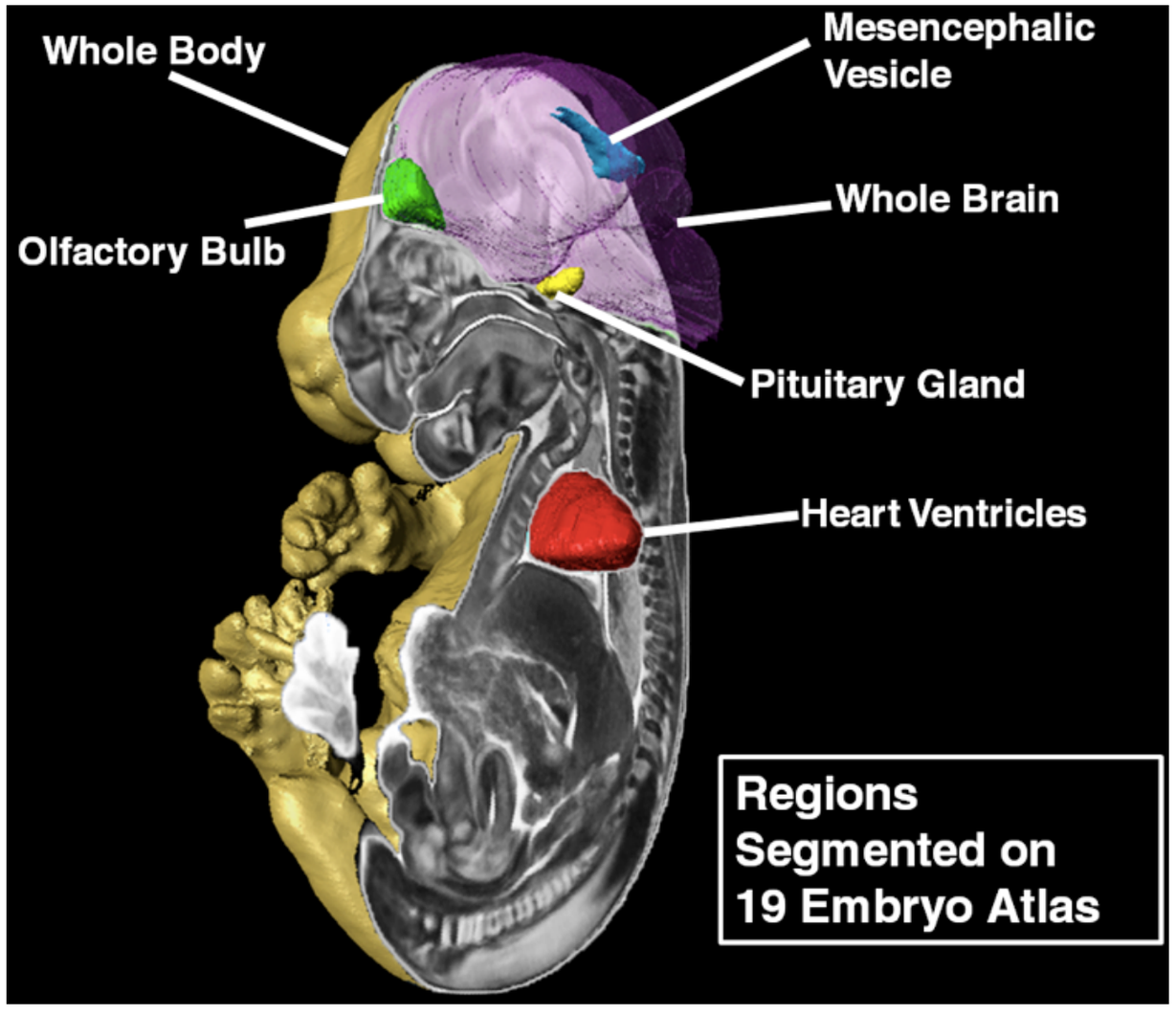
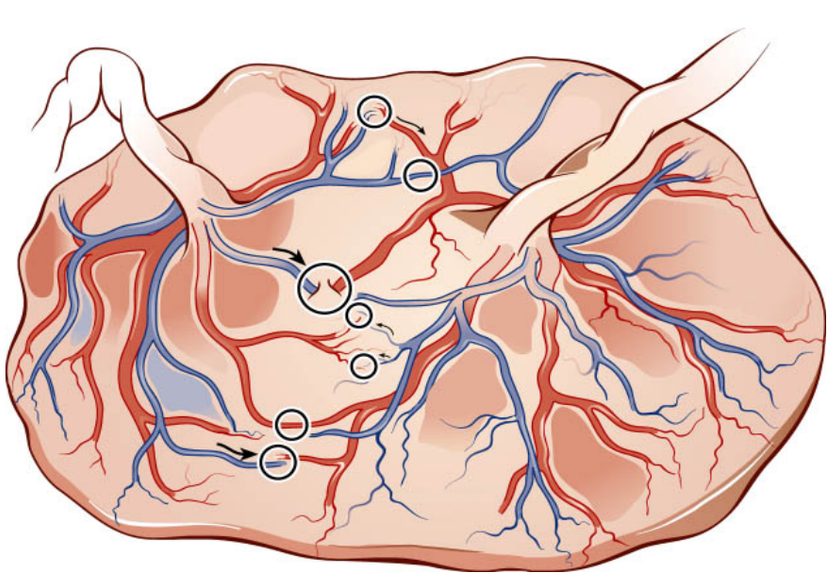
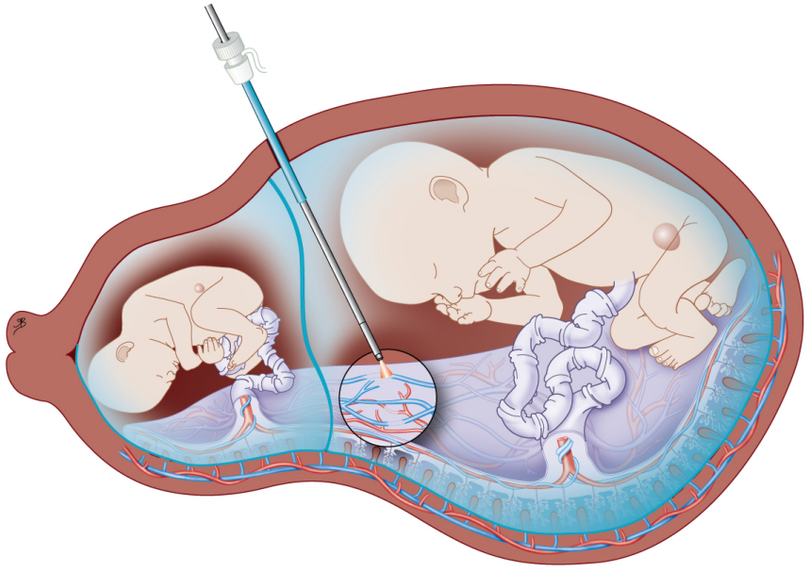


Image guided intervention

- Twin-to-Twin transfusion syndrome (TTTS)





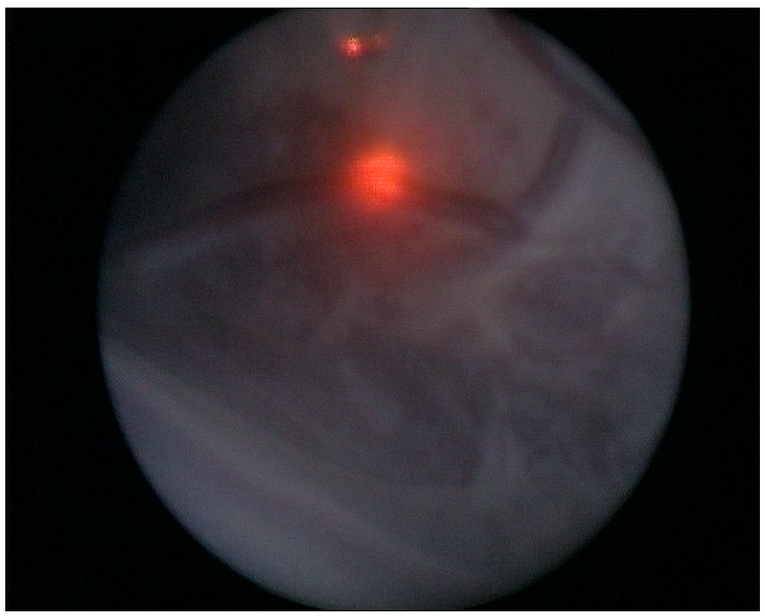
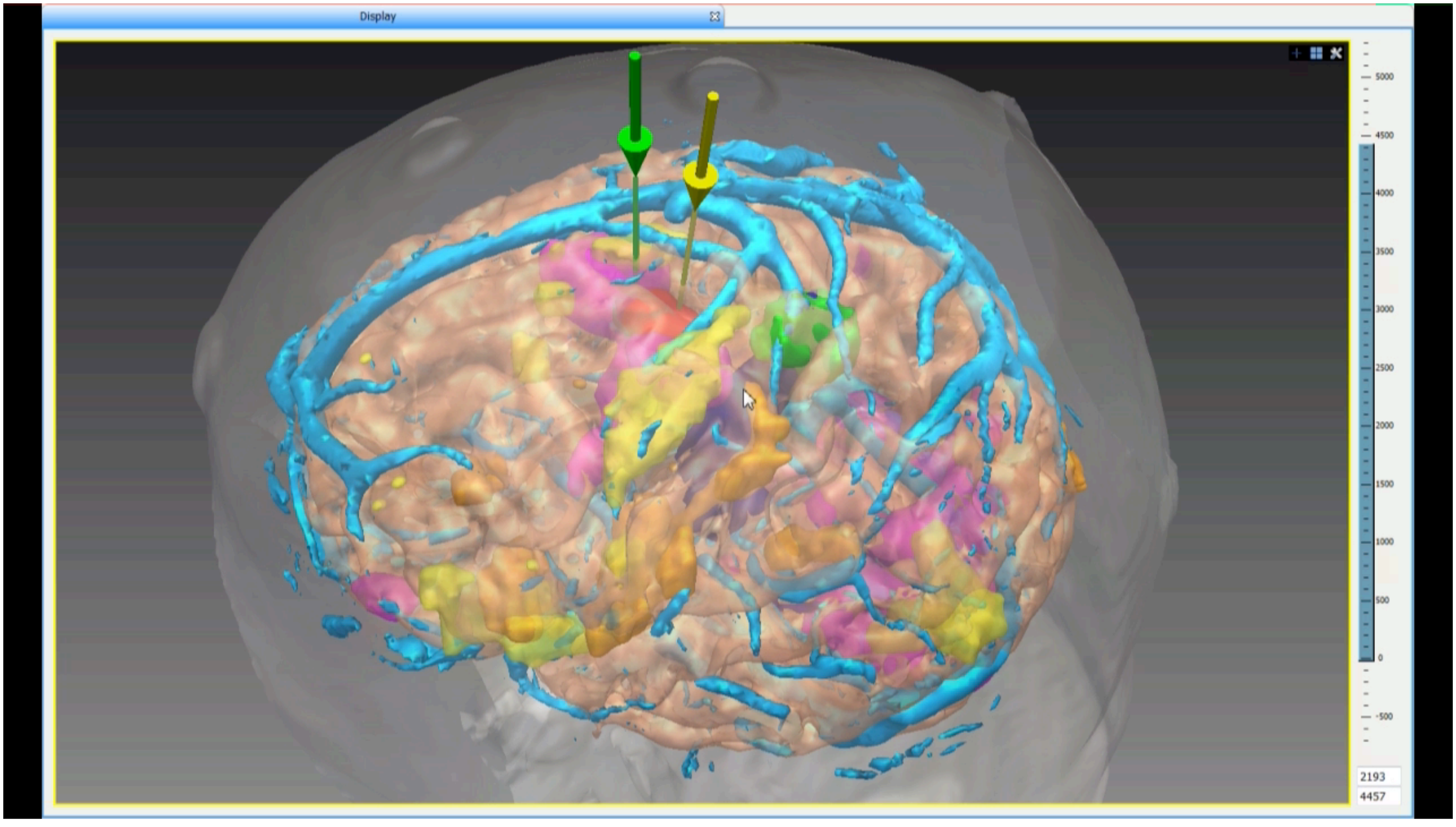


Image guided surgery

- Epilepsy electrode placement



Questions?