Neuroimaging For Forensic Psychologists

September 23, 2011

MIRECC
VISN 19 ROCKY MOUNTAIN NETWORK

Hal S. Wortzel, MD

Director, MIRECC Neuropsychiatric Consultation Services and Psychiatric Fellowship

VISN 19 MIRECC, Denver Veterans Hospital

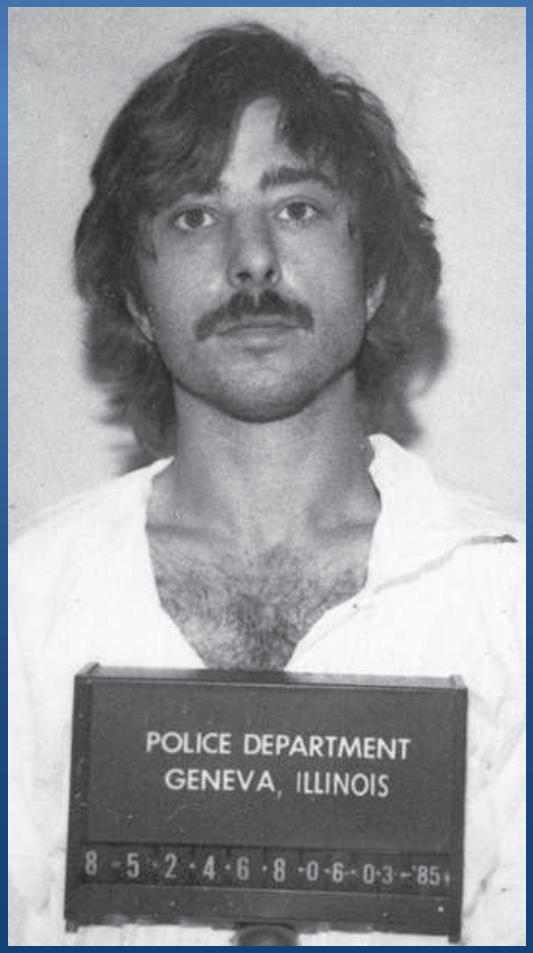
Assistant Professor of Psychiatry

Faculty - Neurobehavior Disorders Program and Division of Forensic Psychiatry

University of Colorado School of Medicine

Last year, functional magnetic resonance imaging made its debut in court.

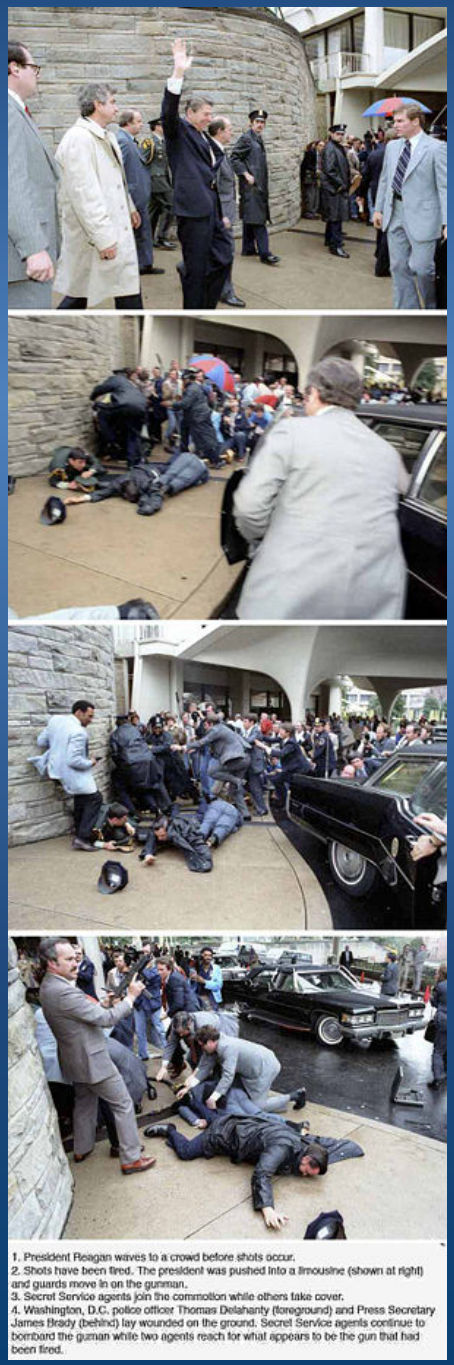
- Sentencing phase of murder trial for Brian Dugan
- 1983 - kidnapped, raped, and beat to death 10-year-old girl
- 1984 - raped and drowned 27-year-old nurse
- 1985 - raped and killed 7-year-old girl



Virginia Hughes:Head case.Nature 464: 340-42, 2010

Jack Ruby's Defense

- Claimed he shot Oswald during seizure
- Thus unable to appreciate the nature and wrongfulness of actions
- Battle of experts surrounded different interpretations of a rhythmic temporal theta burst electroencephalographic abnormality



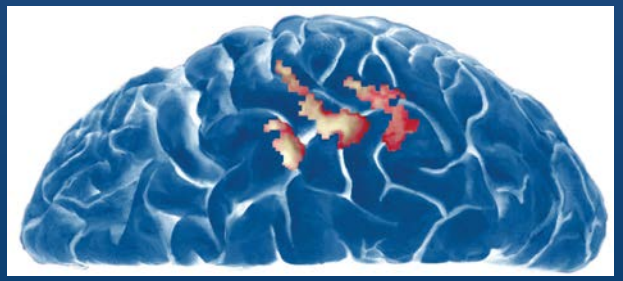
1. President Reagan waves to a crowd before shots occur.
2. Shots have been fired. The president was pushed into a limousine (shown at right) and guards move in on the gunman.
3. Secret Service agents join the commotion while others take cover.
4. Washington, D.C. police officer Thomas Delahanty (foreground) and Press Secretary James Brady (behind) lay wounded on the ground. Secret Service agents continue to bombard the gunman while two agents reach for what appears to be the gun that had been fired.

John Hinckley's Defense

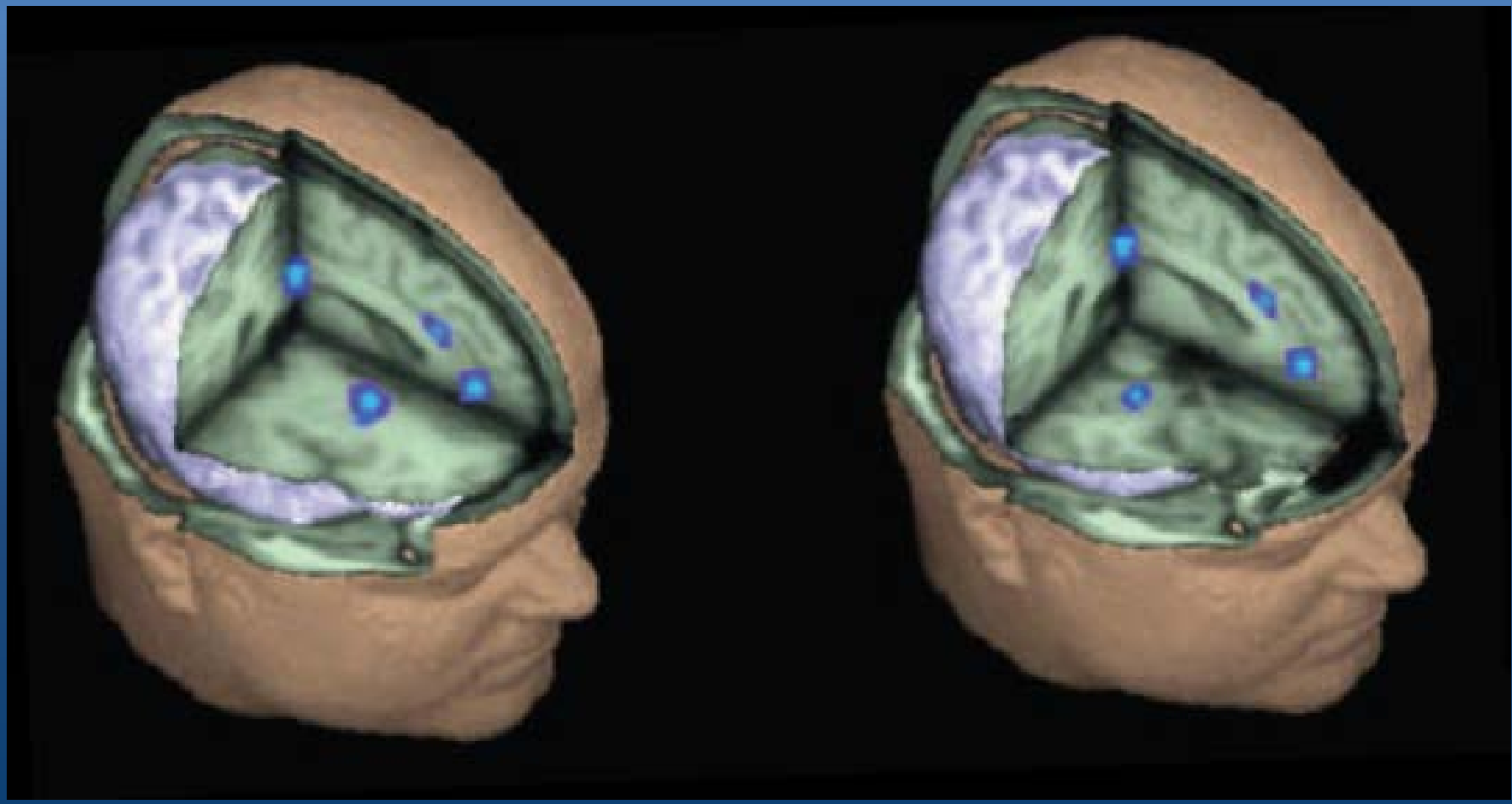
- Clash of experts over significance of Hinckley's widened sulci on CAT-scan
- Defense experts argued pattern evidenced a proper diagnosis of schizophrenia
- Many outraged by the not-guilty-by-reason-of-insanity verdict
- Often cited as a powerful impetus to major reforms, at national level, surrounding insanity defense

Polarizing?

- *"It is a dangerous distortion of science that sets dangerous precedents for the field."*
  - Helen Mayberg
- *"Kiehl got a lot of criticism, but I think what he did is perfectly reasonable."*
  - Scott Grafton



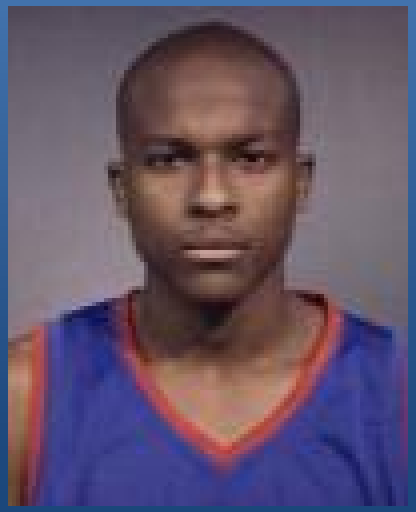
Criminal psychopaths show less activity than non-criminal control subjects in specific emotion-processing areas of the brain, according to Kent Kiehl's testing.



Closer to home...

Death penalty for Aurora witness-killer Ray

- Denver Post, June 8, 2009



Vivian Wolfe and Javad Marshall-Fields were both 22 when they were killed.

Goals and Objectives

1. Structural Neuroimaging
2. Functional Neuroimaging
3. Medicolegal applications

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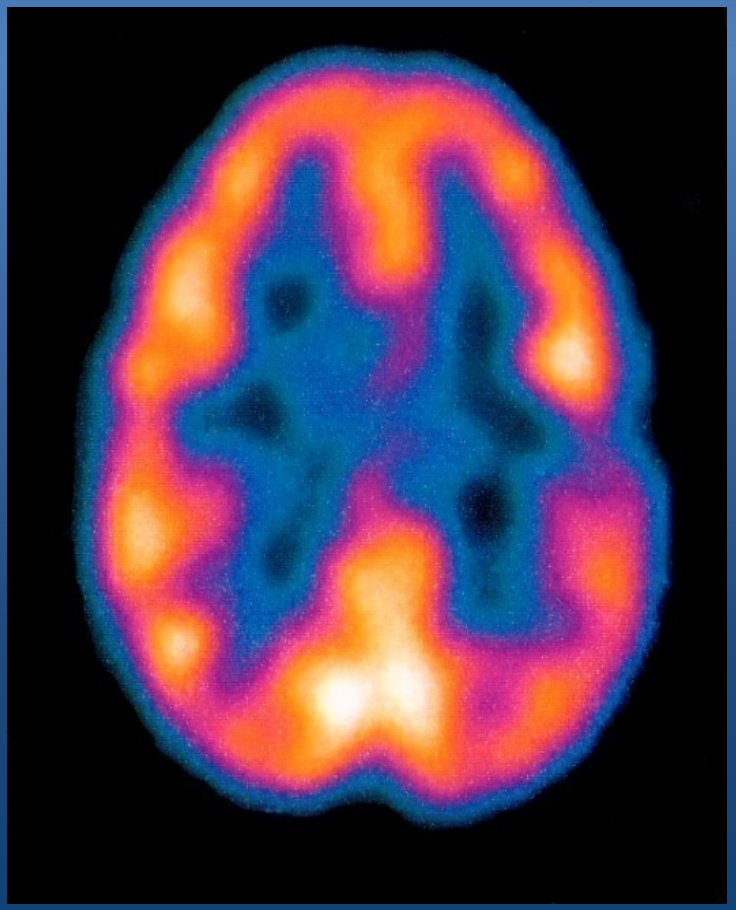
Structural v. Functional



Indications

- Indications may derive from either diagnosis or clinical signs and symptoms
- Information gained may assist in differential diagnosis
- May alter treatment plan
- Inform prognosis

Diagnosis or Medical Condition

- TBI
- Significant alcohol abuse
- Seizure d/o with psychiatric symptoms
- Movement d/o
- Autoimmune d/o
- Eating d/o
- Poison or toxin exposure
- Sustained delirium

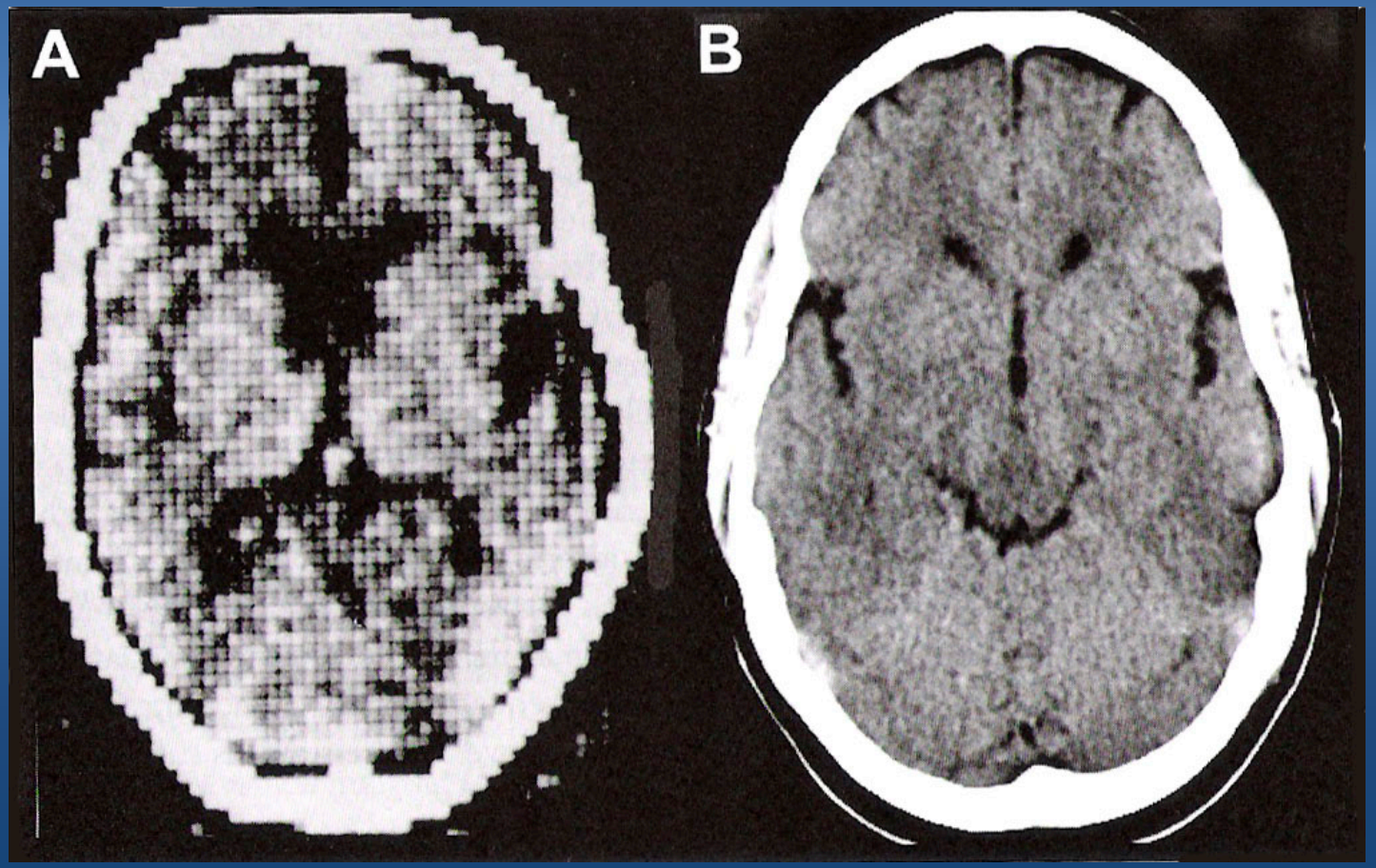
Hurley RA et al., Neuropsychiatry and Behavioral Neurosciences, 2008

Clinical Signs and Symptoms

- Dementia or cognitive decline
- New-onset mental illness > age 50
- Initial psychotic break
- Presentation at atypical age for diagnosis
- Focal neurological signs
- Catatonia
- Sudden personality changes

Hurley RA et al., Neuropsychiatry and Behavioral Neurosciences, 2008

Computed Tomography (CT)

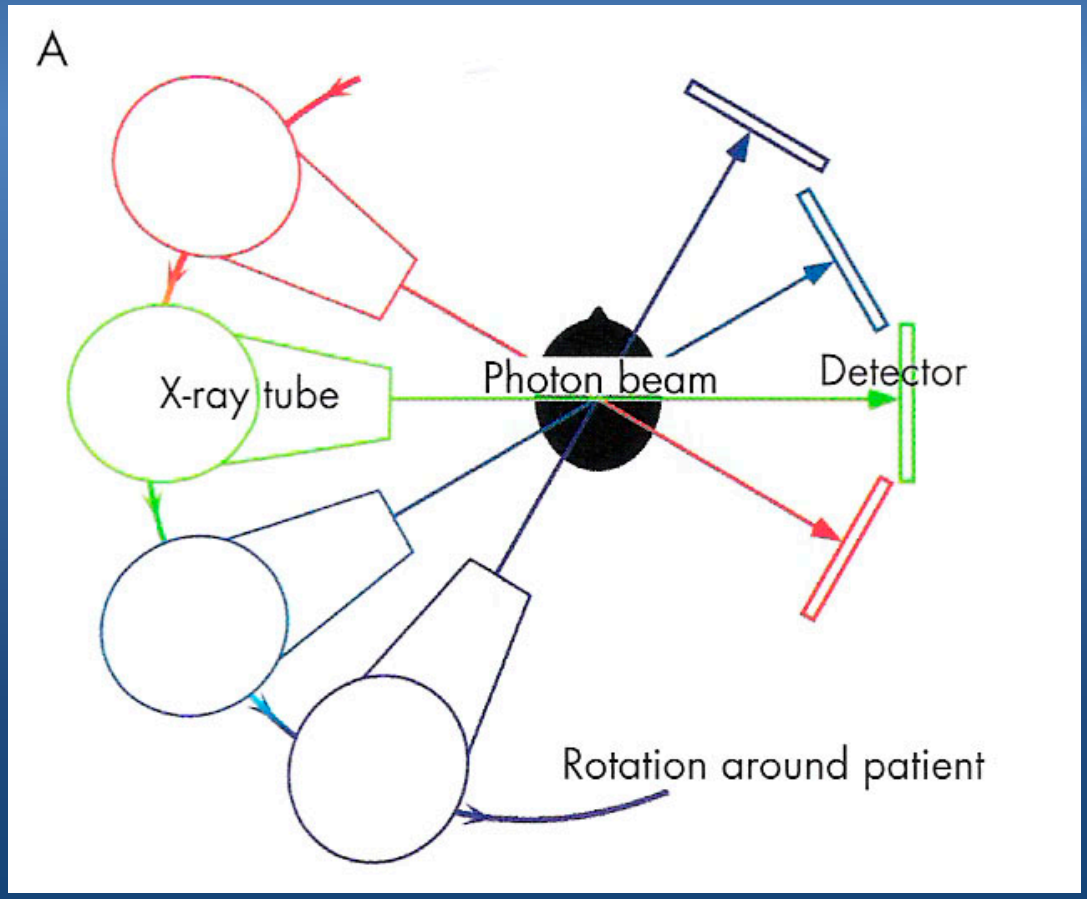


1st Generation (1975)

Modern CT

CT

Based upon X-rays and attenuation

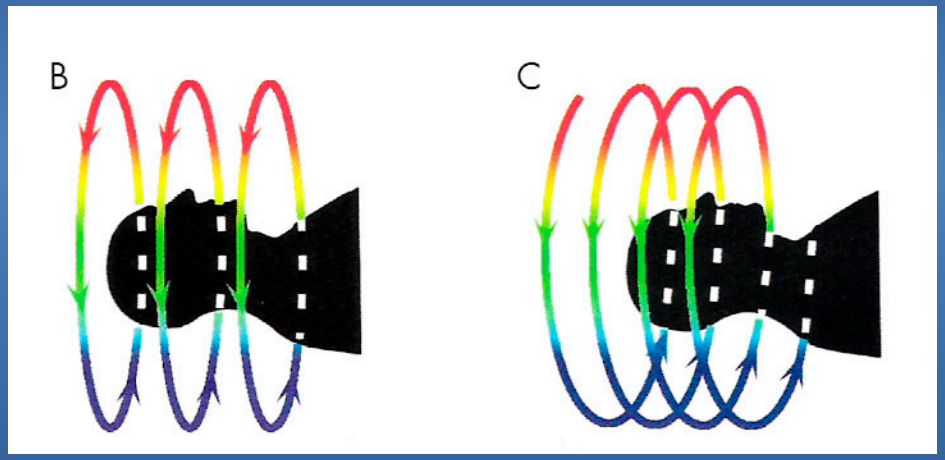


Images record tissue density as measured by variable attenuation

Grey-scale Appearance on CT

Tissue	Appearance
Bone	White
Calcified Tissue	White
Clotted Blood	White
Grey Matter	Light Gray
White Matter	Medium Grey
CSF	Near Black
Water	Near Black
Air	Black

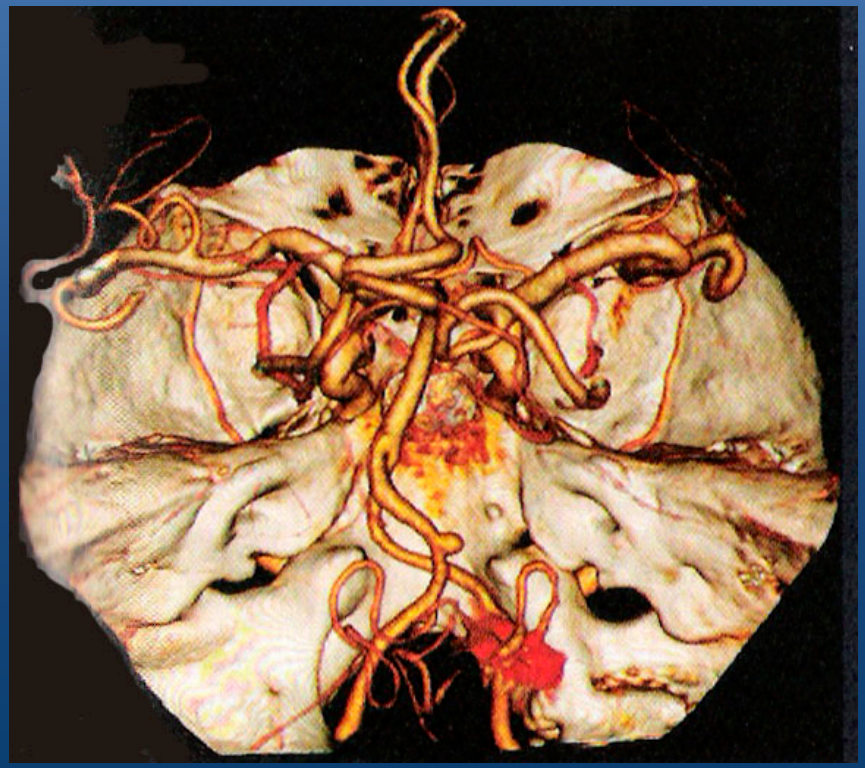
Speed and Dimensions



Spiral scanners introduced in the 1990's

Rapid image acquisition and ability to reconstruct coronal, sagittal, and 3D images.

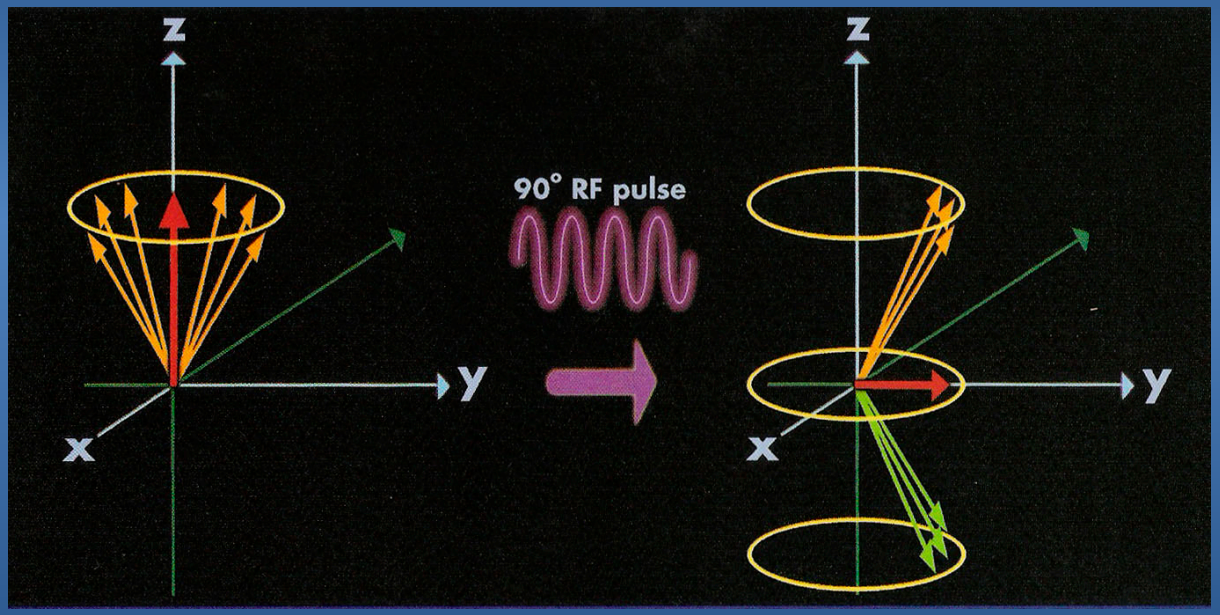
3D image revealing vetebral artery aneuysm.

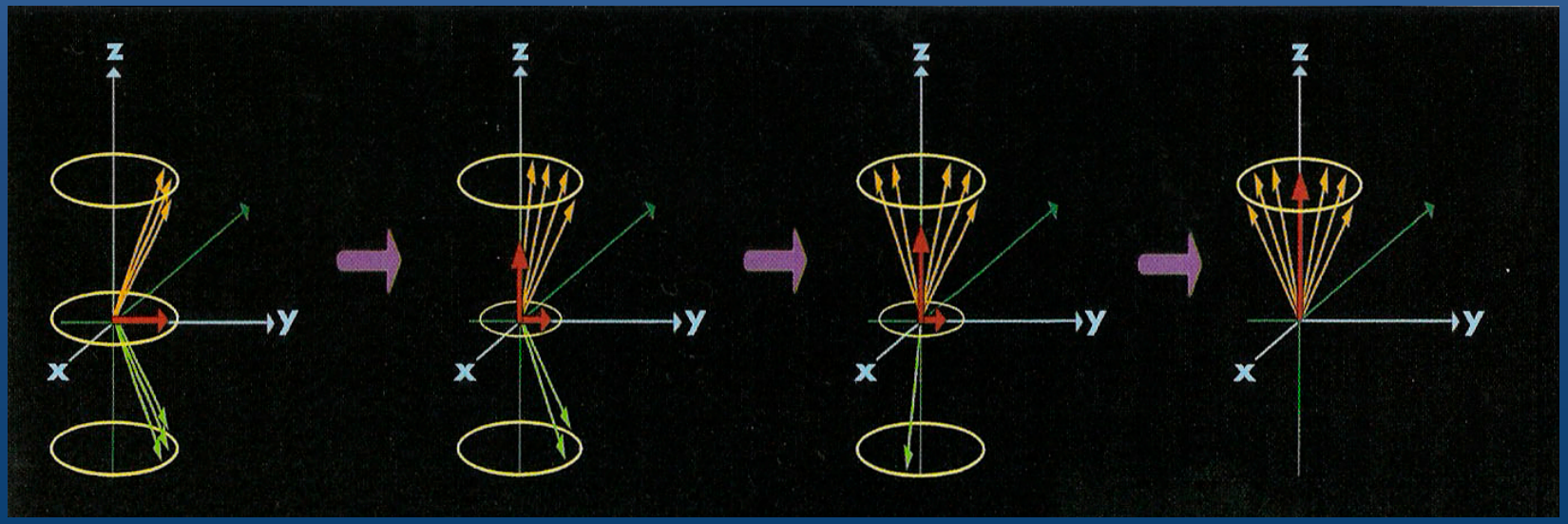


Magnetic Resonance Imaging (MRI)

- Based upon manipulating small magnetic field around nucleus of hydrogen atoms
- H atoms align in MRI strong magnetic field
- Radio frequency pulses applied and absorbed by H nuclei as they lose alignment
- Gradually relax back into alignment, releasing energy in a characteristic pattern depending on tissue type
- Coils detect released energy, convert to electrical signal, and processed by computer

Pulse and Relaxation





MRI

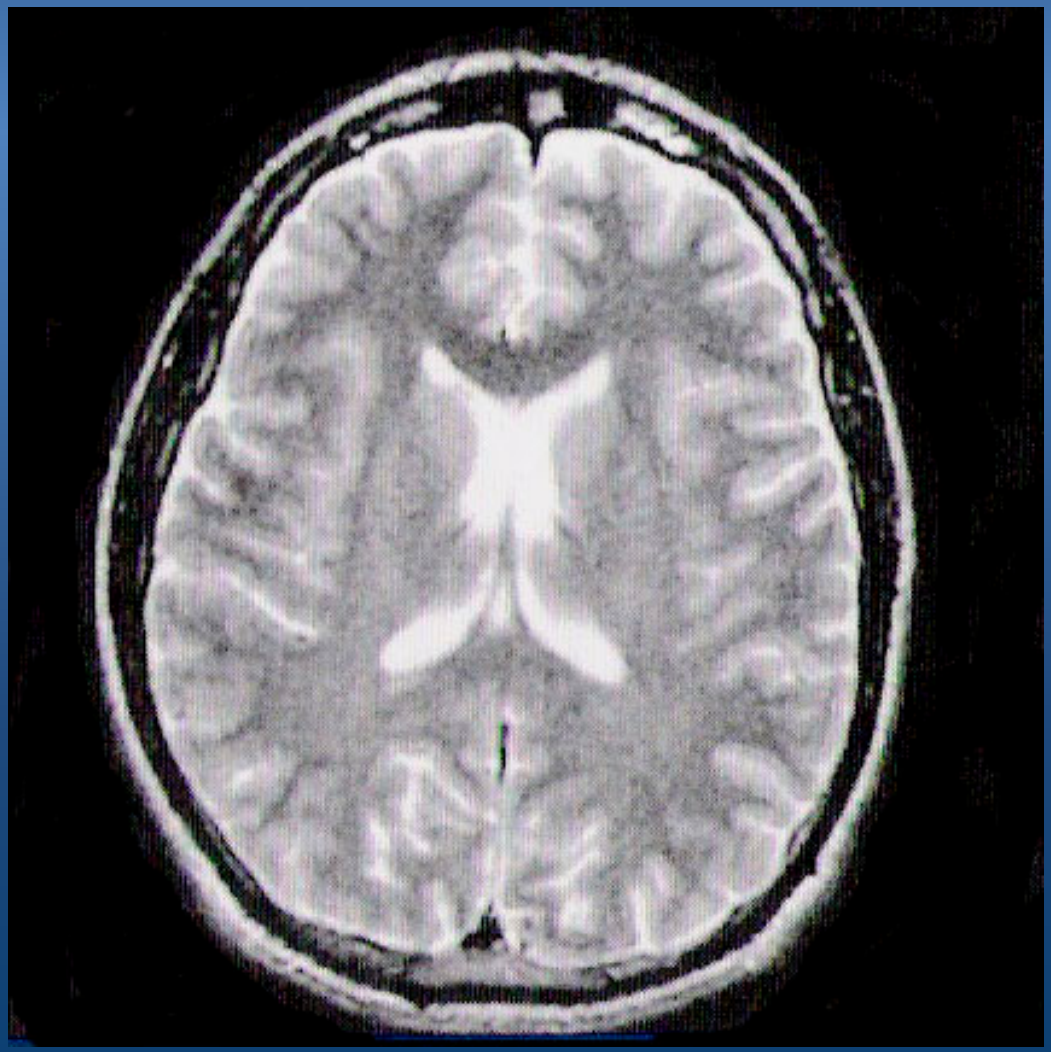
- RF and magnetic field pulses manipulated to create different pulse sequences
- Pulse sequences with different sensitivities to different aspects of H atom behavior, yielding unique information about tissue
- Examples: T1, T2, FLAIR, GE, DWI

T1 Weighted MRI

- Best for visualizing normal neuroanatomy
- Sharp boundaries between grey matter, white matter, and CSF
- Bone white, white matter light grey, grey matter medium grey, water/CSF/air black

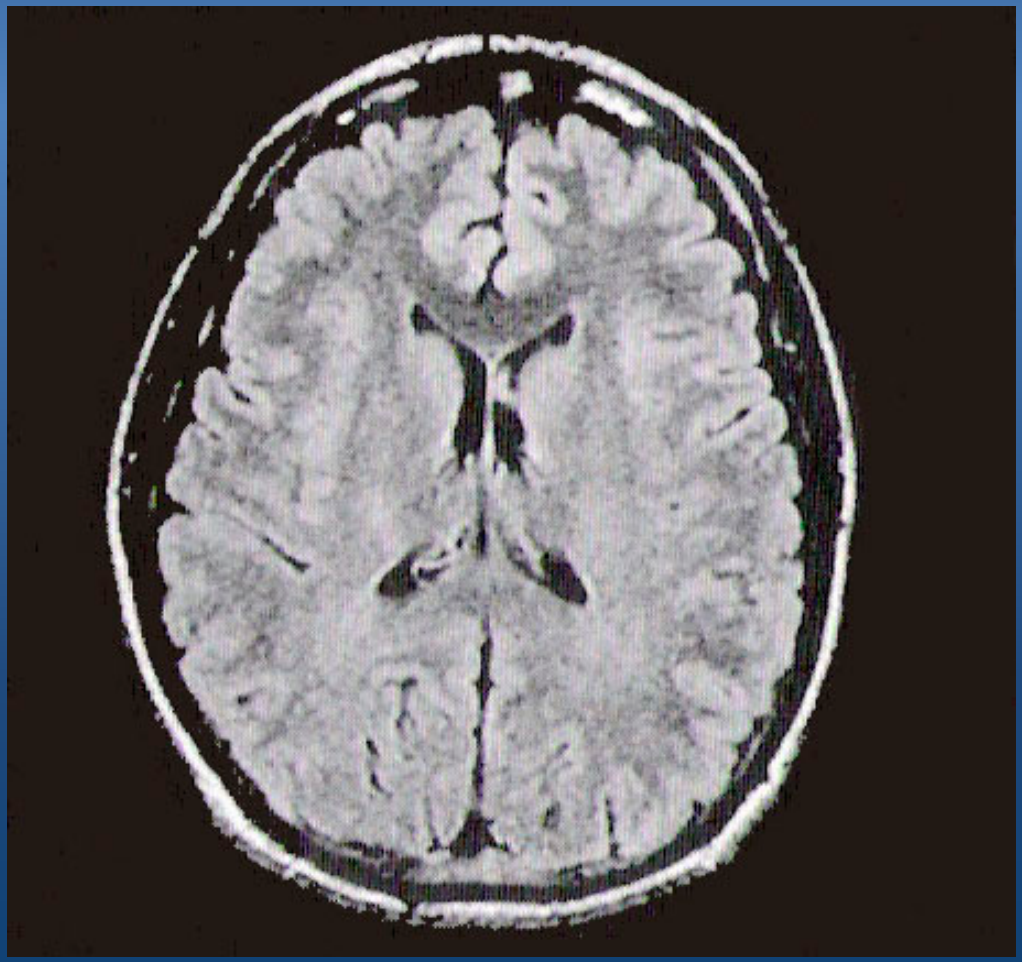
T2 Weighted MRI

- Less distinct boundaries between white and grey matter
- Best for displaying pathology
- Pathology appears bright, reflecting water/edema
- Gray matter medium gray, white matter dark grey, CSF and water white



Fluid Attenuated Inversion Recovery (FLAIR)

- Variant of T2 with intense CSF signal nullified
- Improved identification of subtle lesions; ideal for neuropsychiatric uses
- Easier to see pathology adjacent CSF-filled spaces



Diffusion-Weighted Imaging (DWI)

- Sensitive to speed of water diffusion
- Visualizes area of ischemic stroke in 1st few hours

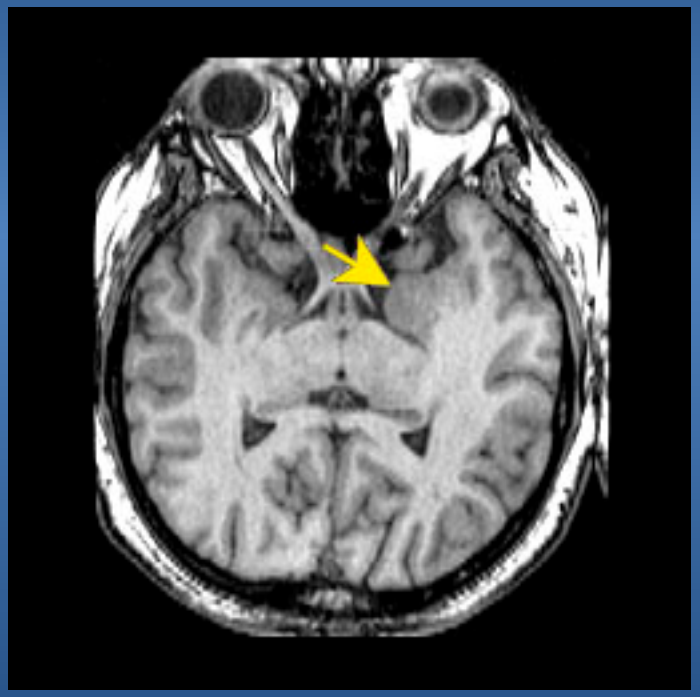
Gradient Echo (GE)

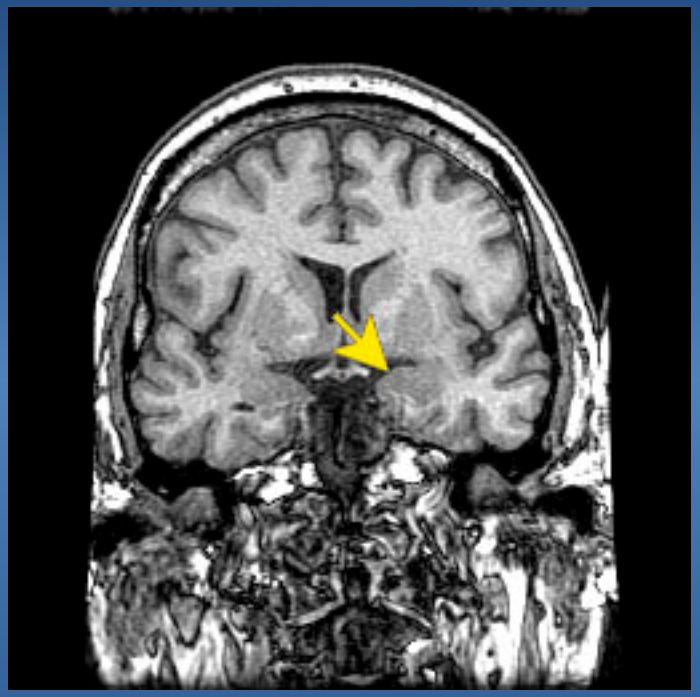
- Enhanced ability to detect fresh blood or chronic hematoma
- Acute and chronic hemorrhage as very low signal (black)

CT v. MRI

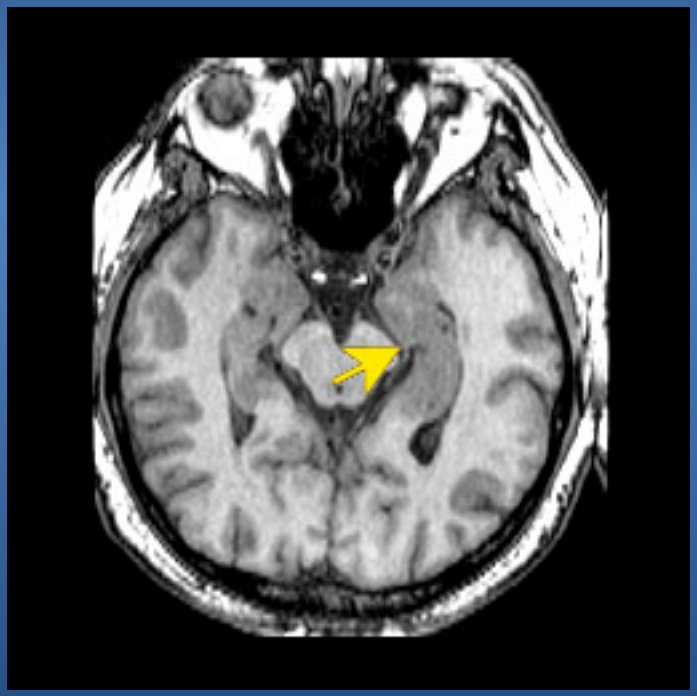
Table 1–10. Comparison of CT and magnetic resonance imaging (MRI)

	CT	MRI
Speed	Rapid acquisition time: full-body scan requires less than 3 minutes	Longer acquisition time: brain scan requires approximately 10 minutes
Cost	Relatively inexpensive	More expensive
Availability	Readily available at most U.S. hospitals	Less accessible
Spatial resolution	Up to 1 mm^2	Generally superior to CT
Contraindications	Radiation load limits use in pregnant women, children	Tighter gantry and longer acquisition time increase incidence of claustrophobia Electronic devices (pacemakers, nerve stimulators) are absolutely contraindicated Metal in body a relative contraindication
Clinical	Acute setting or medically unstable patient Status postacute head trauma Suspect: acute bleed, fractures, lytic lesions, mass effect, herniation, calcified lesions	Subacute or chronic setting Superior sensitivity for acute ischemic injury Suspect: ischemia, intraparenchymal or gray–white junction, white matter lesions, contusion, infection Superior posterior fossa and brain-stem visualization

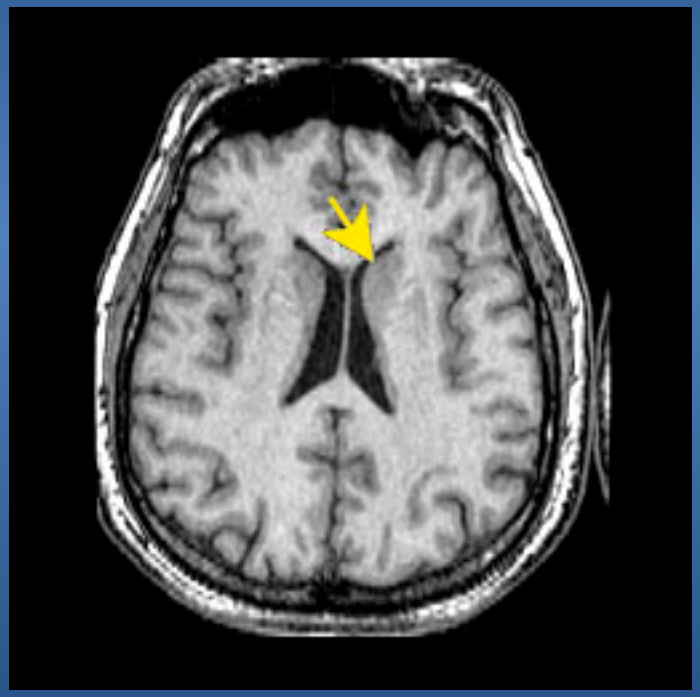


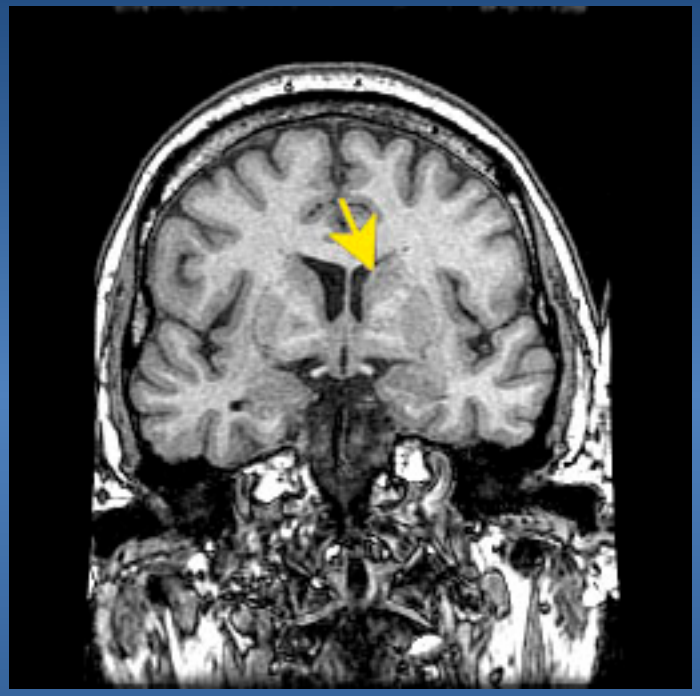


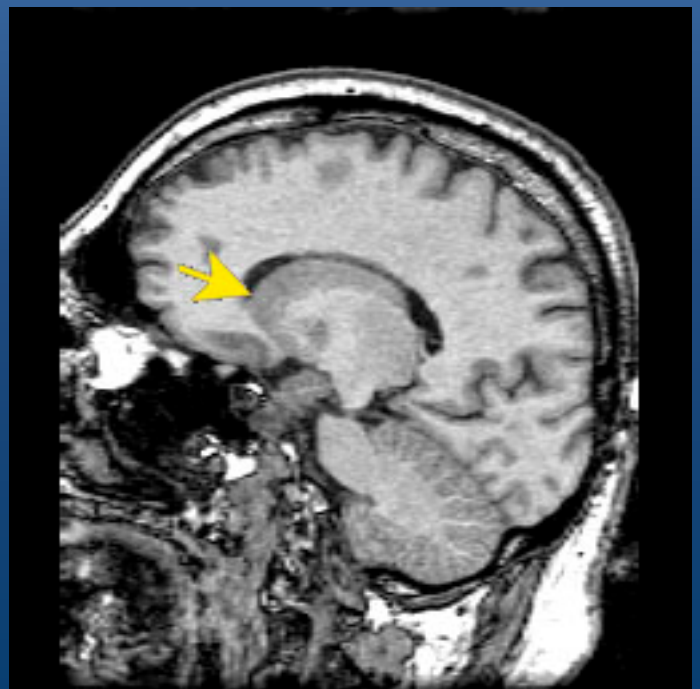
Amygdala



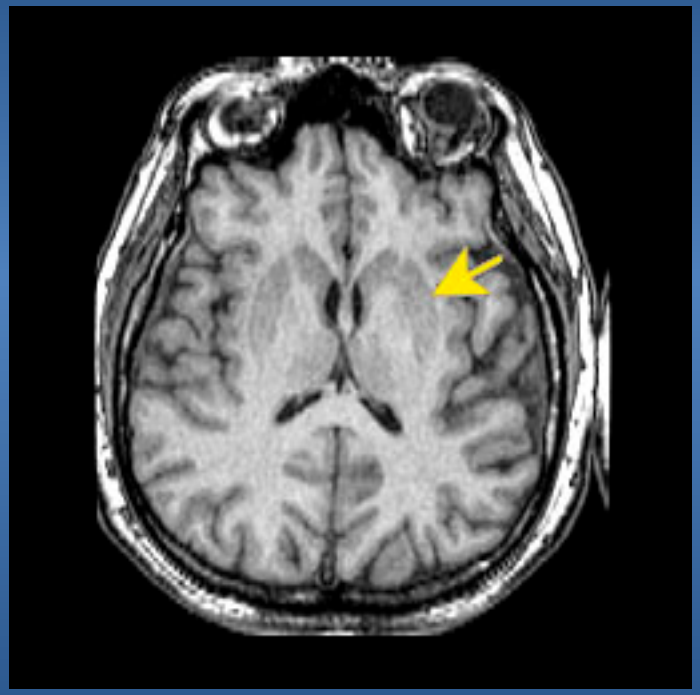
Hippocampus

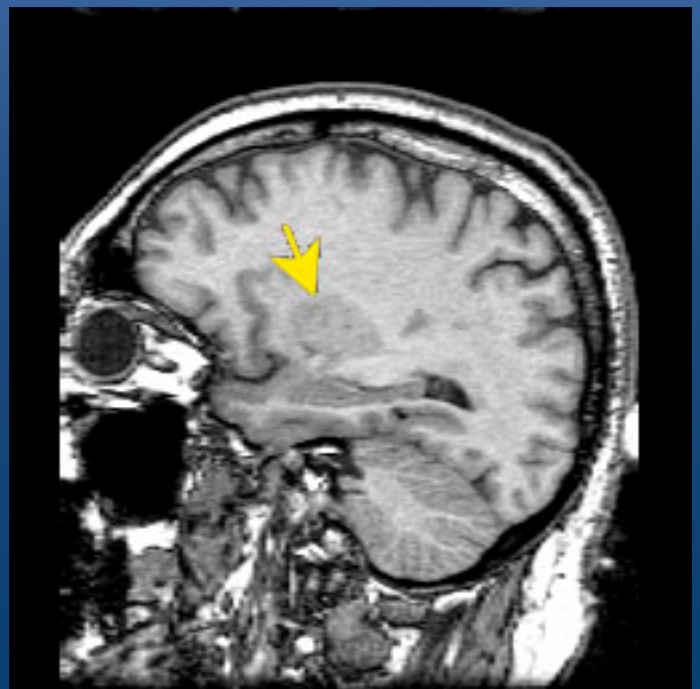




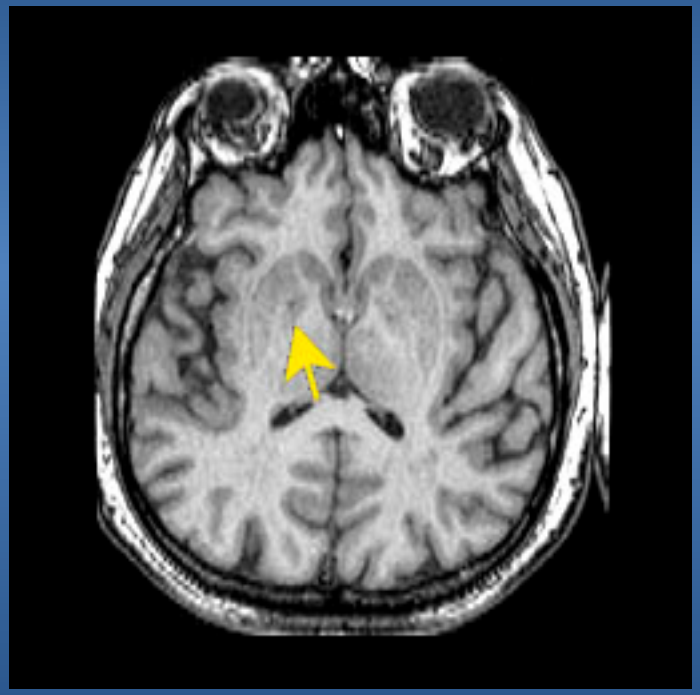


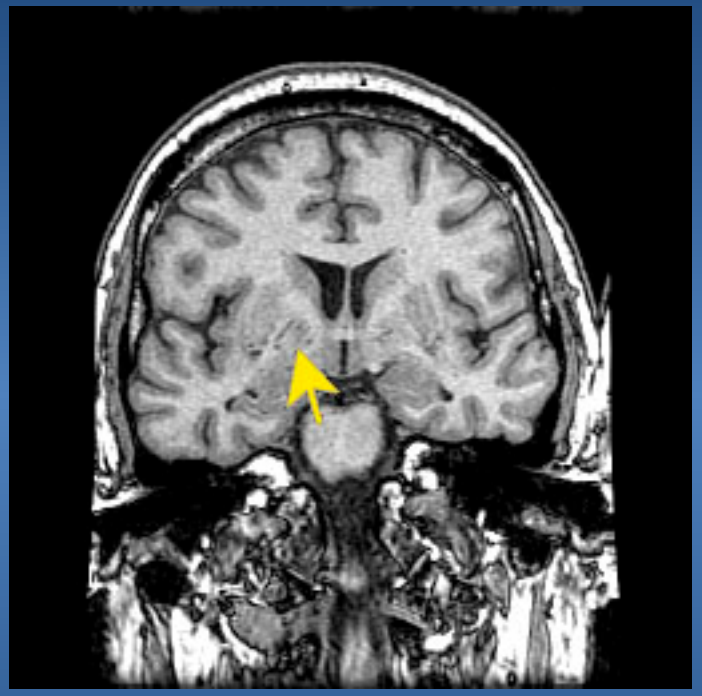
Caudate Head

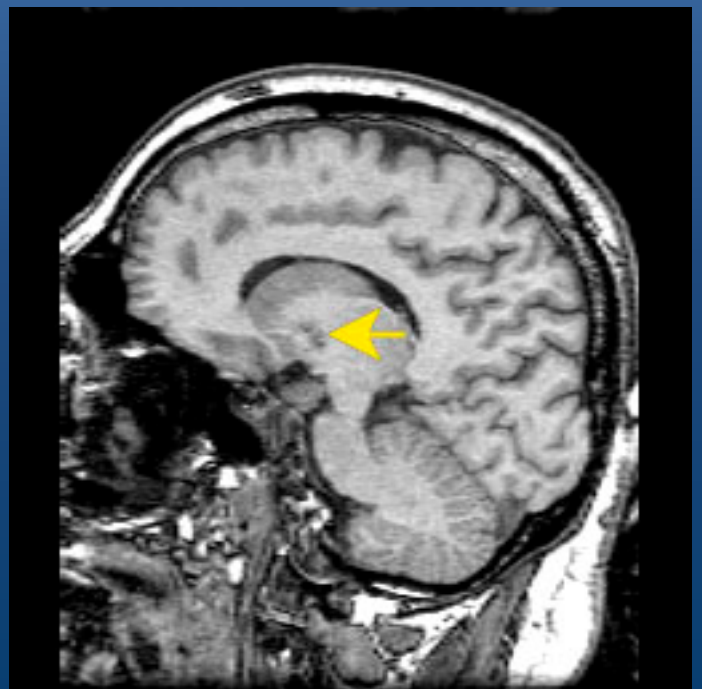




Putamen

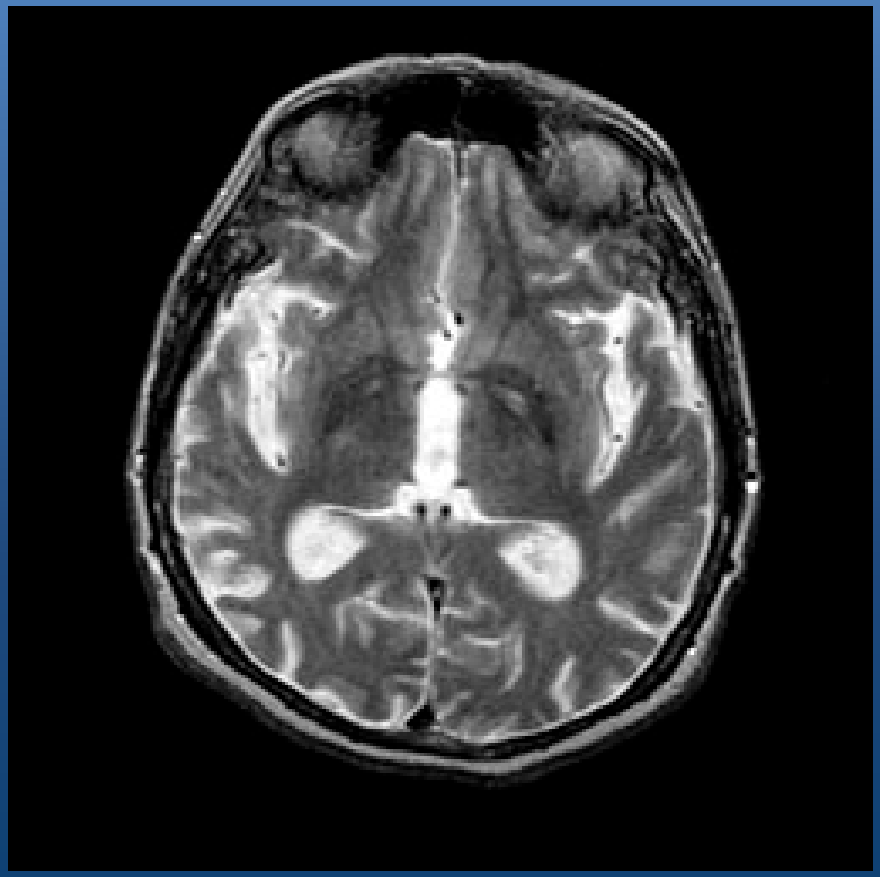


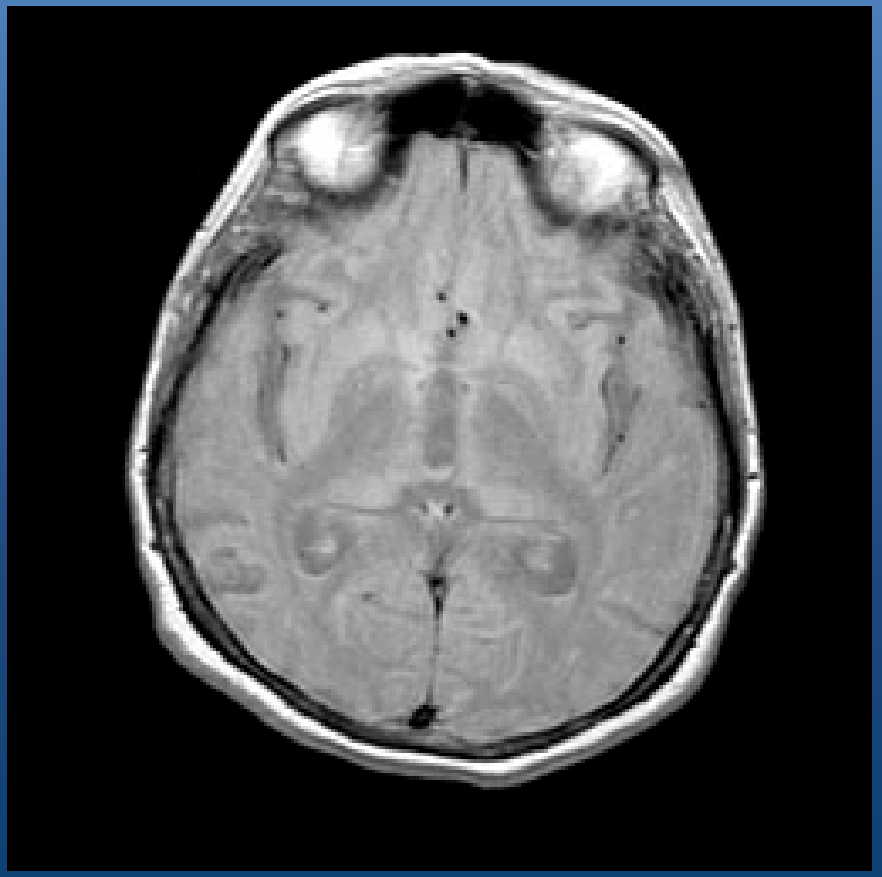




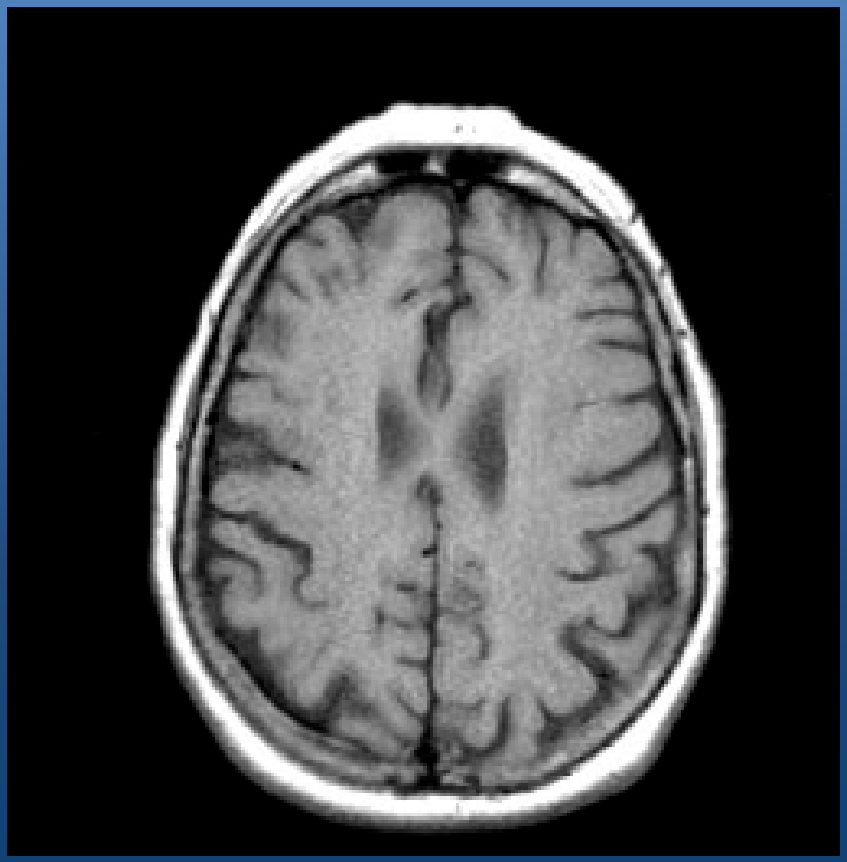
Globus
Pallidus

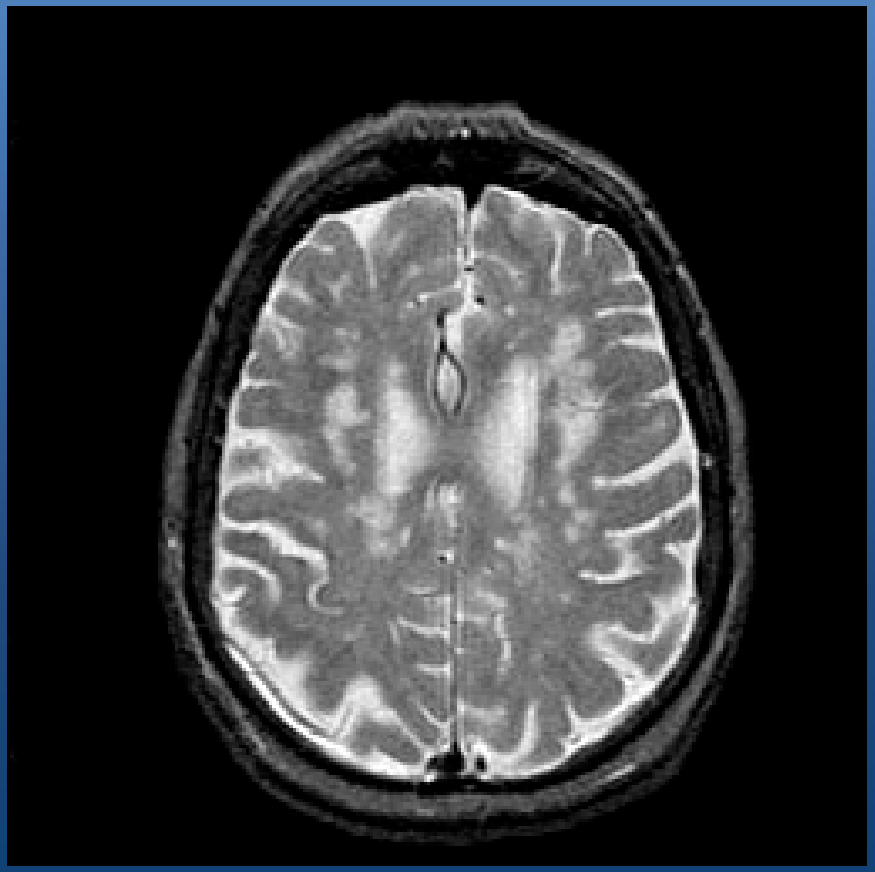
Alzheimer's Disease





Vascular Dementia





Gradient Echo (GE) MRI with Hemorrhage

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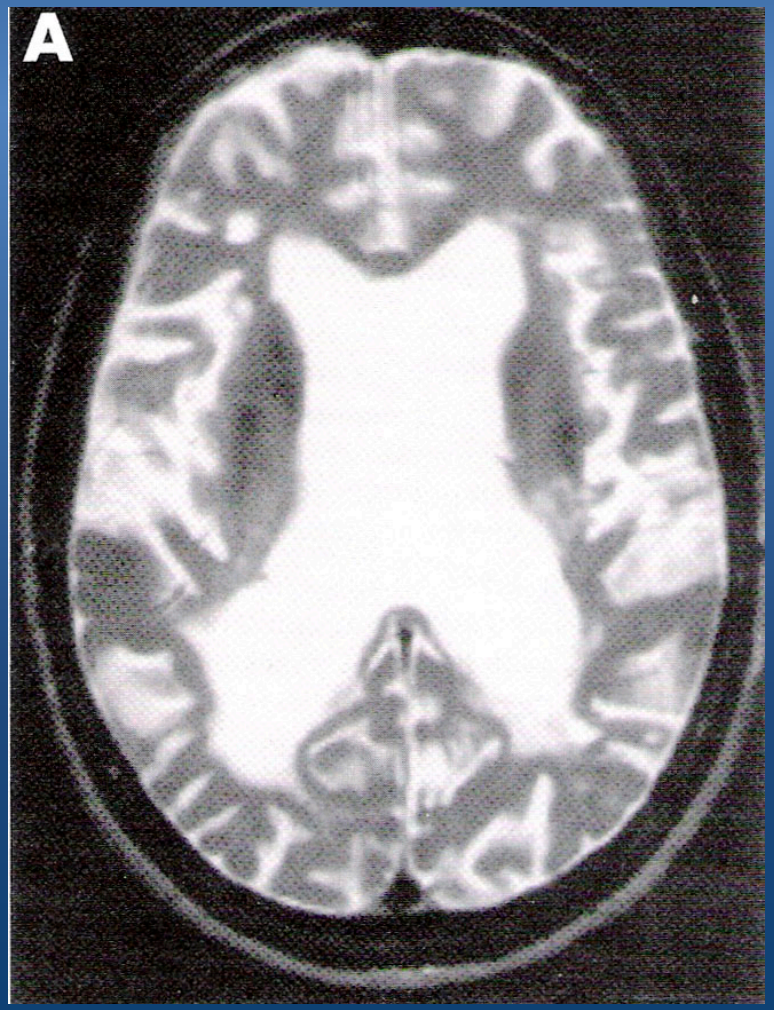
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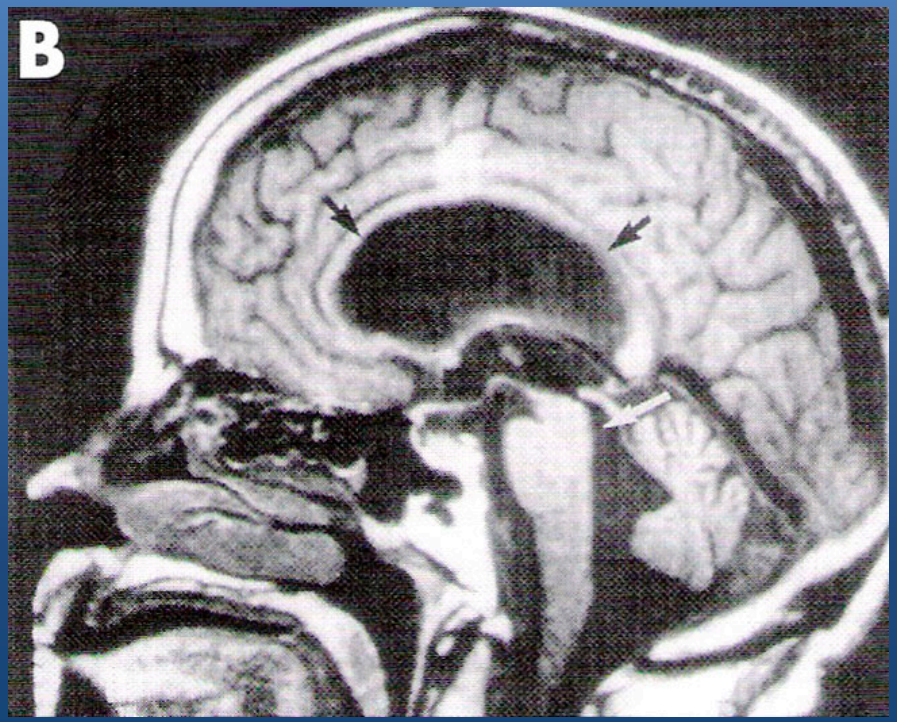
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A

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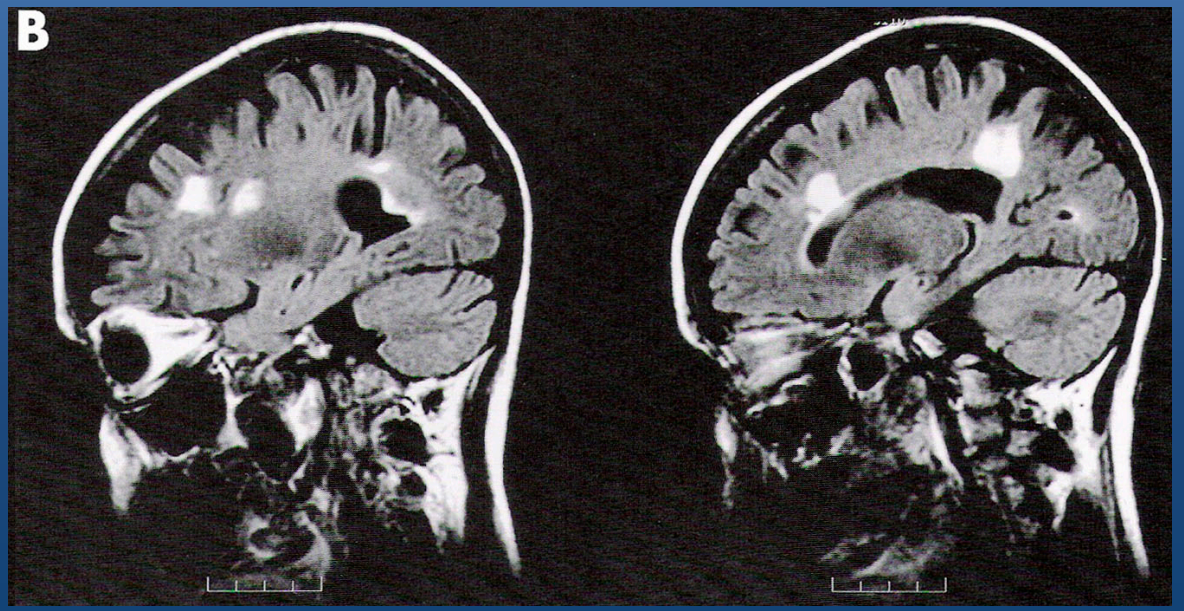
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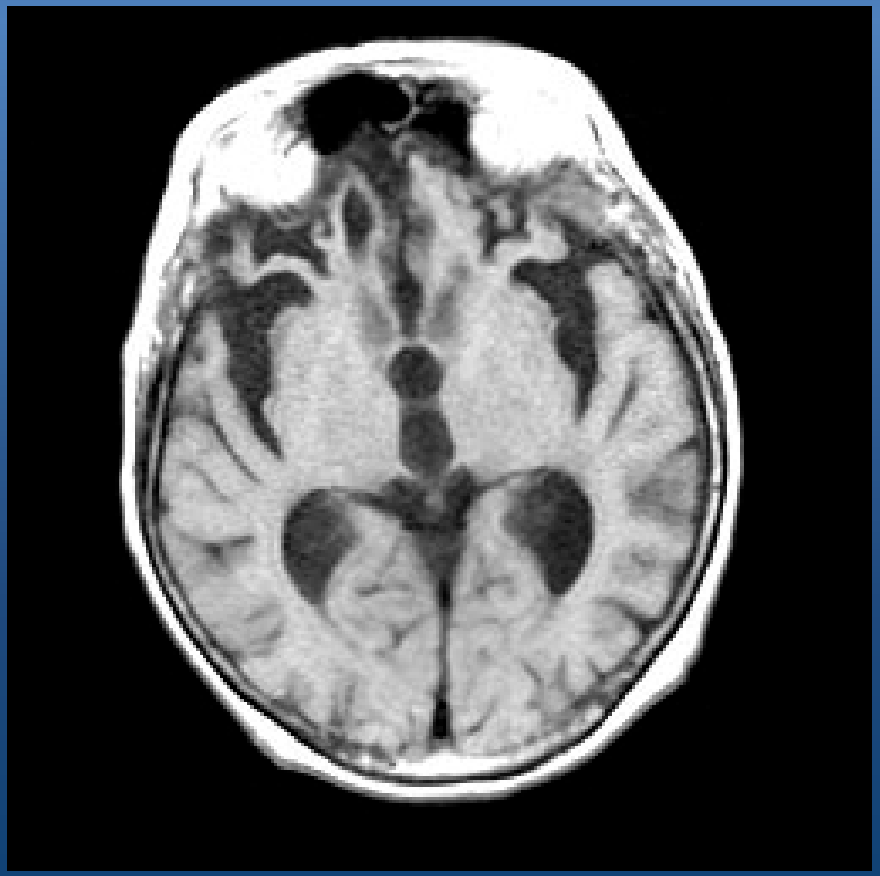

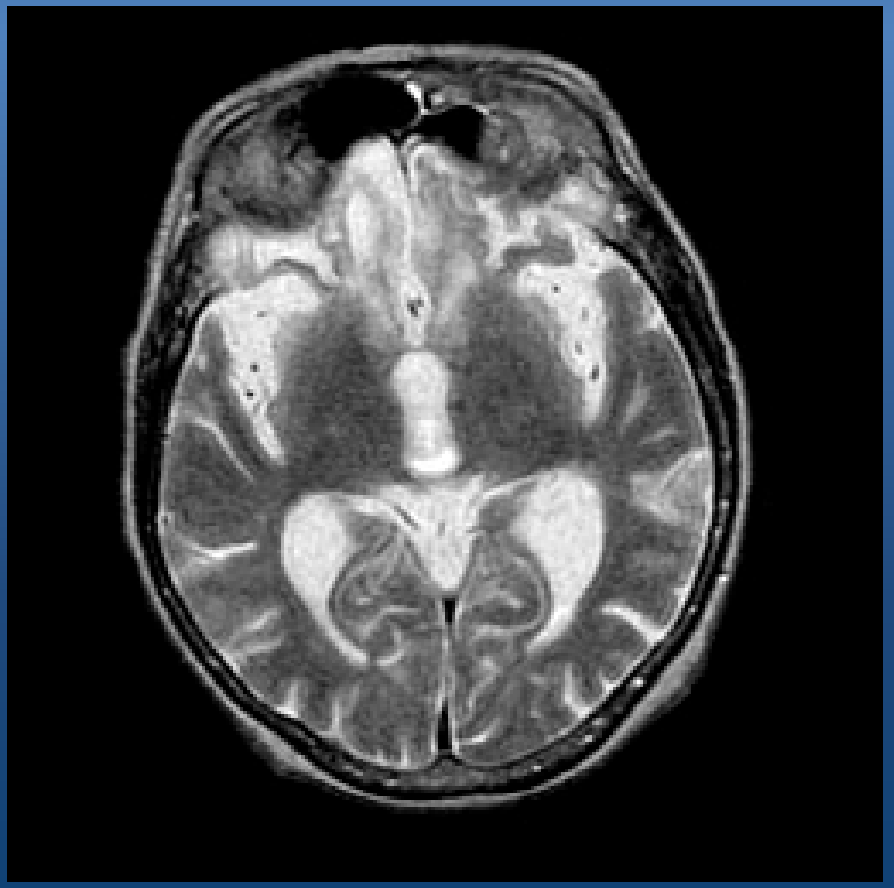

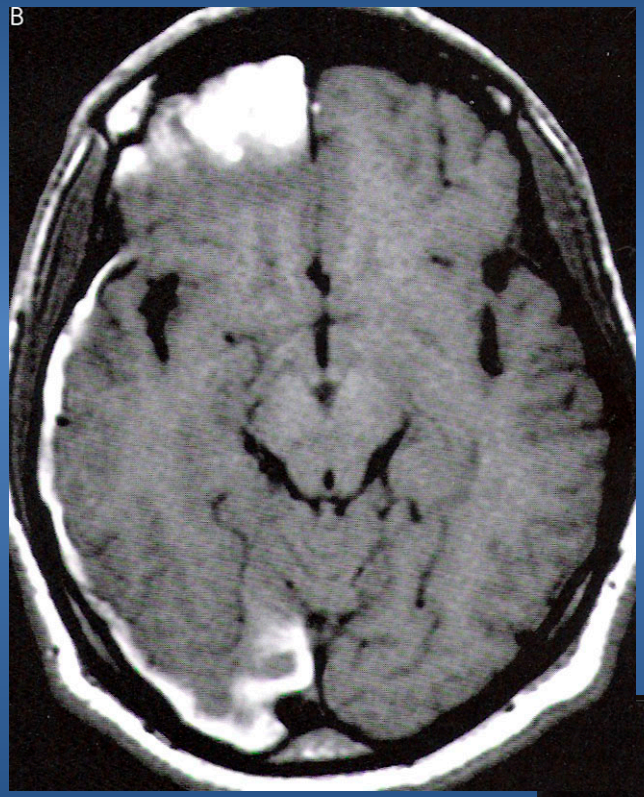
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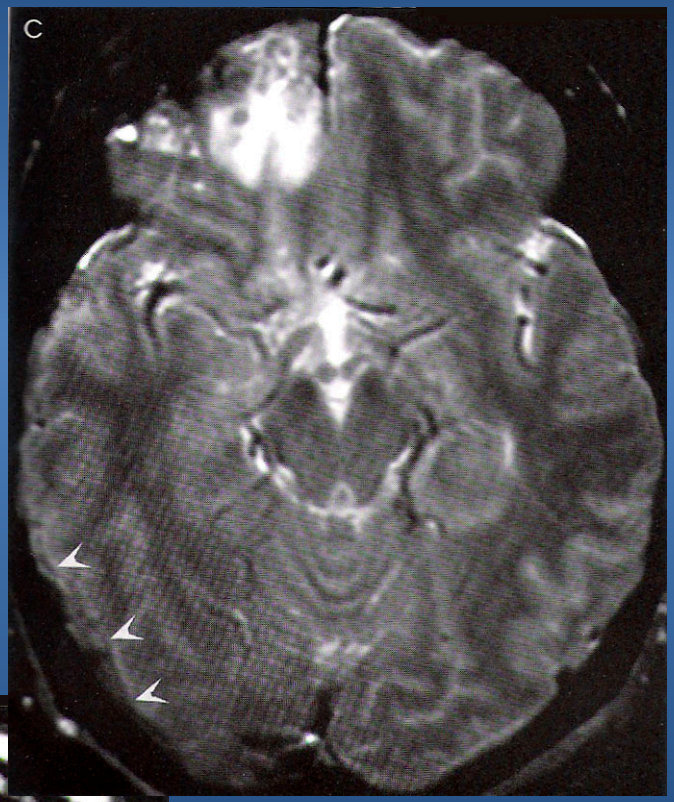
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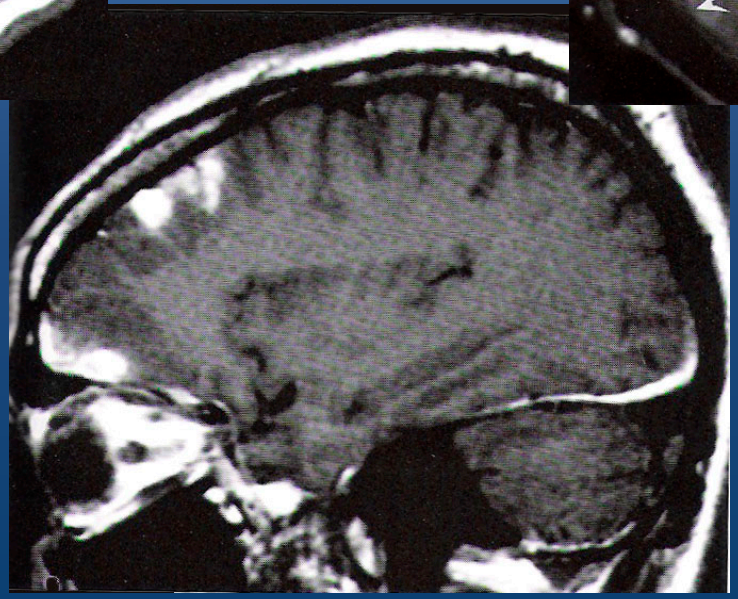

PET & SPECT

- Measure radioactive decay to create images of tissue function
- Unstable nuclides incorporated into desired molecules
- Emit photons as they return to more stable state
- Captured by detectors, processed by computer, to yield functional image of tissue

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PET & SPECT

- In principle, any function can be measured by labeling compound that crosses blood-brain barrier and interacts with relevant cellular machinery
- Blood flow
- Glucose Metabolism
- Neurotransmitter function

SPECT of rCBF in Alzheimer's Disease

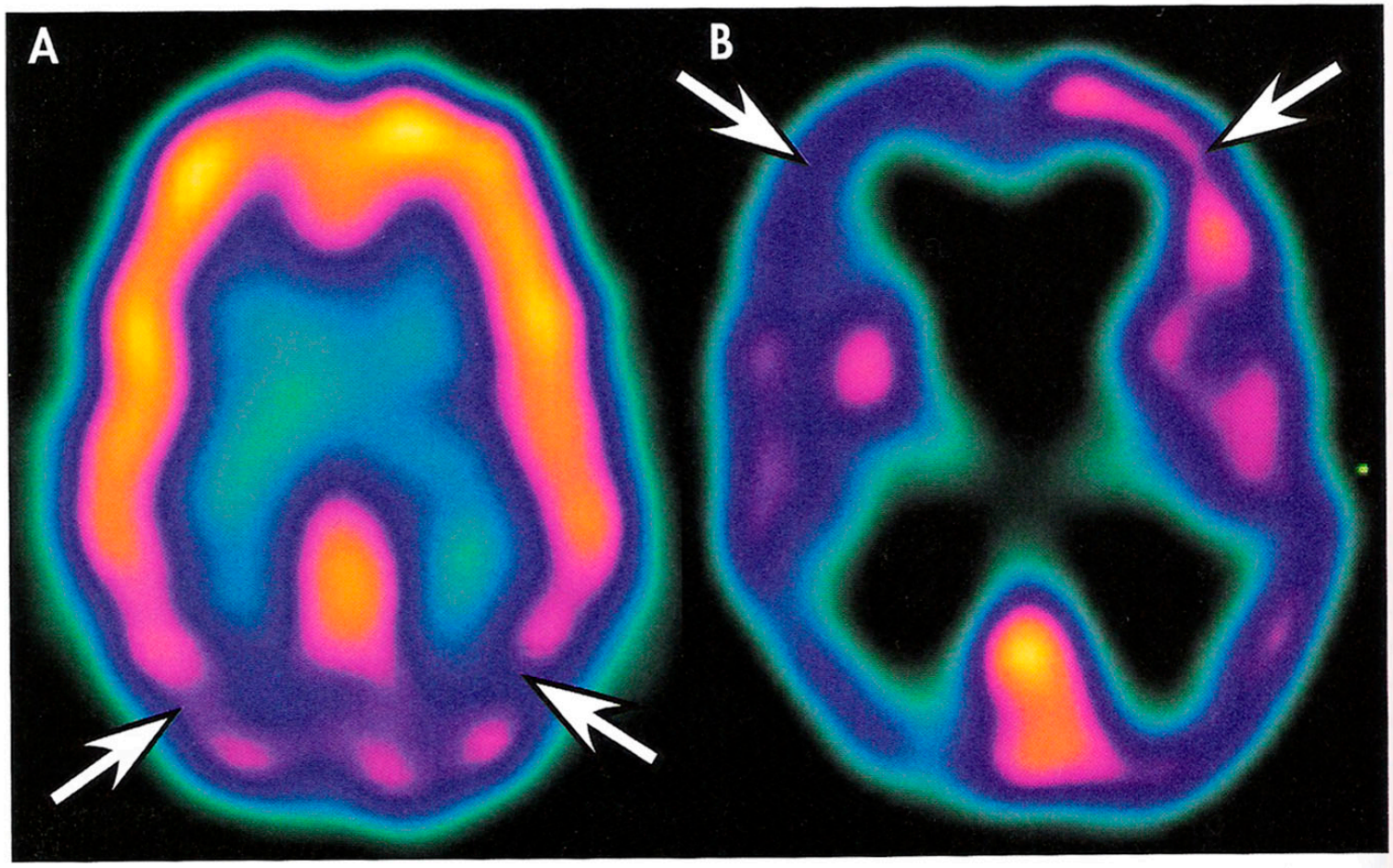


FIGURE 7–21. Regional cerebral blood flow (rCBF) in Alzheimer's disease. (*A*) As imaged here with single-photon emission computed tomography, rCBF is decreased in posterior temporoparietal cortex in early Alzheimer's disease (*arrows*). (*B*) As the disease progresses, frontal lobe involvement is common (*arrows*).

(Cummings and Mega, 2003)

SPECT of Epileptic Focus

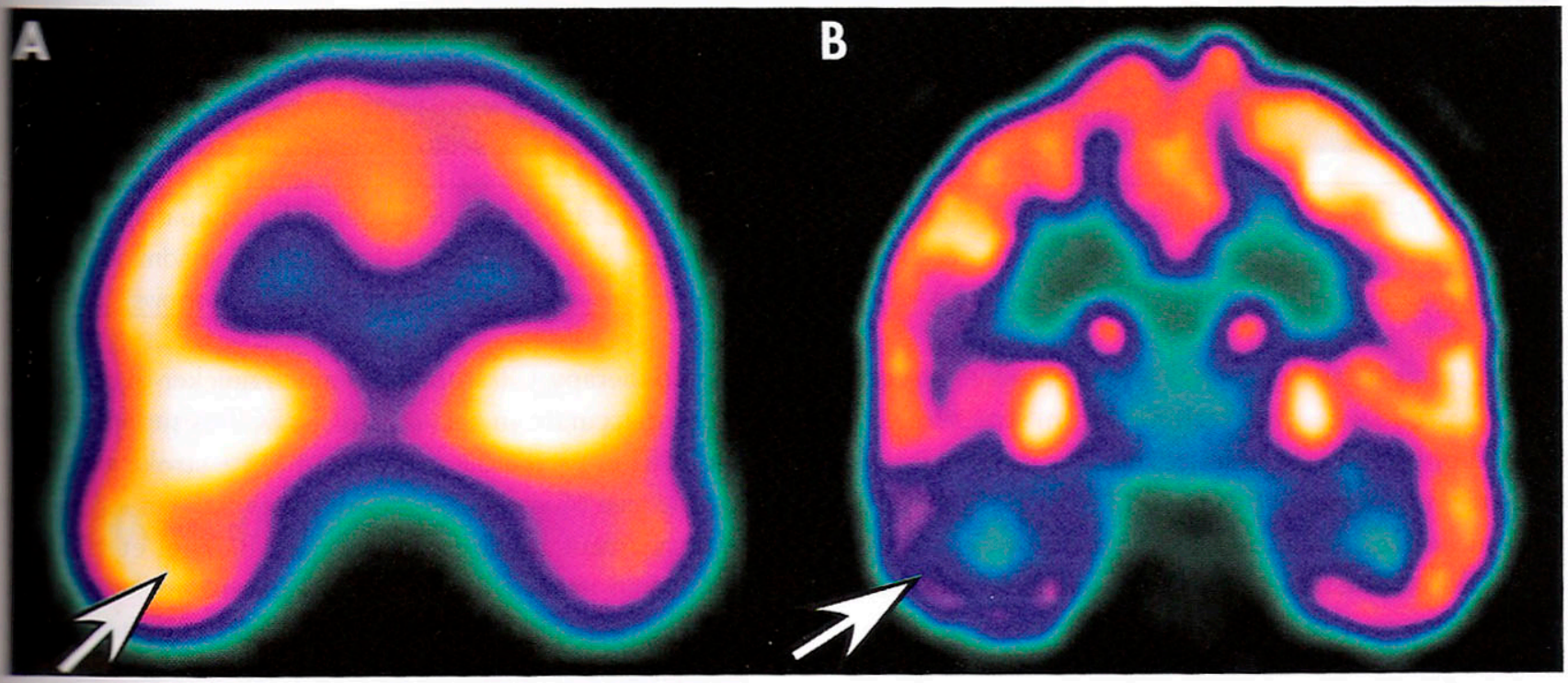


FIGURE 7–27. Nuclear medicine imaging is useful for visualizing the area of an epileptic focus. (*A*) Scans obtained during a seizure (ictal scan) will show increased perfusion or metabolism, as illustrated here with a coronal single-photon emission computed tomographic image of cerebral blood flow (*arrow*). (*B*) Scans obtained in the absence of seizure will show decreased perfusion or metabolism, as illustrated here with a coronal positron emission tomographic image of cerebral metabolism (*arrow*).

(Cummings and Mega, 2003)

PET of Glucose Metabolism in normal v. Alzheimer's Disease

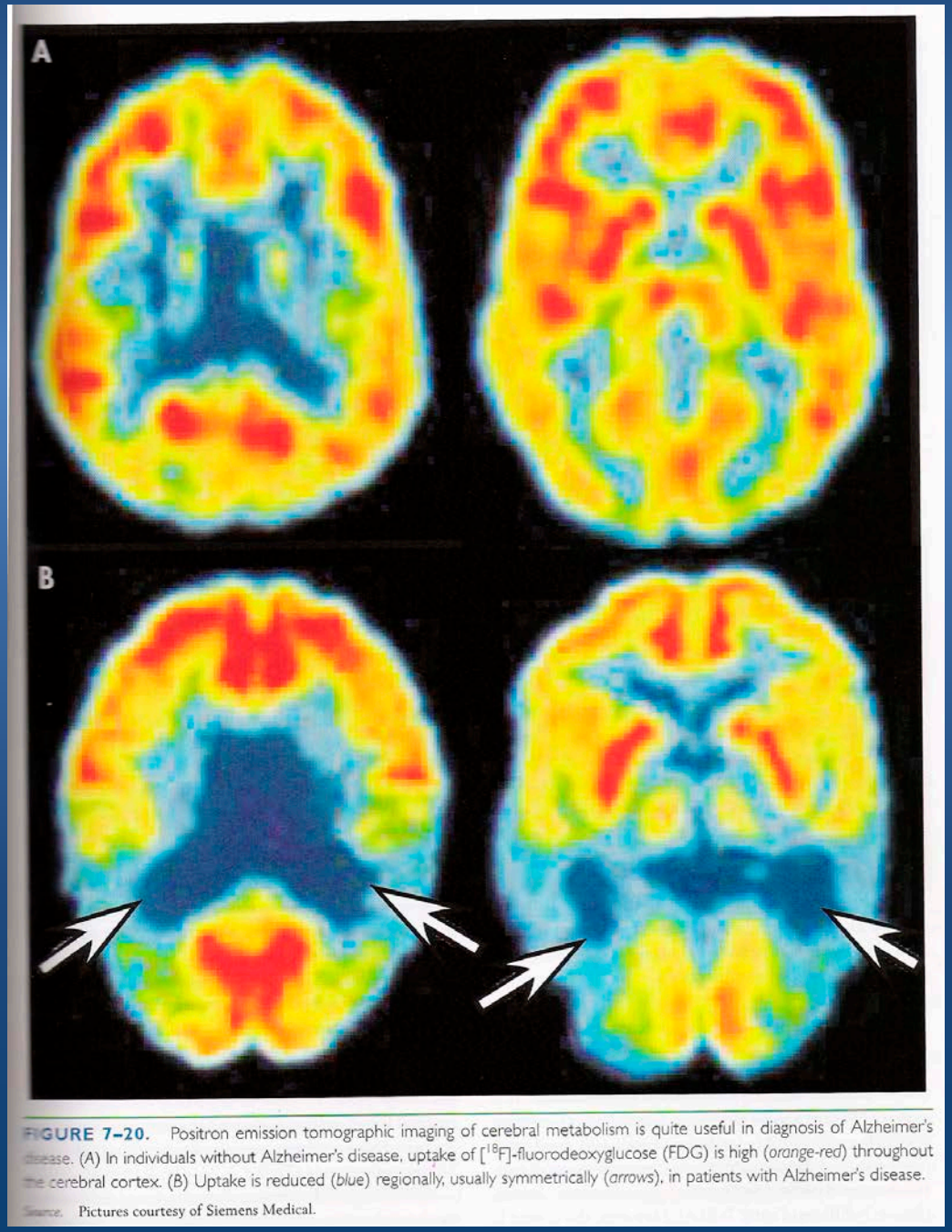


FIGURE 7–20. Positron emission tomographic imaging of cerebral metabolism is quite useful in diagnosis of Alzheimer's disease. (A) In individuals without Alzheimer's disease, uptake of [^{18}F]-fluorodeoxyglucose (FDG) is high (*orange-red*) throughout the cerebral cortex. (B) Uptake is reduced (*blue*) regionally, usually symmetrically (*arrows*), in patients with Alzheimer's disease.

Source. Pictures courtesy of Siemens Medical.

fMRI

- Based on modulation of image intensity by oxygenation state of blood
- Deoxyhemoglobin highly paramagnetic and distorts local magnetic fields
- BOLD (Blood Oxygen Level Dependent) image intensity based on local balance of oxygenated and deoxygenated hemoglobin
- A natural magnetic resonance contrast agent

fMRI

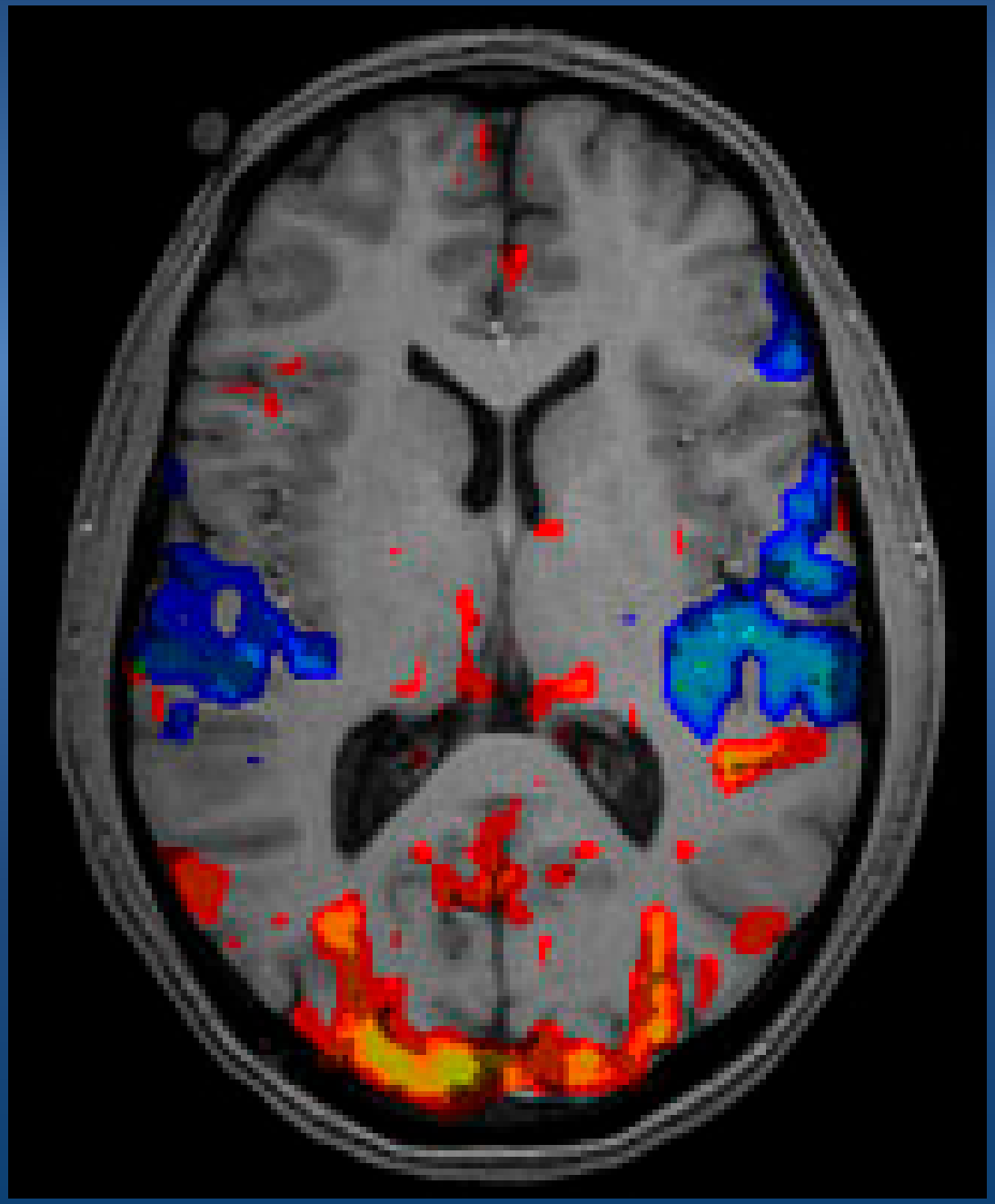
- Totally noninvasive with no ionizing radiation or radiopharmaceuticals
- With neural activity increase in blood flow exceeds oxygen needs, resulting in slight increase in venous oxygenation
- Increase detected by comparing signal intensity at baseline and activation
- Ideally, two scanning conditions differ only in cognitive function under study

fMRI

- Excellent spatial resolution
- Most MRI scanners can be modified for fMRI
- Subject to artifact, especially movement
- Data analysis remains time-consuming and controversial
- Should be considered a research technique, though a powerful one

fMRI:

- Activation with visual stimulus v. darkness



DTI

- Powerful and new tool for evaluating brain structure, especially white matter
- Exploits water's differential diffusion along versus across axons
- Provides information on axonal direction and integrity
- Images modified for sensitivity to water movement in different directions

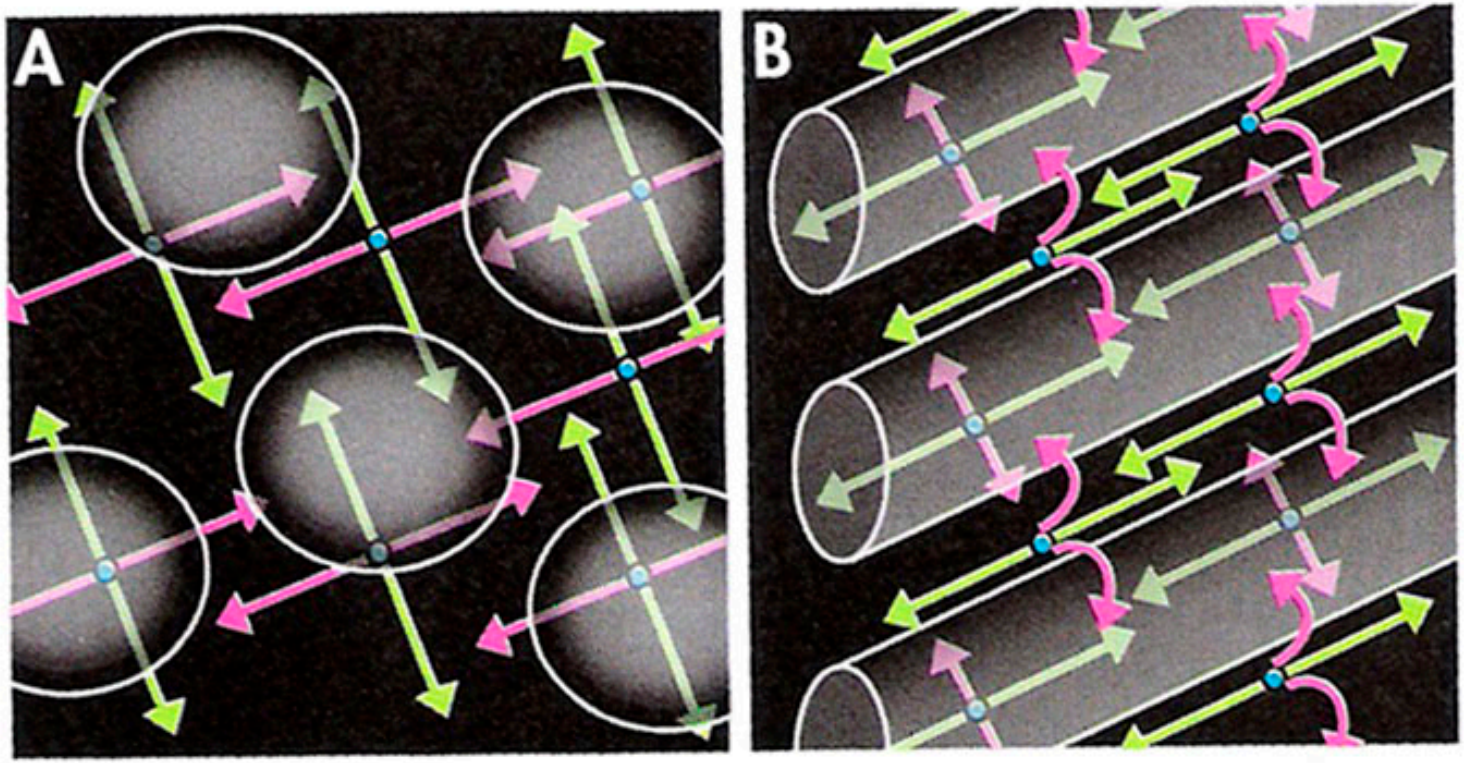


FIGURE 7–12. Gray matter contains cell bodies and processes and is quite heterogeneous. Water diffusion is the same in all directions (isotropic), as indicated by (*A*) the similar length of the green and pink arrows. White matter contains tightly packed axons. Water diffusion is faster (*B*, *green arrows*) along the length of (parallel to) axons than it is (*B*, *pink arrows*) across axons.

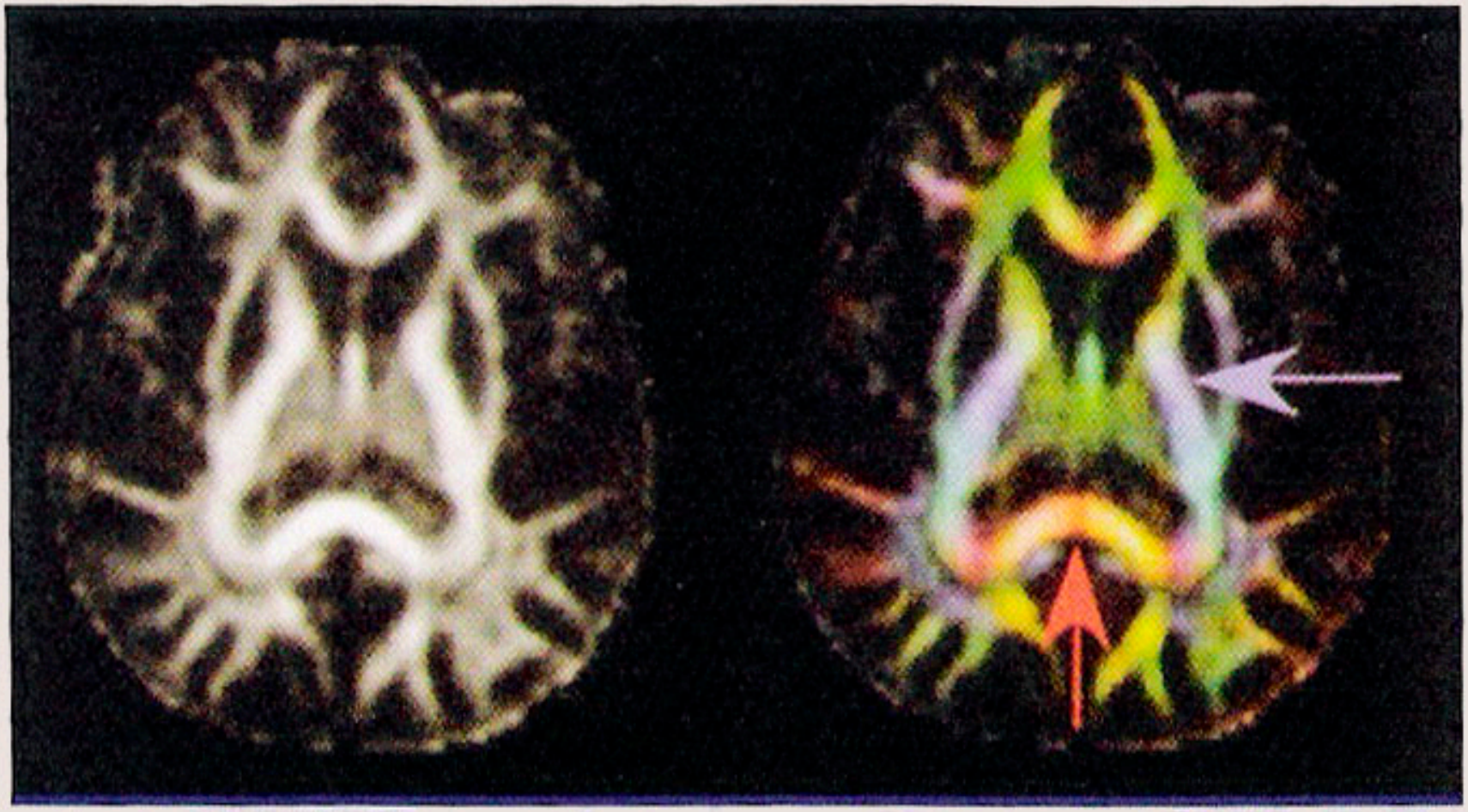


Figure 2–19. Diffusion tensor imaging (DTI). Anisotropy map *(left)* and color-coded DTI *(right)* of a healthy control subject.

MRS

- Noninvasive technique based upon same basic principles of nuclear MR
- Enables interrogation of tissues' chemical environment
- Provides relative quantification of particular compounds and their constituents
- Most current MR involves ^{1}H (proton MR)

MRS

- In vivo measurement of psychoactive drugs in the human brain (Li+)
- In vivo measurement of GABA levels
- Observe changes induced by experimental agents, explore mechanisms of action, develop new medications
- Characterize neurochemical effects in a specific brain area and help evaluate treatment efficacy

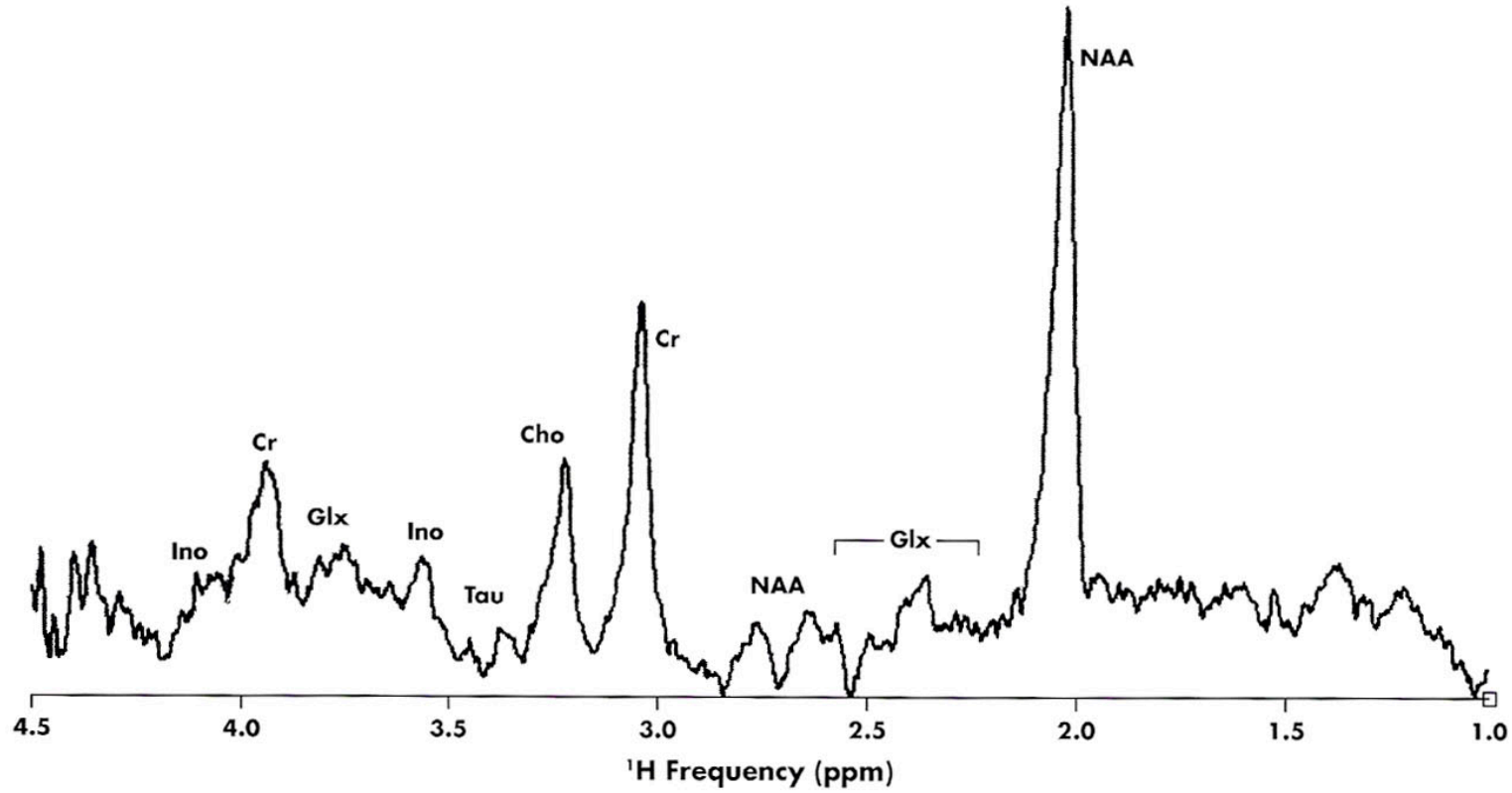


Figure 5–1. Proton spectrum recorded on a 4-tesla magnetic resonance scanner of brain tissue in vivo from a healthy 21-year-old man.

Point-resolved spectroscopy (PRESS) recording from a 6-mL volume localized in the motor cortex, right hemisphere; volume size=6 mL, echo time=23 msec, repetition time=3000 msec, 64 averages. Apodization with line broadening of 2.5 Hz applied. Abbreviations for peaks: Cho=choline compounds (choline, phosphocholine, glycerophosphocholine); Cr=creatine and phosphocreatine; Glx=spectral region of peaks for glutamate, glutamine, and GABA; Ino=myoinositol; NAA=*N*-acetyl-aspartate; Tau=taurine.

MEG

- Magnetoencephalography records magnetic fields produced by intraneuronal electric current
- Right-hand rule
- Magnetic fields essentially unaffected by scalp and skull
- Better for deep-brain sources
- Detects tangential current sources, neurons in sulci running parallel to scalp

MEG

- Good localization (relative to EEG) and temporal resolution
- Magnetic source imaging combines MEG and MRI, used to evaluate seizure foci
- Expensive shielding required to contend with ambient magnetic noise; Earth’s field billionfold stronger
- Essentially research tool at present

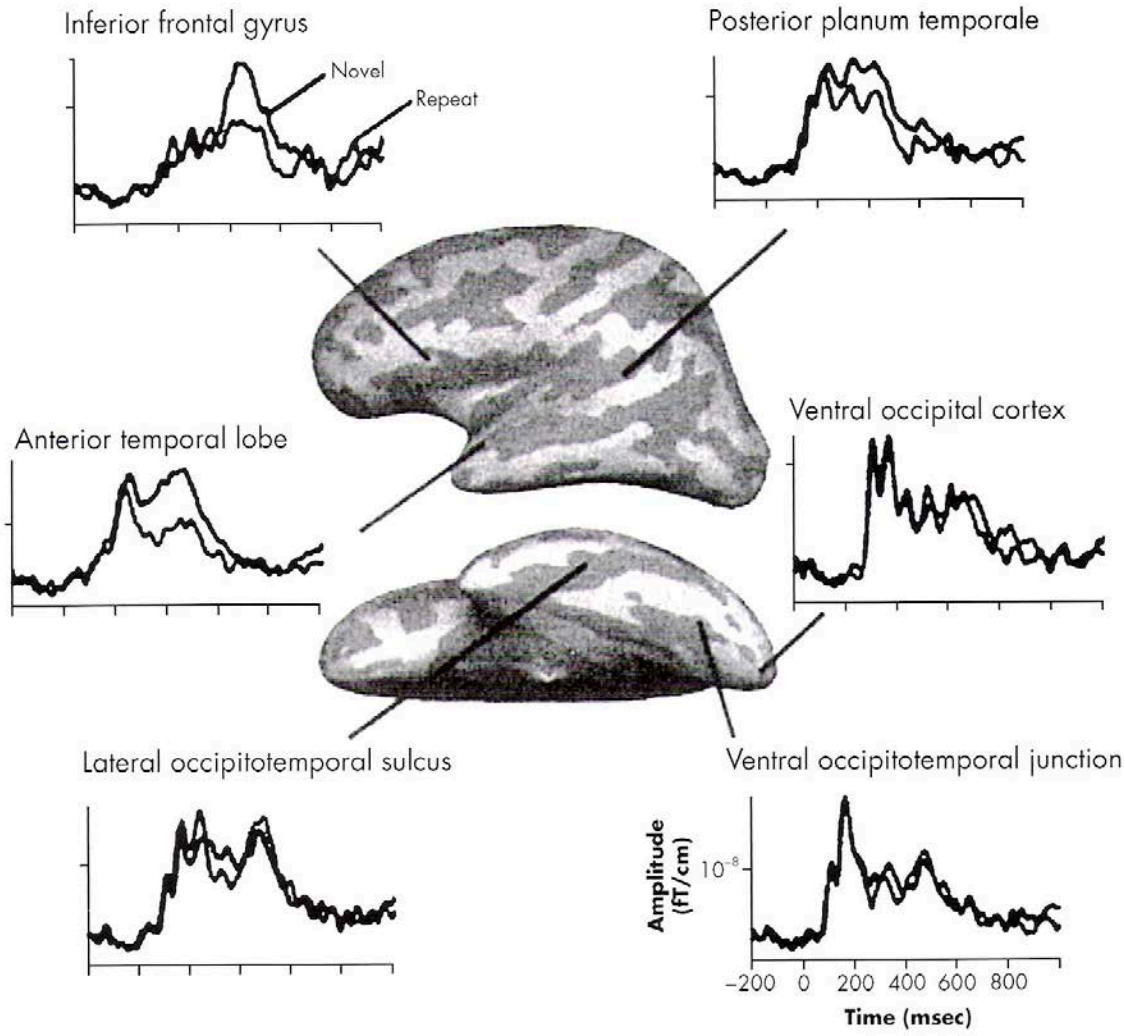


Figure 6–4. Time courses of MEG data at selected brain locations.
Waveforms show activity in response to words that are novel or repeated during a word-stem completion task. Occipital regions are activated early and do not change with repetition, whereas more anterior regions activate later and show strong replication effects.

Source. Reprinted from Dhond RP, Buckner RL, Dale AM, et al.: "Spatiotemporal Maps of Brain Activity Underlying Word Generation and Their Modification During Repetition Priming." *Journal of Neuroscience* 21(10):3564–3571, 2001. Copyright 2001, The Society for Neuroscience. Used with permission.

QEEG

- Provides information that cannot be extracted by visual inspection
- Potentially enhances intra- and interrater reliability
- Absolute power- measure of energy intensity in frequency bands
- Coherence- measure of phase consistency of two sources

QEEG

- Pharmaco-electroencephalography: QEEG use to detect drug-induced changes
- Potential uses in drug development and early prediction of clinical response
- Somewhat controversial; more research is needed
- ANPA's research committee (2006):
  "As a clinical laboratory test, qEEG's cautious use is recommended in attentional and learning disabilities of childhood, and in mood and dementing disorders of adulthood."

Evidentiary Usefulness is Specific to the Imaging Modality and Condition Being Studied

For instance, Cerebral SPECT imaging for mTBI…

Wortzel HS, Filley CM, Anderson CA, Oster TJ, Arciniegas DB: Forensic Applications of Cerebral Single Photon Emission Computed Tomography in Mild Traumatic Brain Injury. Journal of the American Academy of Psychiatry and Law 36(3):310-22, 2008

Basic Biostatistics Terms

- Sensitivity: probability that test is positive if patient has the disease
- Specificity: probability of negative test result given patient does not have the disease
- Positive Predictive Value: probability that patient has the disease given a positive test result
- Negative predictive Value: probability the patient is free of the disease given a negative test result

Related Opinions

- Society of Nuclear Medicine Brain Imaging Council…
- "The forensic application of nonreplicated, unpublished or anecdotal SPECT or PET observations is inappropriate and has ominous implications. This can lead to unsupportable conclusions if introduced as objective evidence."
- Given lack of evidence and need to testify with "reasonable medical certainty" SPECT evidence is seldomly appropriate

Related Opinions

- Mayberg (1996)
  - Inability to establish relationships between patterns and specific illness
  - Even greater difficulty linking patterns to specific neuropsychiatric signs and symptoms
  - Until relationships are established, forensic applications of functional imaging neither scientifically justified or legally permissible

Related Opinions

- Reeves et al. (2003)
  - Technological aspects of modern imaging are inaccessible to many experts and laypersons and potential source of misguidance
  - Color-coding: seemingly simple choice that may be easily manipulated to create illusions of contrast
  - SPECT may offer more in the way of jury seduction than clinical science

Must engage this literature critically and with appreciation for higher legal standards for evidentiary usefulness...

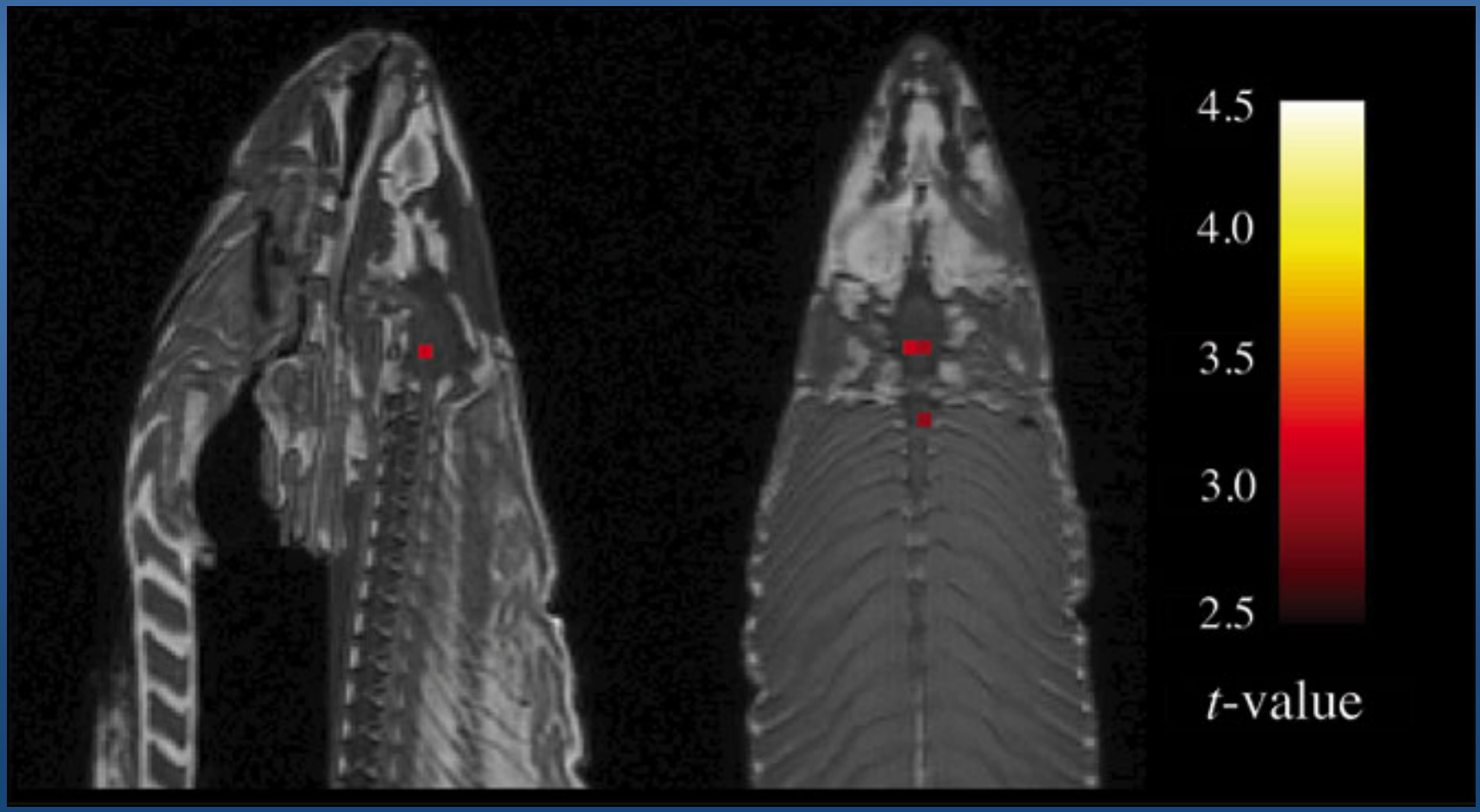
An Analysis of Regional Cerebral Blood Flow in Impulsive Murderers Using Single Photon Emission Computed Tomography

The authors explored differences in regional cerebral blood flow in 11 impulsive murderers and 11 healthy comparison subjects using single photon emission computed tomography. The authors assessed subjects at rest and during a computerized go/no-go concentration task. Using statistical parametric mapping software, the authors performed voxel-by-voxel t tests to assess significant differences, making family-wide error corrections for multiple comparisons. ***Murderers were found to have significantly lower relative rCBF during concentration, particularly in areas associated with concentration and impulse control. These results indicate that nonemotionally laden stimuli may result in frontotemporal dysregulation in people predisposed to impulsive violence.***

Consider the results in light of the methods...

Of the 11 in the under 30 group, eight had a history of drug abuse, Including cocaine, marijuana, methamphetamine, heroin, ecstasy, and alcohol; three reported prior head Trauma without loss of consciousness; two had a history of physical abuse; one had received a diagnosis of schizoaffective disorder prior to seeking a scan, and one had been treated for bipolar disorder prior to seeking a scan. Three subjects had been taking tricyclic antidepressants leading up to the time of their scans (one of whom was also taking benztropine), and one had been taking a serotonin and norepinephrine reuptake inhibitor (SNRI); these subjects had been off of their medications with an appropriate wash-out period prior to their scans (tricyclic antidepressant washout15 days; SNRI washout 4 days). One other had previously been on a selective serotonin reuptake inhibitor (SSRI). One subject was scanned while taking an antipsychotic.

Error?



Scanning Dead Salmon in fMRI Machine Highlights Risk of Red Herrings

N of 1

Who was violent?

Thanks Dr. Filley!

Not a New Problem…

- Not just forensic contexts, but "commercialization" for clinical purposes
- Adinoff and Devous (2010) argue early misapplications of neuroimaging, if left unchallenged, may poison the waters…
  - ***"Unfortunately, if previously led astray by unsupported claims, patients and their doctors may be less inclined to utilize scientifically proven approaches once these are shown in the peer-reviewed literature to be effective. It is therefore incumbent upon all of us to monitor and regulate our field. We encourage physicians to remain vigilant of unproven approaches practiced by our peers and to immediately report these trespasses to their state medical boards.***"
- Litigation, with adversarial environment and compensation issues, can lead to early transgressions… charge issued to preserve the scientific merit of emerging technologies must fall to forensic psychiatrist/psychologist too

Forensic Applications

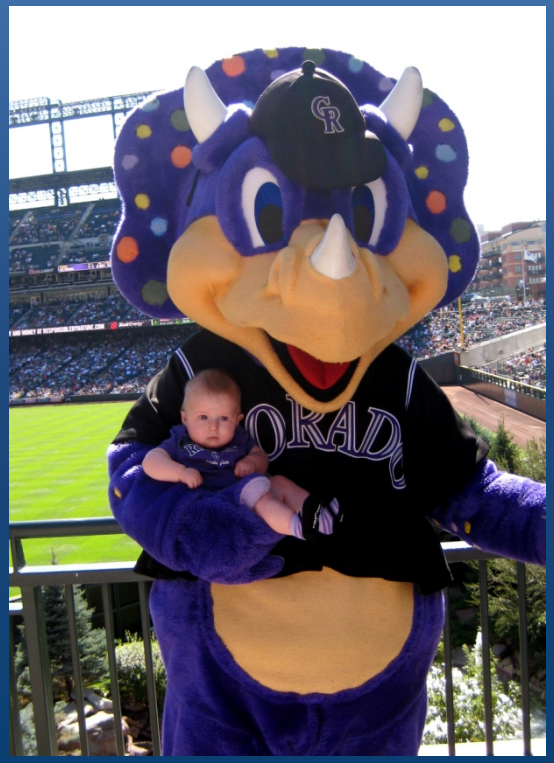
- From the medicolegal perspective, it is imperative to keep in mind that nearly all psychiatric diagnoses are ultimately clinical diagnoses
- While neuroimaging can assist in diagnoses it is not, in and of itself, a solo diagnostic tool
- Neuroimaging rarely provides picture of individual's state of functional ability; level of impairment, cognitive, behavioral, or emotional, requires careful clinical assessment and attention to real-world performance

Forensic Applications

- In the forensic setting, beyond a given diagnosis, a specific capacity is typically at issue.
- For instance, competency to proceed to trial typically requires a rational and factual understanding of criminal court procedure and the ability to participate and cooperate in one’s own defense.
- While any given illness potentially threatens this capacity, existence of such is not dispositive on the medicolegal issue.
- For example, defendant with AD and neuroimaging evidence of such may still possess the requisite capacities. Alternatively, an individual with normal neuroimaging but otherwise meeting criteria for Alzheimer's disease may demonstrate impairments that preclude the relevant legal capacity.

Thanks!

Questions & Comments…



Baby Daphne loves Dinger!