MR Physics

Joseph V. Fritz, PhD
Dent Neurologic Institute
Sunday, January 20, 2013
9:00 – 9:50 AM

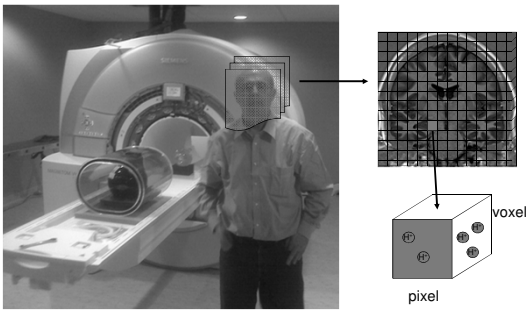
Disclosures

- Siemens Medical Systems
  - Research Agreement
- Philips Healthcare
  - Research Agreement
- Toshiba Medical Systems
  - Pending Research Agreement
- Zogenix, Merz, Ipsen
  - Advisory Board

~~MRI Physics~~

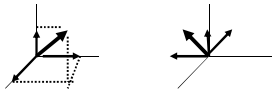
Recipe to Creating Images without Radiation

What's In an Image

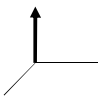


Vector Math

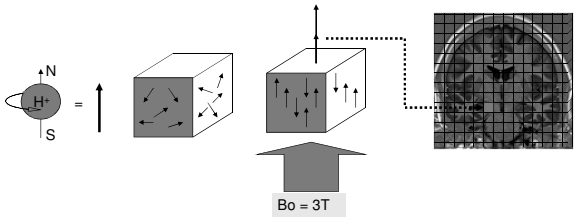
- How Much Is Pointing in Each of 3 Axes?



- Add Up Components, Then Recombine

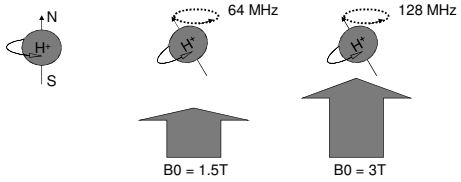


Measuring Proton Density via Net Magnetization

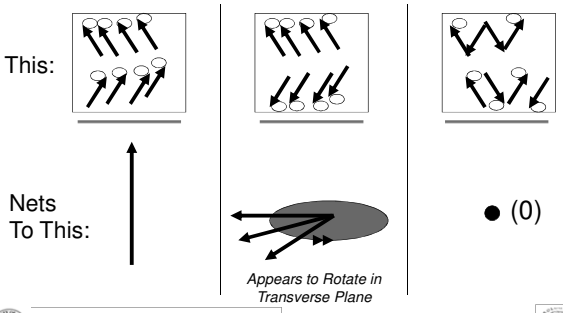


(More Align Parallel as Bo Increased)

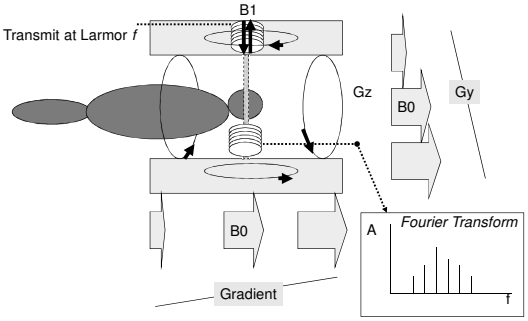
Precessional Motion and the Larmor Frequency



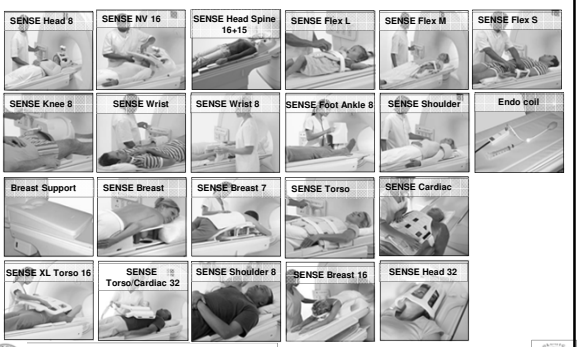
Making the Net Magnetization Detectable



Spatial Localization Using Gradients

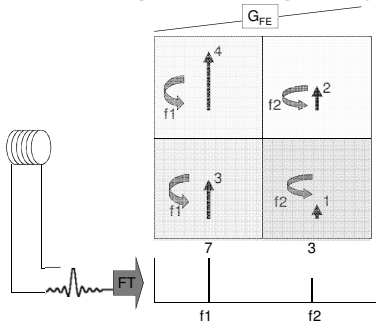


Example Receiver Coil Portfolio

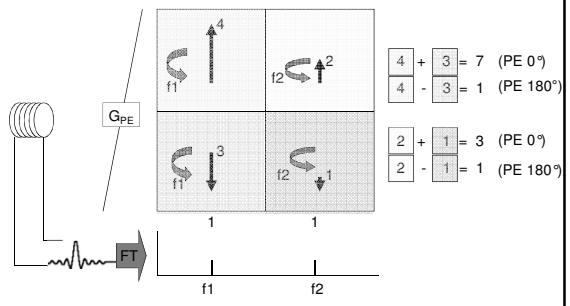


Courtesy Philips Healthcare
c 2007

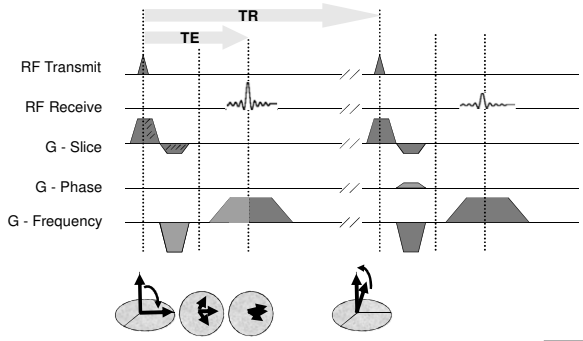
Image Encoding: Frequency



2nd Acquisition, Phase Change



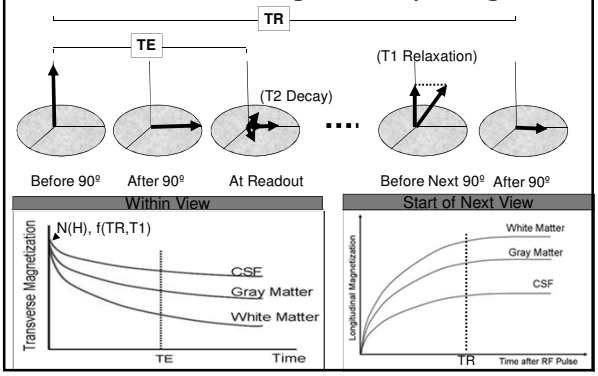
Typical Field Echo Sequence



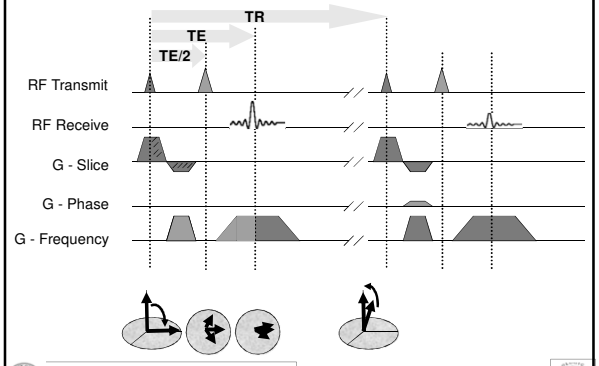
Summary of Localization Strategy

1. Gradient Varies Larmor Frequency along Slice Direction.
2. Transmit Coil at Desired Slice's Larmor Frequency to Excite Desired Anatomy
3. 2nd Gradient: Temporarily Vary Precessional Frequency along PE Direction to Create Phase Distribution
4. 3rd Gradient: Vary Larmor Frequency along 3rd Direction while Receive Coil "Listens" (Echo)
5. Use Fourier Transform to Decode "Echo" into Frequency Bins (along FE)
6. Repeat for Multiple Phase Distributions along PE
7. Use Algebra to Compute Discrete Pixel Values (2D FT)

In MRI, Timing is Everything

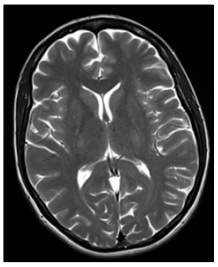


Spin Echo Sequence



Long TR, Long TE

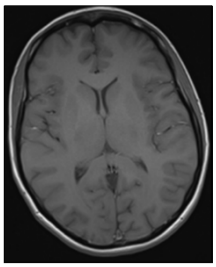
- T2 Weighted
- Signal Loss from Phase Dispersion
- More Loss with White/Gray Matter than CSF
- Plenty of Time for Complete T1 Recovery Each View



TR 2000, TE 120

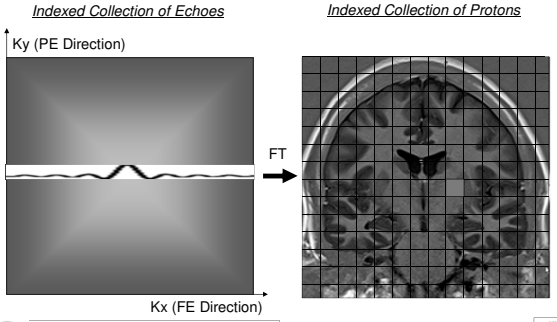
Short TR, Short TE

- T1 Weighted
- Signal Loss from Incomplete Longitudinal Magnetization
- More Loss from CSF than Gray/White Matter



TR 500, TE 10

K-Space vs. Image Space



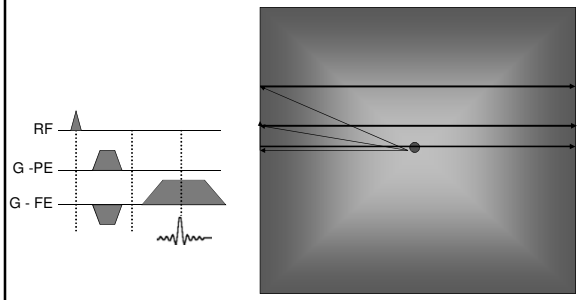
Some Characteristics of K-space

- One Point in K-Space Affects Entire Image, One Pixel formed from All of K-Space
- Center = Contrast, Edges = Resolution
- If Do Not Collect Periphery ➔ Blurry, Ringing
- If Too Few Echoes Sparsely Separated ➔ Wrap-Around (Aliasing)
- If Physical Motion Between PE Steps ➔ Ghosting (Misaligned "Plane Waves")

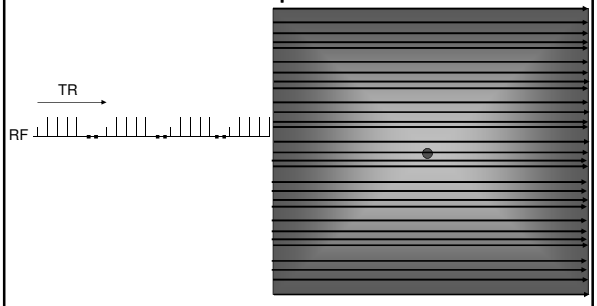
Walking Through K-Space To Collect My Echoes

- An Easy Way to Understanding Many Sequences
- Start at Center
- Use PE and FE Gradients to "Steer" and "Accelerate"
- Think "Etch-a-Sketch" or "Pac-Man"
- "Receiver Bandwidth" = Speed of Collecting Echoes while Traveling

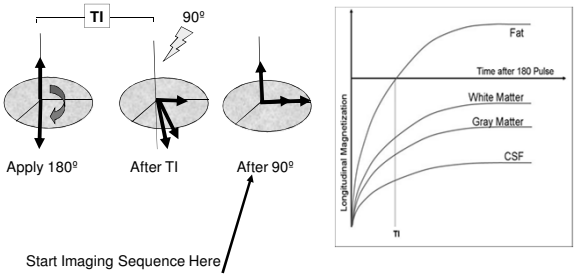
Walking Through K-Space Illustration



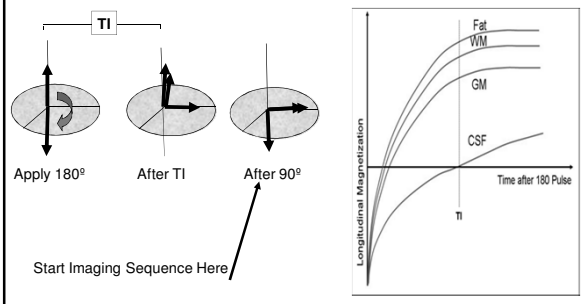
Fast Spin Echo



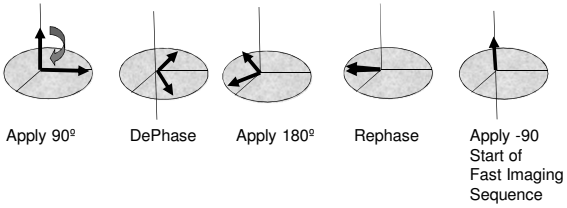
Inversion Recovery: STIR
Fat Nulled



Inversion Recovery: FLAIR
CSF Nulled



Magnetization Preparation
in Diffusion Imaging



- Starting Magnetization Less if "Dephase" ≠ "Rephase"
- Stationary Protons Retain Signal (Restricted Diffusion)

Many "Pulse Sequence" Choices

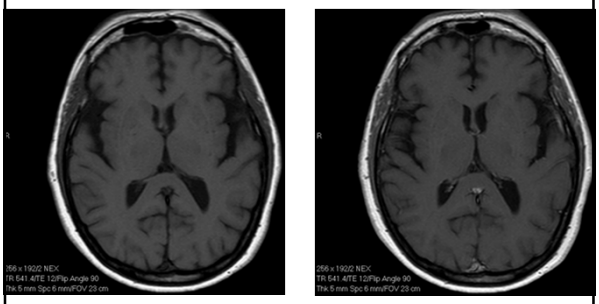
- TR/TE/TI
- Flip Angle
- Matrix
- Field of View
- Slice Thickness
- NEX
- Bandwidth
- Spin Echo
- Field Echo
- 3D
- Turbo Factor
- Echo Planar
- SENSE
- …

Fundamental Tradeoffs: Resolution – SNR – Speed

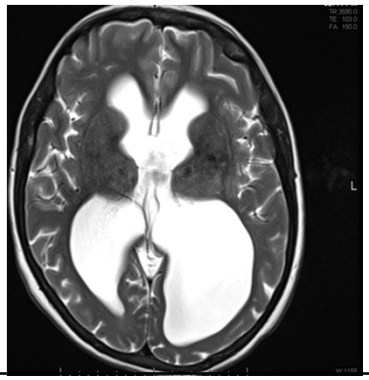
- Resolution Increases with
  - More Voxels in FOV (Bigger Matrix, Small FOV, Thin Slice)
- SNR Increases with
  - More data, Listen Longer, Less Resolution
  - Field Strength
    (More Net Protons, … consider Safety, Artifacts, T1 Contrast)
  - Receive Coil Matched to Anatomy
- Time Decreases with:
  - Collecting Less Data (eg Less Resolution, Fewer Averages)
  - Shorter TR (contrast)
  - More Data per TR
    (eg FSE, EPI, GRASE, Parallel Imaging)
    Careful with Blurring, J-coupling, distortion, Aliasing

Example Images and Parameters

Name that Sequence…



Name that Sequence



Name that Sequence

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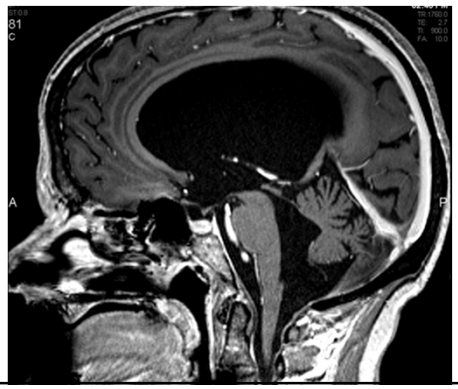

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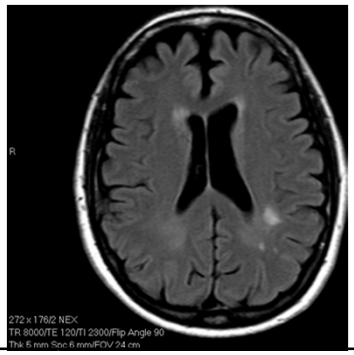
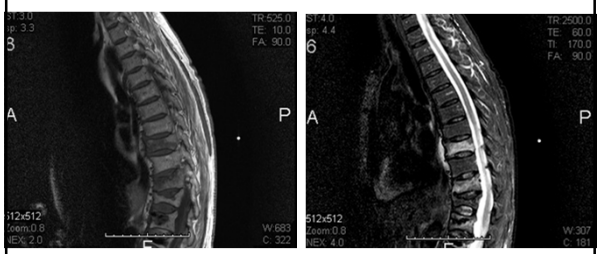
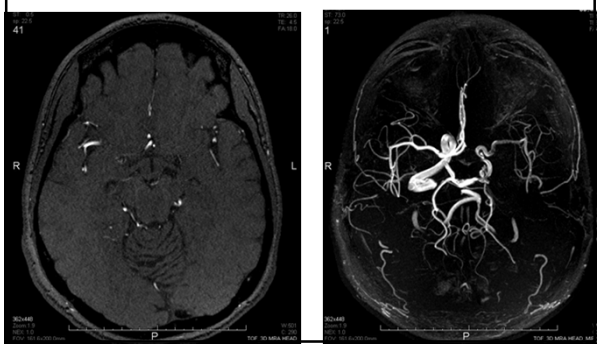


What is the Sequence on the Rt?



Sequences????

????



Specialized Sequences

Contrast Perfusion Methods

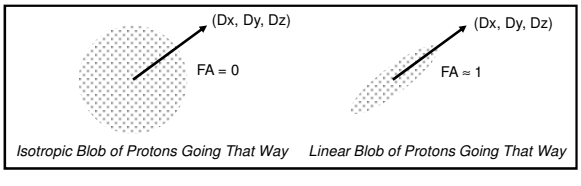
- Contrast in Tissue Accelerates Dephasing
- Dynamic Acquisition
- Track Voxel by Voxel about every 2 seconds
- Post Processing
  - MTT, TTP, CBF, CBV
  - Exchange Model => Permeability

Arterial Spin Labeling: Non Contrast Perfusion

- No Injection
- Pulse or Continuous Saturation of Inflowing Blood
- Collect Many Times With and Without Saturated Inflow, Then Subtract
- Only Difference Should be Where Tagged Blood Traveled

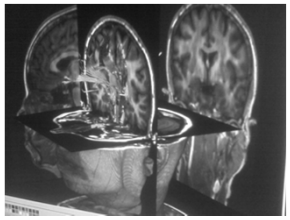
Diffusion Tensor Imaging: Fractional Anisotropy

- Determine the Direction and Shape of Diffusion
- Repeat Diffusion "Probe" in at least 6 Directions



Resulting Graphics of White Matter

- FA = Brightness
- Color = Direction
- Connect Similar Dots = Representation of Tracts that Linearly Restrict Diffusion



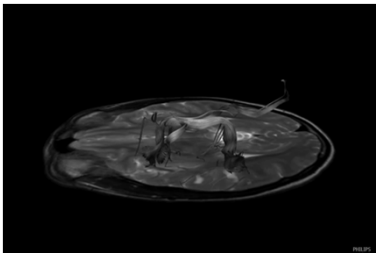
Functional Imaging: BOLD

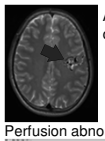
- Blood Oxygenation Level Dependent Imaging
- Oxy vs. De-oxy Hg Changes Iron Environment
- Iron Affects Nearby Magnetic Field
- Variation in Larmor Frequencies within Voxel Changes Net Magnetization

Simple Paradigm to Tag Function

- Scan Entire Brain Every Couple Seconds
  - FE-EPI = fast single shot, & susceptibility weighted
- Do Something that Affects Local O2 Uptake
- Continue Scanning While Interleaving Another Task With Different O2 Affect
- Subtract Image Sets (after a lot of averaging)
- Threshold "Meaningful" Differences
- Overlay on a Registered Anatomic Image

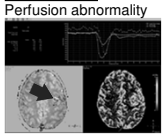
Surgical Guidance Using Combined FiberTracts and fMRI





AVM on T2

Perfusion abnormality

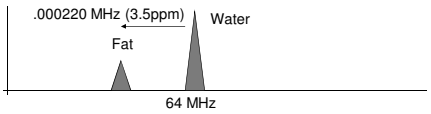


Arcuate Fasciculus (DTI)
Broca & Wernicke (fMRI)

Courtesy: Philips & University of Leuven, Belgium

Very Basic MR Spectroscopy

- eg Fat and Water 3.5 ppm Separation
- Larmor Frequency of Protons in
  Water = 1.5T x 42.58 MHz/T = 64MHz
  Fat = 3.5 ppm slower due to e^- shielding
  = about 220 Hz Lower



Water – Fat Shift

Chemical Shift due to Shielding => Different Larmor *f* 's

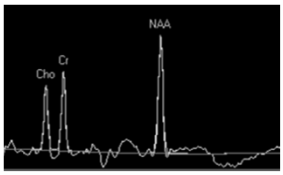
- Tune "RF Slice Select" or "Sat Bands" to Excite or Destroy Fat or Water
- Phase Cycling: Fat & Water Precess In and Out of Phase (Another Fat Suppression Method)
- Different Frequency => Chem Shift Artifact Misplaces Fat (Incorrect Frequency Encoding)

Detecting Metabolite Concentrations

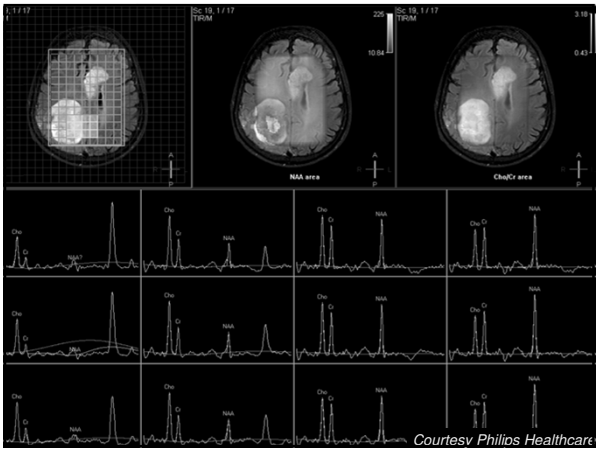
- Metabolites "Shielded" Differently
- Protons "See" Different Bo Field
- Just Excite One Big Voxel
- Frequency Variation = Metabolites instead of Spatial Location
- Fourier Transform = Plot MR Spectrum

Example Proton Spectra

- Long TE Clean, Basic
  - NAA, Cr, Cho: Hunter's Angle
  - Lactate, Lipid
- Short TE Methods
  - Add mI, Glx, etc
- Multivoxel
  - Time Efficient
  - Longer TE, Purists Object



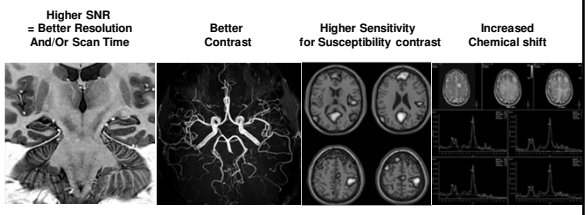
2 ppm



The High Field Trend

- 0.015T → 0.35T → 1.0T → 1.5T → 2T → 2.9T → 3T → 7T ----- -- and still climbing
- More Net Protons: SNR Increases Linearly
  - Trade for Cleaner Images, Higher Resolution, Faster Acquisition
- Greater Chemical Shift
  - MRS Peak Separation, Susceptibility, Magnetization Transfer Contrast
- Greater SAR and Dielectric Effects
  - Reworked Sequences, Different Contrast, Safety Issues
- Equipment and Siting Expensive
  - Superconducting Material, Iron to Contain Field

Why Higher Field Strength?



MR Artifacts

Joseph V. Fritz, PhD
Kaveer Nandigam MD
Kaylan Shastri MD
Dent Neurologic Institute
Sunday, January 20, 2013
9:50 – 10:40 AM

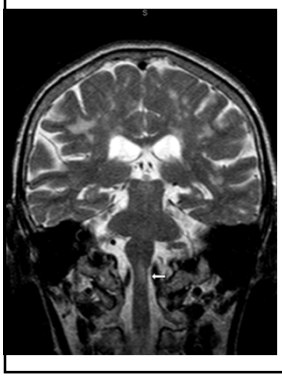
American Society of Neuroimaging
36th Annual Meeting

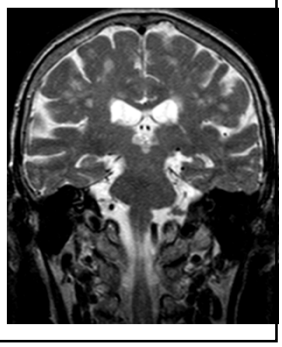
Artifacts

- Partial Volume
- Motion, Flow
- Wrap (Aliasing)
- Gibbs (Ringing)
- Susceptibility (including Intentionally creating SWI)
- Chemical Shift
- Cross Talk

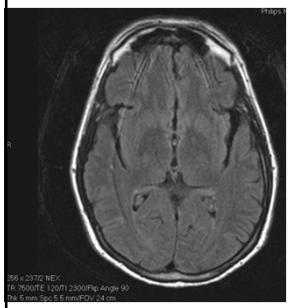
American Society of Neuroimaging
36th Annual Meeting

Artifact or Real?

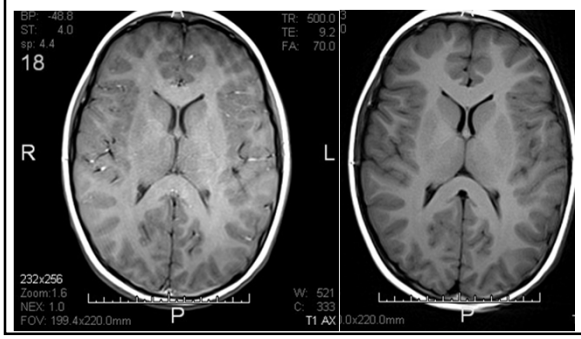




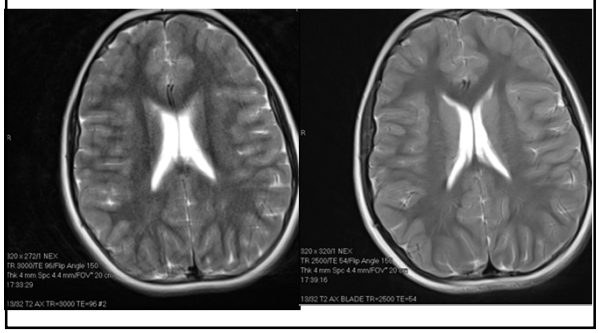
What is the Artifact?



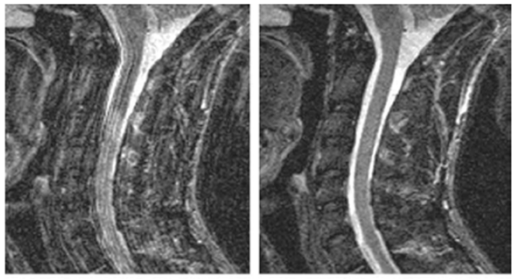
What is done differently?



What is done differerntly?

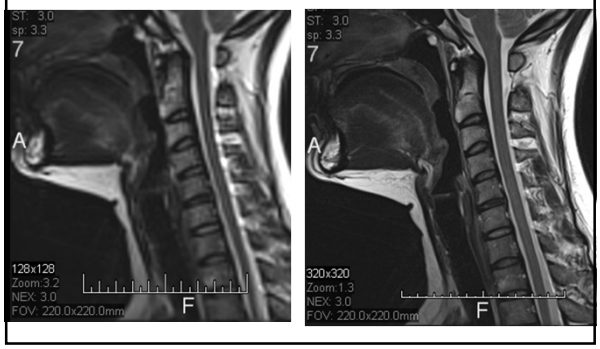


Artifact? Correction?

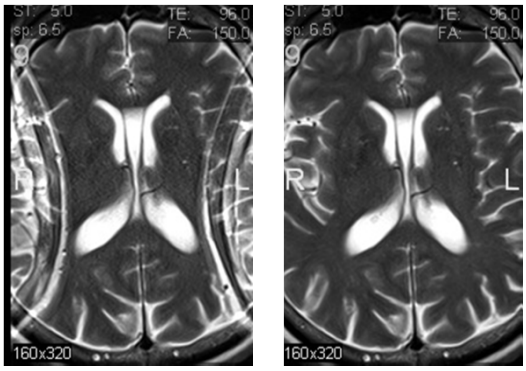


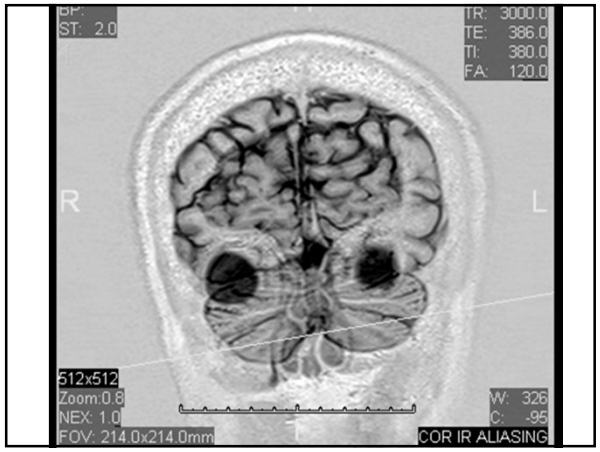
Morelli, et al, RadioGraphics 2011; 31:849–866

Artifact, Correction?



Artifact/Correction?

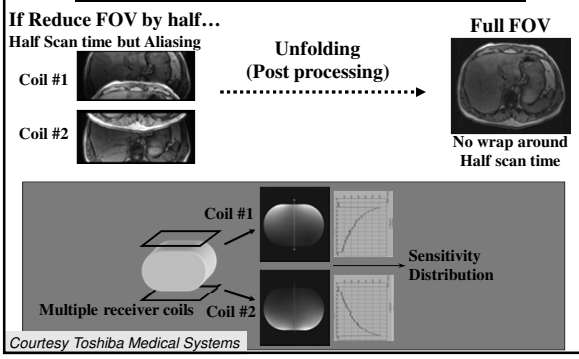




Surface Coils and Parallel Imaging

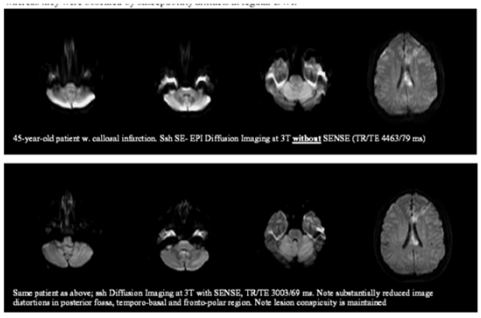
- Small Surface Coil Improves "Filling Fraction"
  - Better SNR
  - Larger FOV with Array (eg. Spine)
  - Depth of Penetration Limited
- PI Trick:
  - Arrange Multiple Coils to Look at Same Anatomy
  - Signal Drops Off Differently from Each Coil
  - Another "Set of Equations" for Free
  - Proportionally Fewer PEs Needed
- Sqrt (N) SNR Loss
  - High Field Advantage: Convert Extra SNR to Speed

Parallel Imaging



Courtesy Toshiba Medical Systems

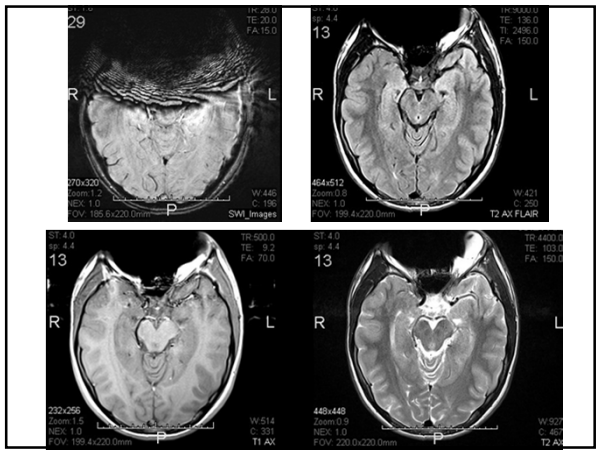
Susceptibility vs. Parallel Imaging



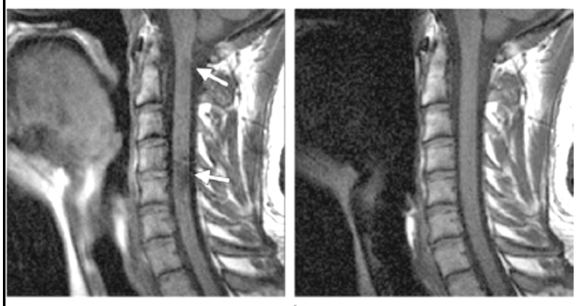
No PI

PI x 3

Kuhl et al, Proc. Intl. Soc. Mag. Reson. Med. 11 (2004)

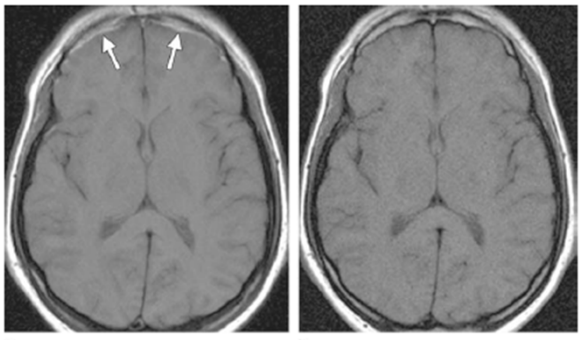


Artifact/Correction?



Morelli, et al, RadioGraphics 2011; 31:849–866

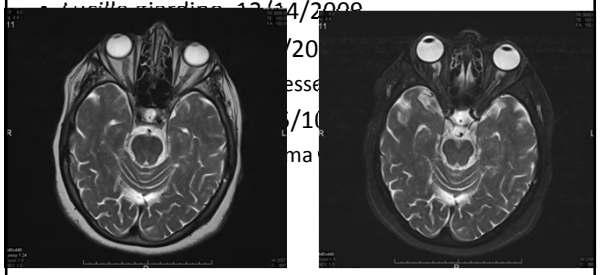
Artifact/Correction?



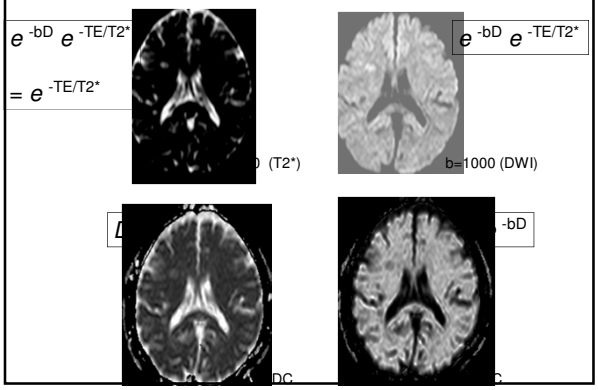
Morelli, et al, RadioGraphics 2011; 31:849–866

What was done on the right?

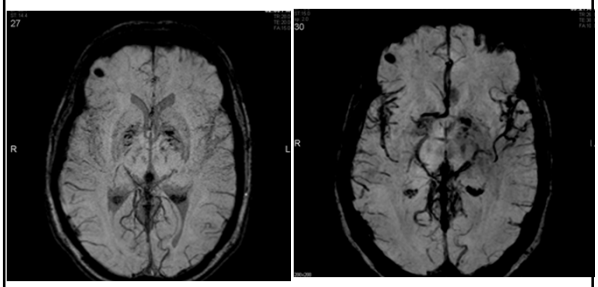
- Lucilla giordino, 12/14/2009
- /20
- esse
- /10
- ma



DWI/ADC & T2 Shine Through



SWI vs. long TE FE



Many Additional Educational Resources

- Society of Magnetic Resonance Technologists
- Joe Hornack Web Site
  - http://www.cis.rit.edu/htbooks/mri/
- Wikipedia
- Manufacturer Web Sites and Operator Manuals
- MRI Safety by Frank Shellock, PhD
- Simply Physics, Moriel Nessaiver
- Medical Imaging Consultants, Inc
- jfritz@dentinstitute.com, www.DentInstitute.com