MRI Pulse Sequences

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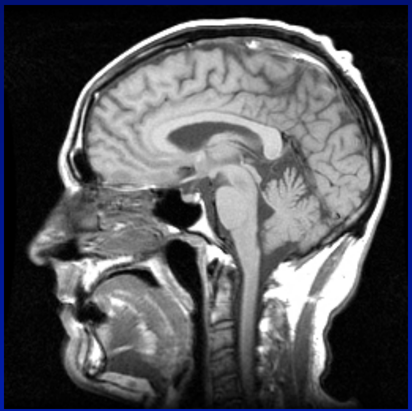
Stanford University

Why is MRI interesting?

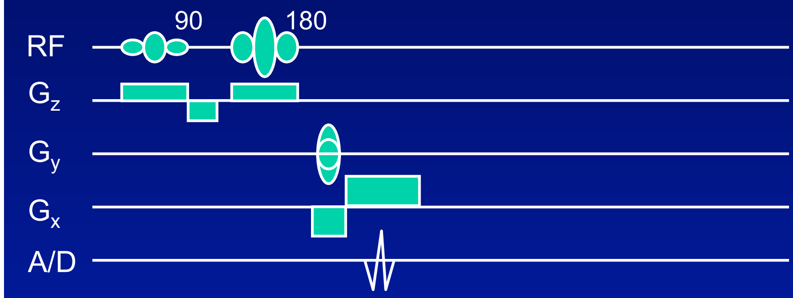
- Great image contrast
- Many unique contrast mechanisms
- Reasonable scan times
- Arbitrary scan geometries
- Many different imaging methods

A simple example

T1-weighted spin echo

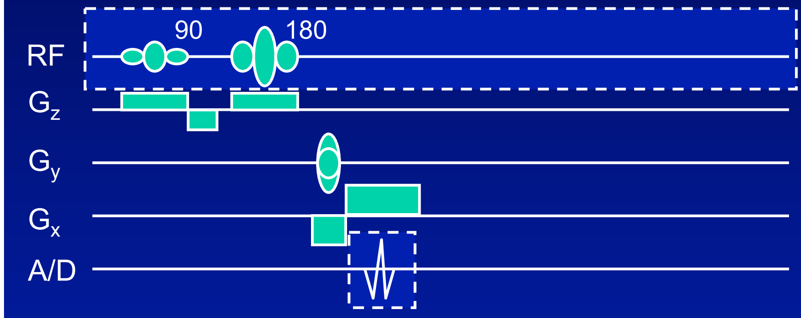


T1-weighted spin-echo



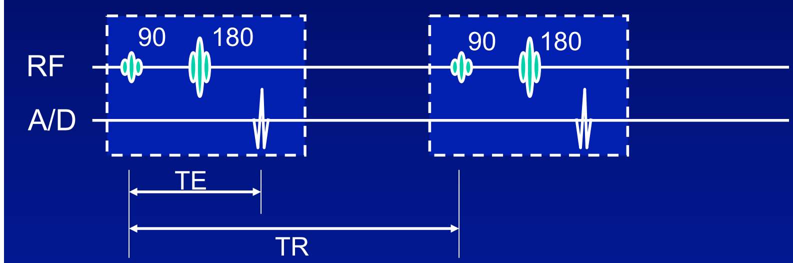
- Contrast
- Imaging volume
- Imaging method

Contrast



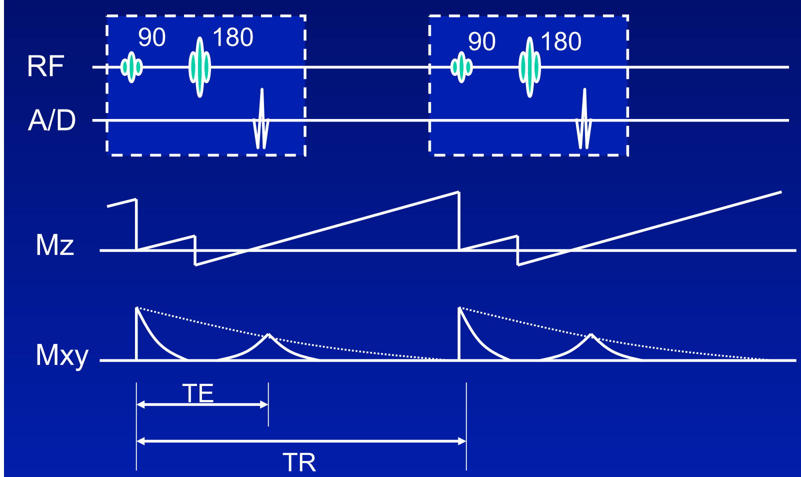
- Contrast determined by
  - RF pulses
  - Pulse sequence timing

Contrast

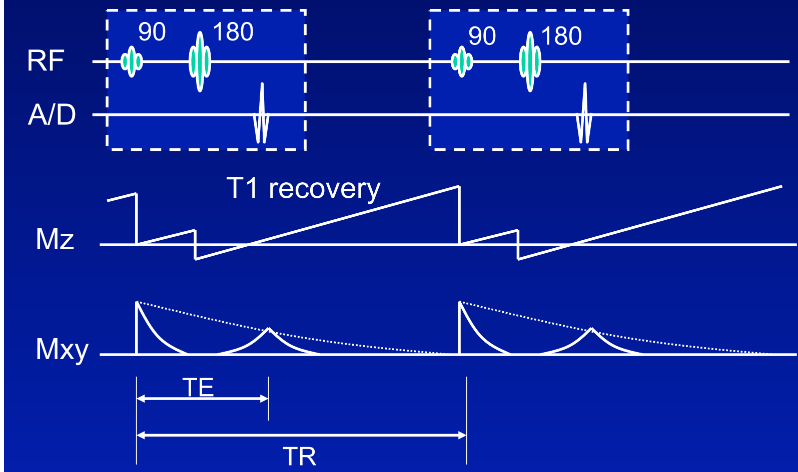


- TE - echo time
- TR - repetition time

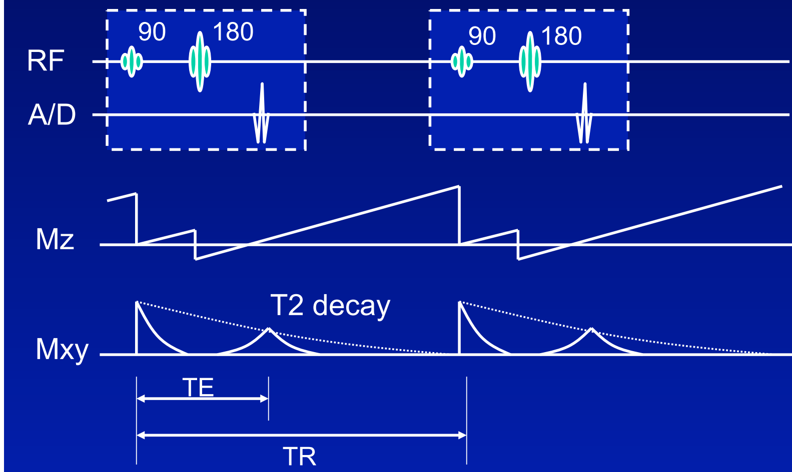
Contrast



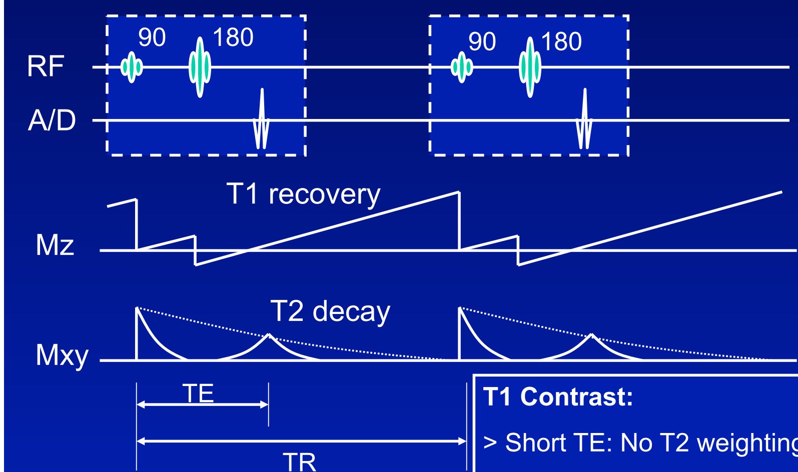
Contrast



Contrast:



Contrast:

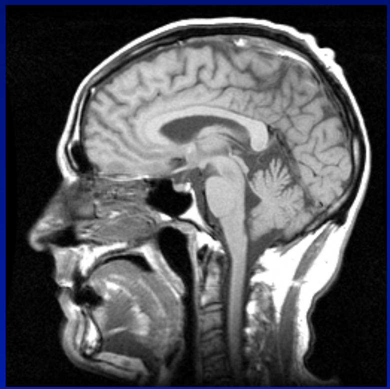


T1 Contrast:

> Short TE: No T2 weighting

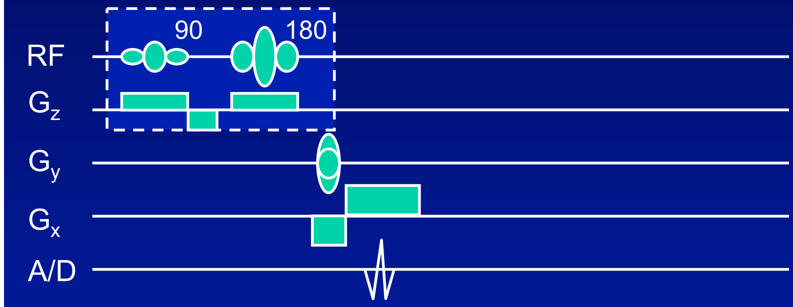
> Short TR: partial T1 recovery

T1-weighted spin echo



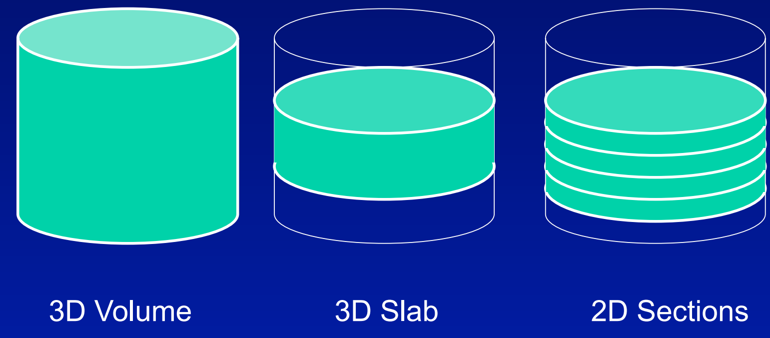
- Gray/white T1's are 800-1000 ms at 1.5T
- T2's are 80-100 ms
- TR is 400 ms
  - Incomplete recovery
- TE is 20 ms
  - Little T2 decay
- Result is T1 weighting

Imaging Volume



- Spatial imaging volume defined by
  - RF pulse shapes
  - Gz gradient

Imaging geometry



Slice selection

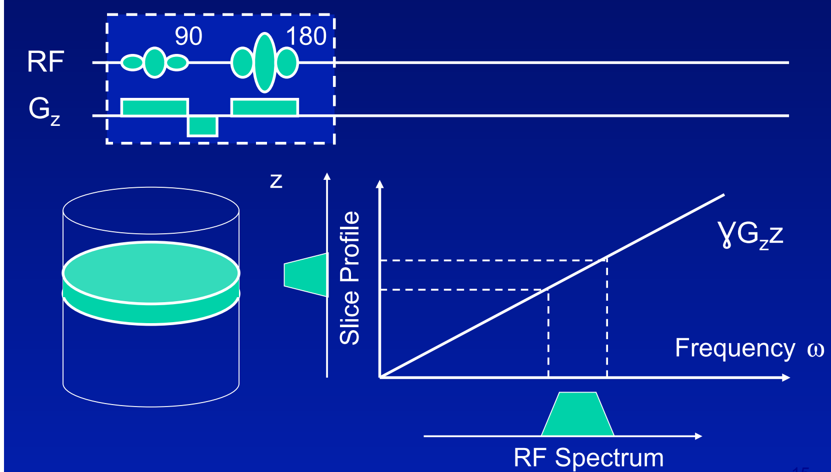
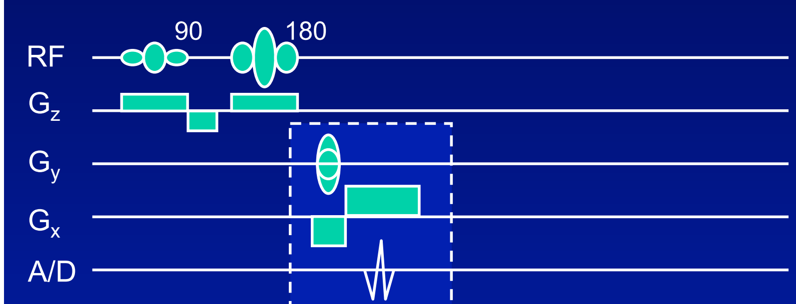
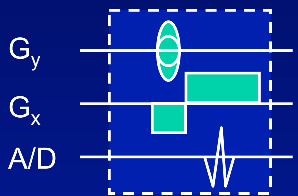


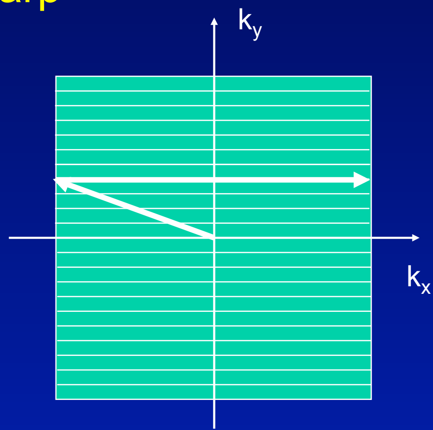
Image encoding



- Contrast has been prepared
- Imaging volume defined
- Imaging gradients encode and acquire image data

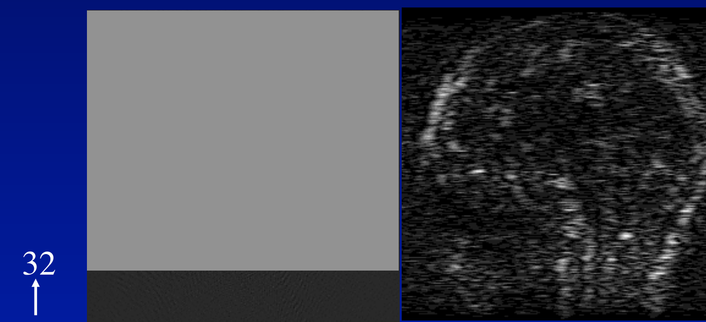
2DFT, or spin warp



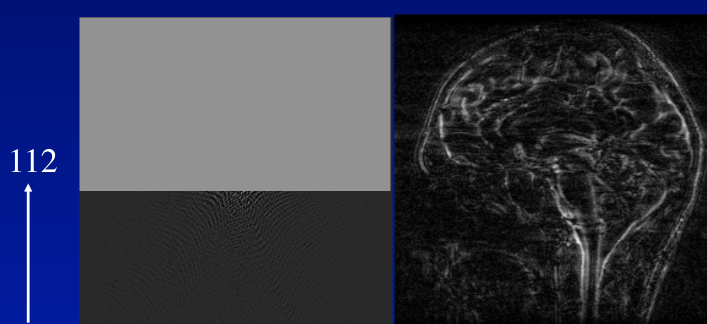


- One line of k-space for each acquisition
- Repeat N times for an NxN image
- Recon is 2DFT
- TR 400 ms, 256x256 image < 2 minutes

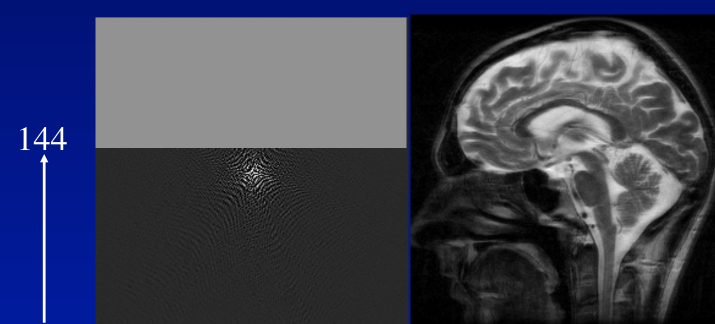
As we fill up k-space…



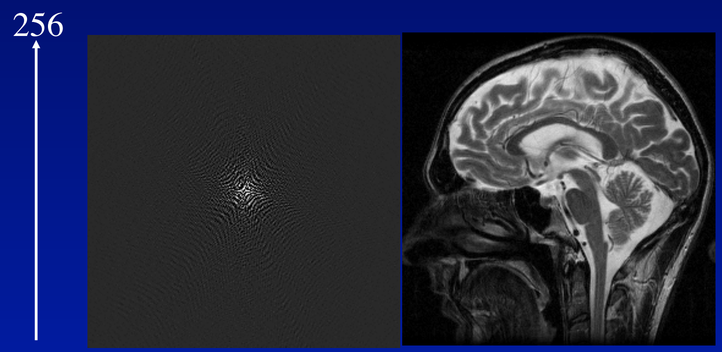
As we fill up k-space…



As we fill up k-space…



As we fill up k-space…



MR Imaging Methods

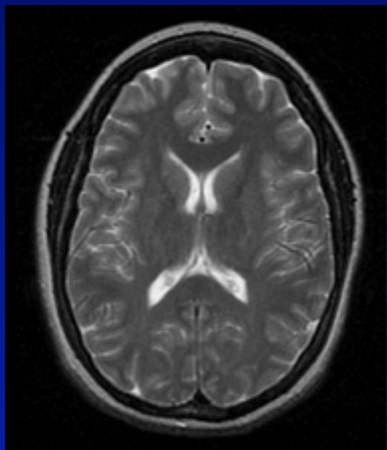
- Determine contrast
- Define the imaging volume
- Acquire the imaging data

Improvements

- More echoes
- Short TR’s
- Faster data collection
- Parallel receive coils

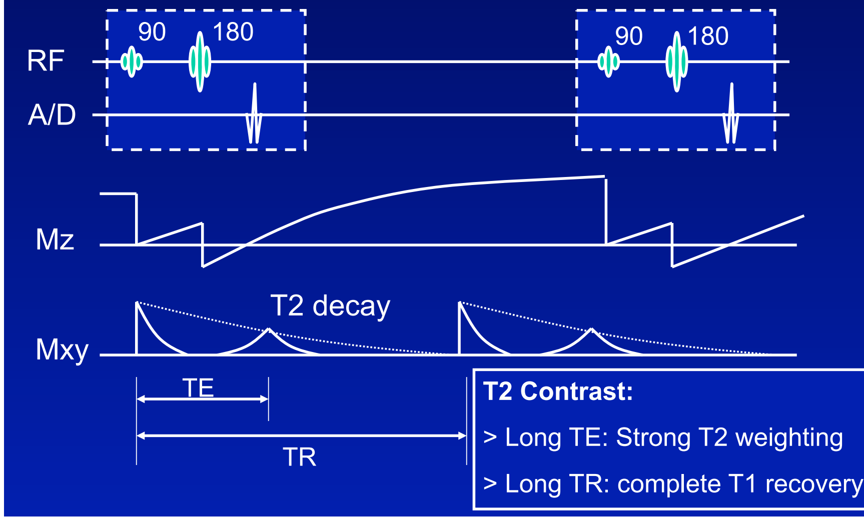
More echoes: spin-echo trains

T2-weighted spin echo

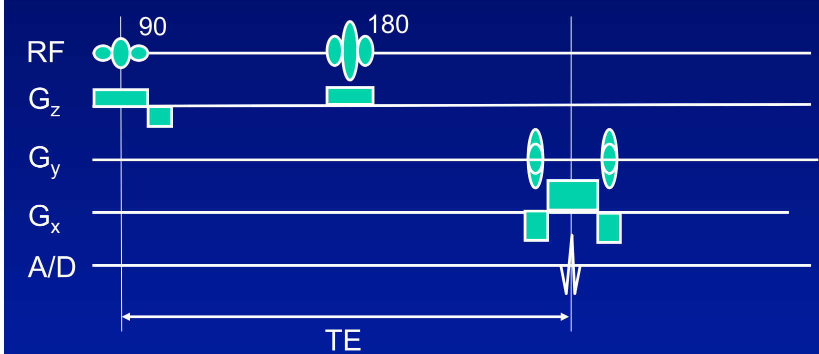


- Gray/white T2's are 80-100 ms
- Gray/white T1's are 800-1000ms
- CSF 300-400 ms T2

Contrast:

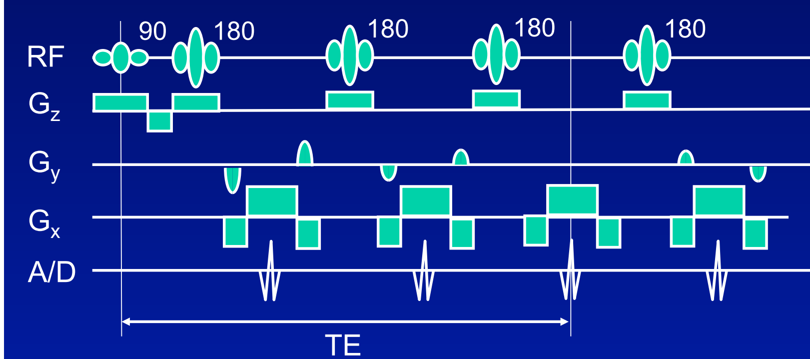


T2-weighted spin echo



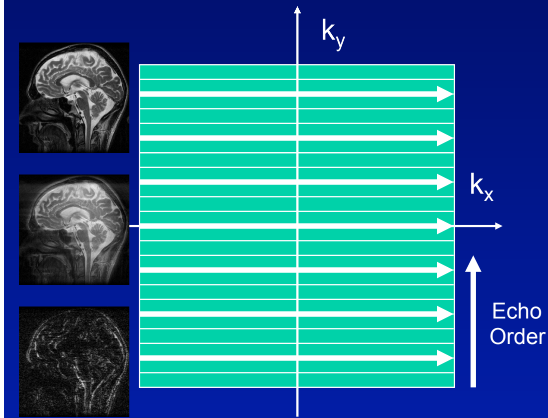
- Long TE for T2 weighting
- Much wasted time

A more efficient solution



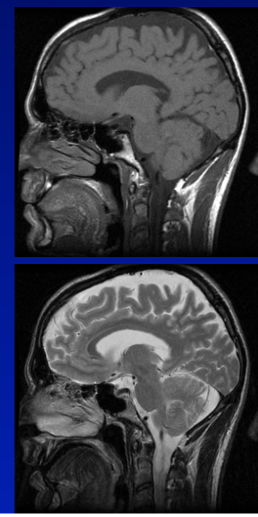
- RARE, Fast-Spin Echo (FSE), or Turbo-Spin Echo (TSE)

Spin-echo train imaging



- M echoes/TR
  M times faster
- Contrast from low frequency TE
- Detail from early/ late echoes

Spin-echo train contrast

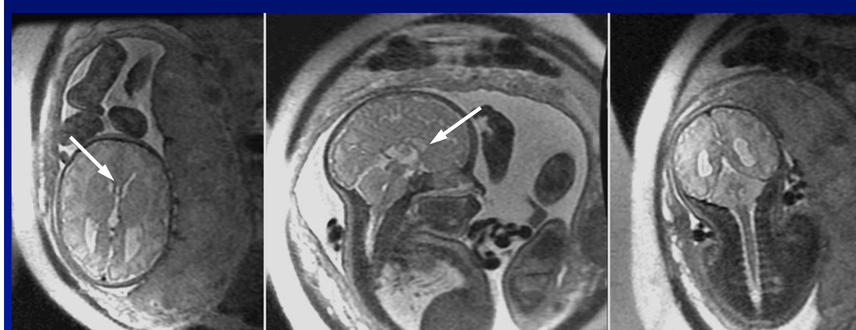


- Echoes can be collected in different orders
- Contrast determined by TE of low frequency echoes
- Early echo: no T2 constrast
- Late echo: strong T2 contrast

Single shot imaging

- Single echo train
- Long TE
- Bowel imaging
- Cholangiography
- Partial Fourier

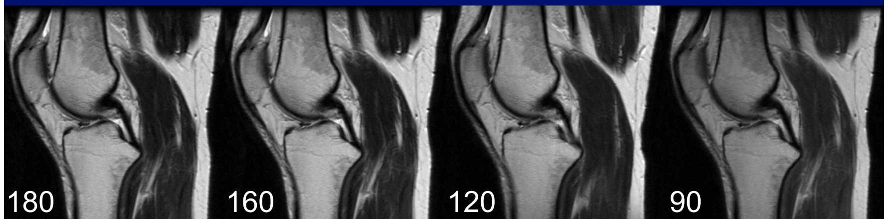
Fetal MRI



35 week old fetus with nodularity along ventricles and failure of development of the corpus callosum

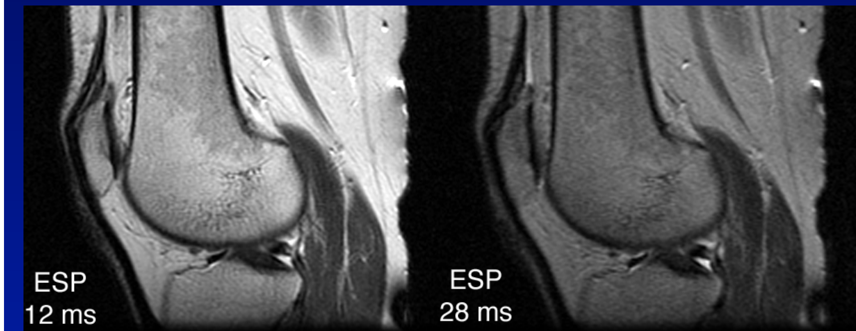
Reed Busse, PhD, GE ASL West

Flip angle of refocusing pulses



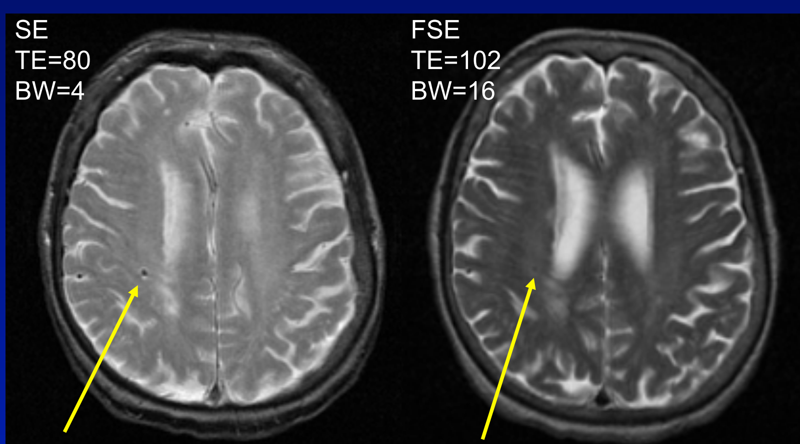
- Refocusing pulses often less than 180
- Mixed contrast
- Longer echo trains
- Lower power

Fat is bright on FSE images



- Same TE = 84 ms
- Lipid spins are J-coupled (T2 relaxation)
- Rapid refocusing hinders normal T2 relaxation

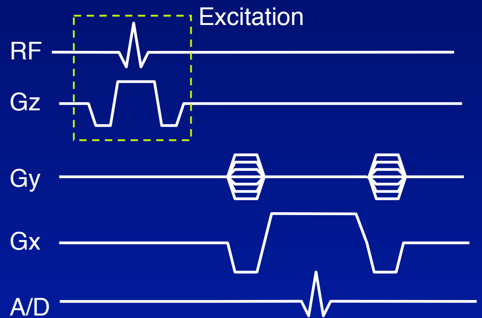
Small hemorrhage visualization



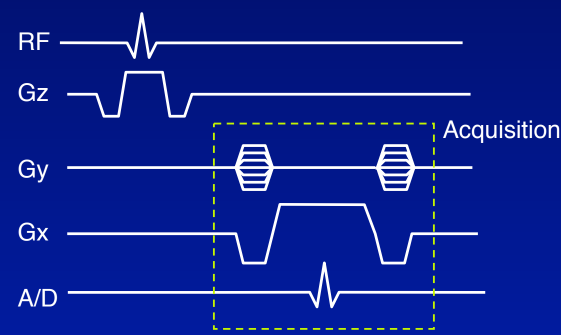
Small hemorrhage hard to see on FSE

Short TR’s: steady-state imaging

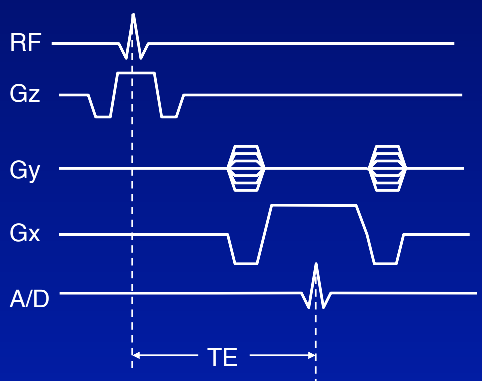
Gradient recalled echo



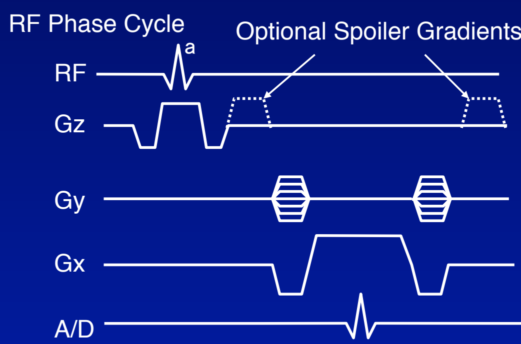
Gradient recalled echo



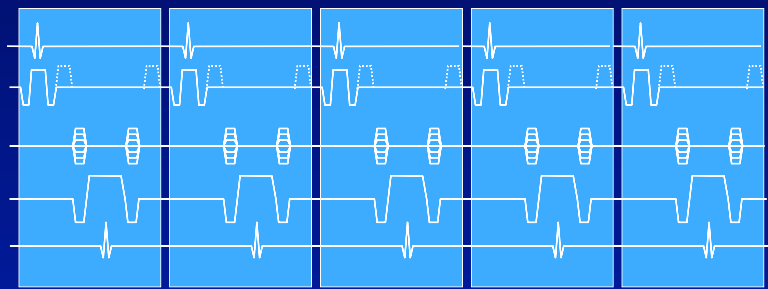
Gradient recalled echo



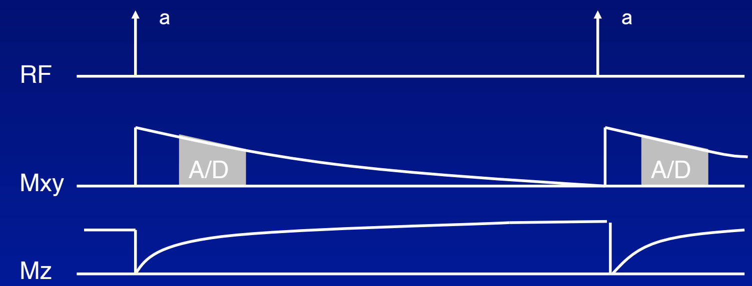
Gradient recalled echo



Steady state GRE

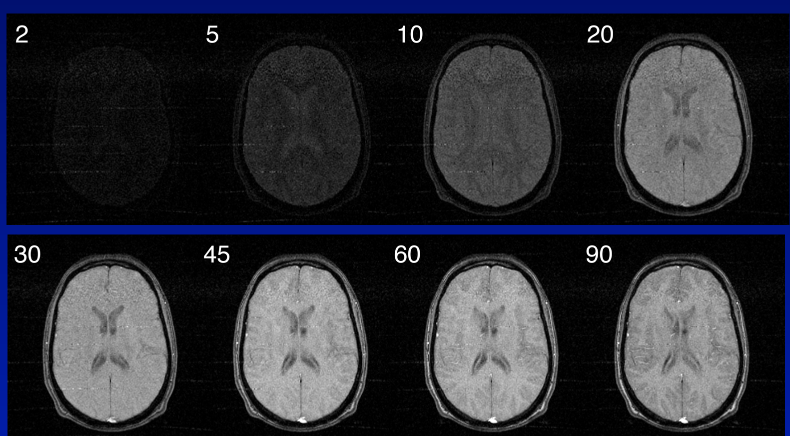


Long TR

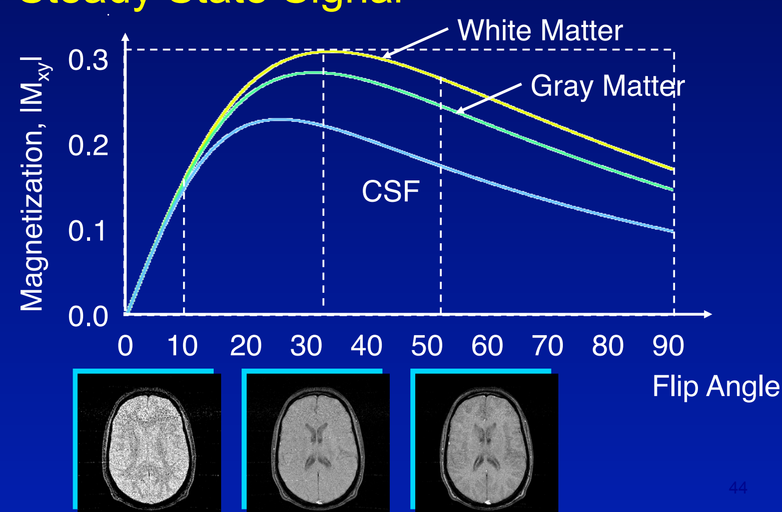


- M_{xy} decays by next TR
- Steady state M_{xy}, M_z
- Depends on TR, flip angle

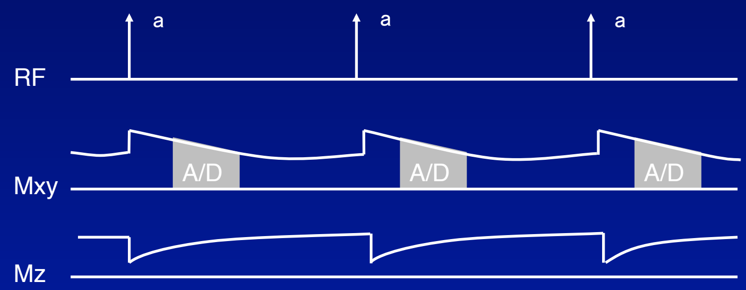
Flip Angle



Steady State Signal

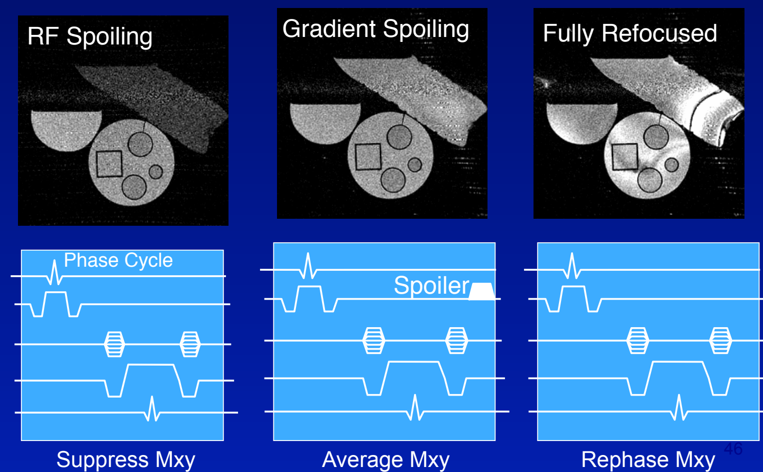


Short TR

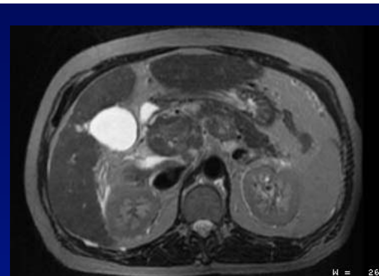


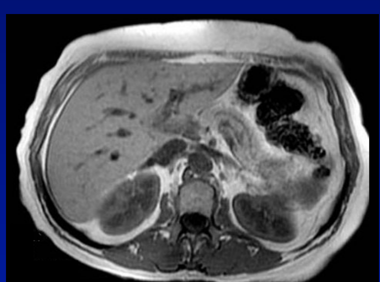
- M_{xy} persists to next TR
- May have shifted in phase
- Adds or subtracts with next FID

Steady state alternatives



Steady-state examples

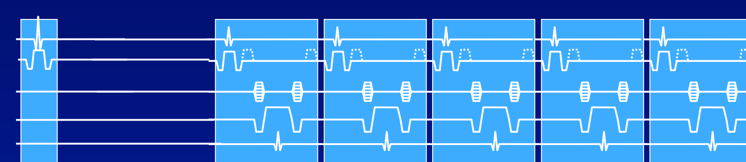

RF Spoiling


Gradient Spoiling


Fully Refocused

Images from: http://www.gehealthcare.com/usen/mr

Prepped GRE

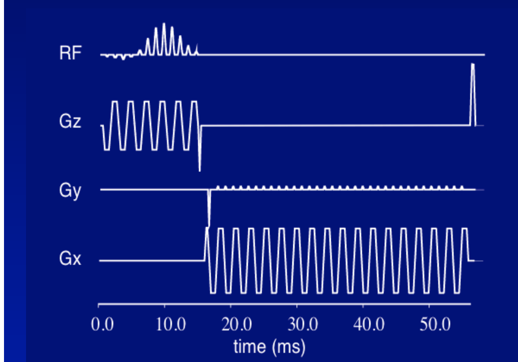


- Initial prep determines contrast
- Imaging in transient state
- Options
  - Inversion (T1)
  - Driven Equilibrium (T2)

T1 Prepped GRE

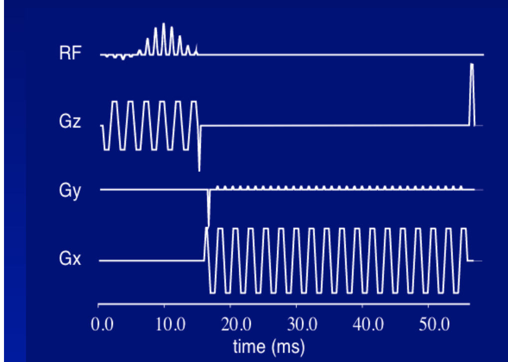
Faster data collection: EPI and spiral

EPI



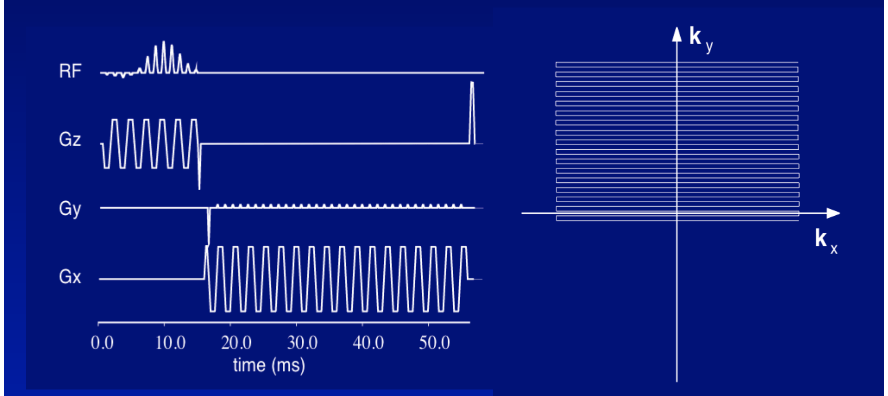
- Single/multiple shot imaging
- Fast gradient switching
- Used for
  – Perfusion
  – Diffusion

EPI



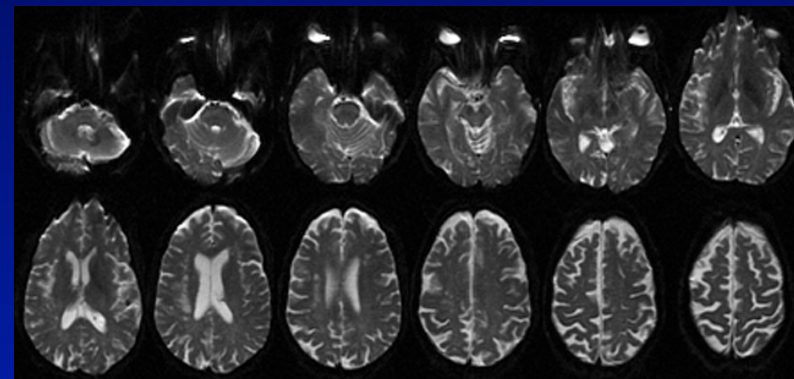
- Spectral-spatial excitation
- Excite only water in a slice

EPI



- 2D raster scan
- Partial Fourier acquisition

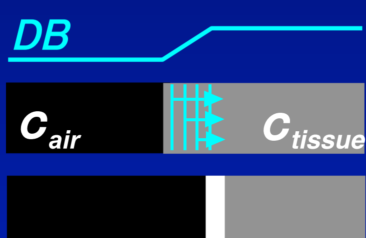
EPI

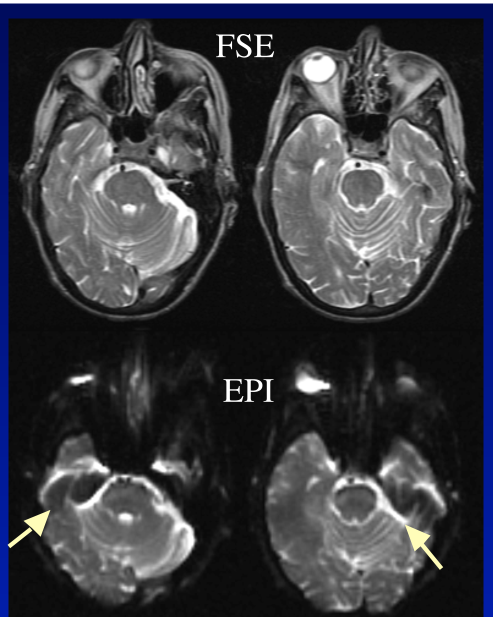


Whole brain coverage in less than one second!

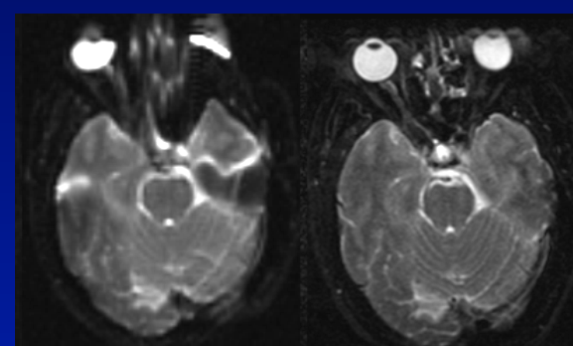
"Piling Up" Artifacts

- Frequency maps to position
- Frequency changes produce distortion





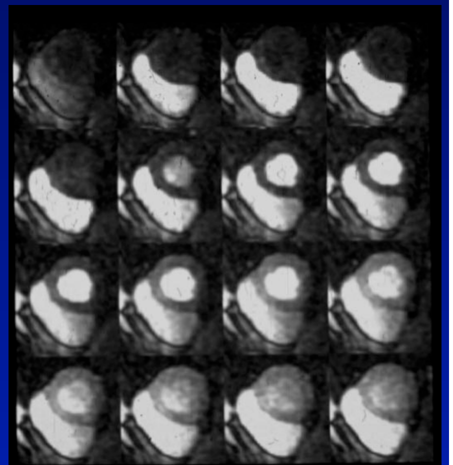
Multishot imaging relieves the artifact



Single Shot EPI   Multishot EPI

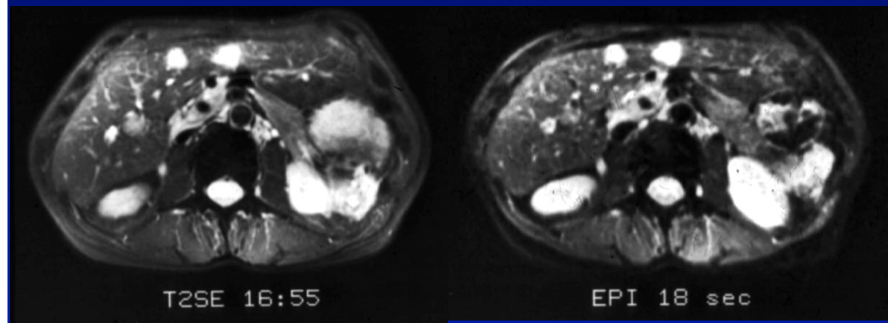
Multishot EPI for Cardiac Perfusion

- 4-6 echoes/shot
- 12 shots
- 80-126 ms scan time
- Contrast enhanced
- RF spoiled



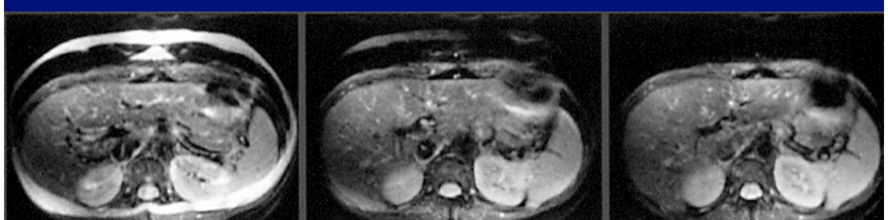
F.Epstein, NIH

Multishot EPI for Abdominal Imaging



K.Butts, Mayo Clinic

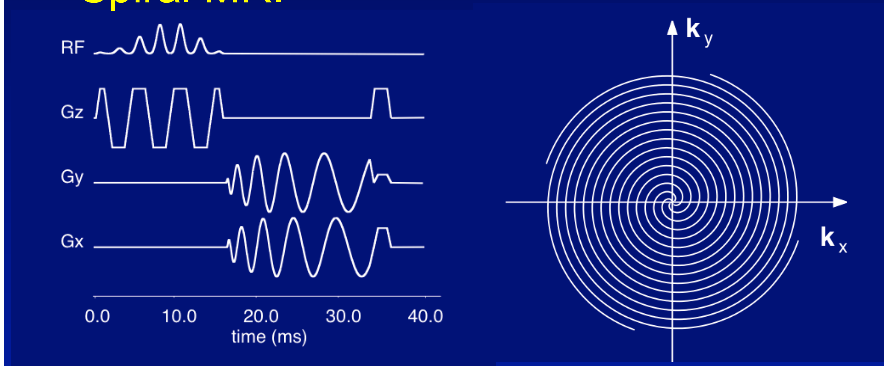
Fat Sat vs. Spatial Spectral RF



Fat Saturation (Fatsat)

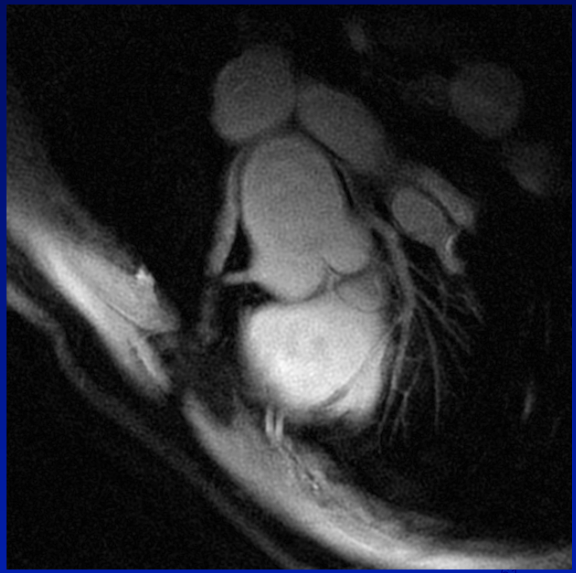
Water Selective Excitation

Spiral MRI



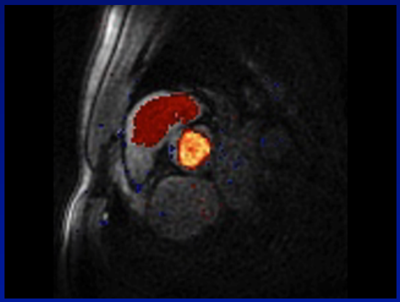
Spiral Coronary Imaging

- 30 shots, gated
- .58 x .58 mm^2
- breathheld

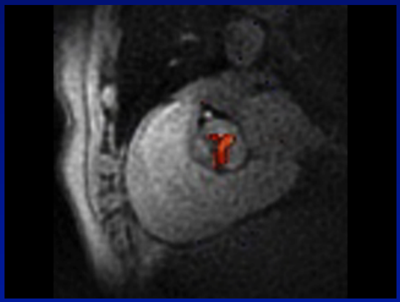


C. Meyer, UVA

Gated Spiral Color Flow

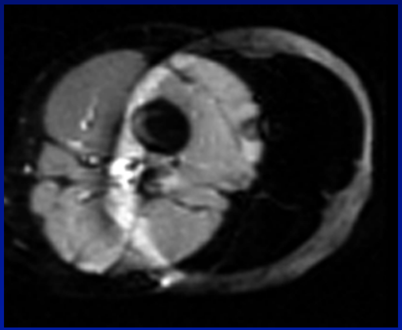


Normal Aortic Outflow
V_{peak} 1.4m/s

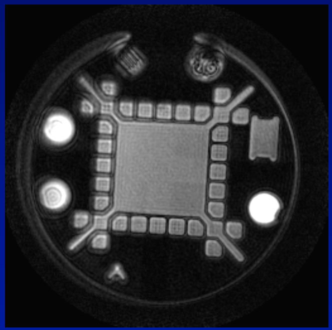


Aortic Stenosis
V_{peak} 4m/s

Off-resonance effects



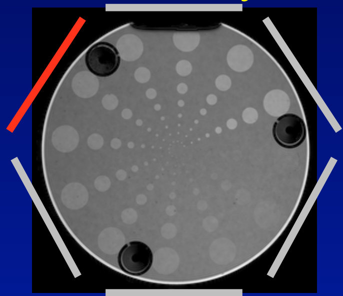
EPI, shift



Spiral, blur

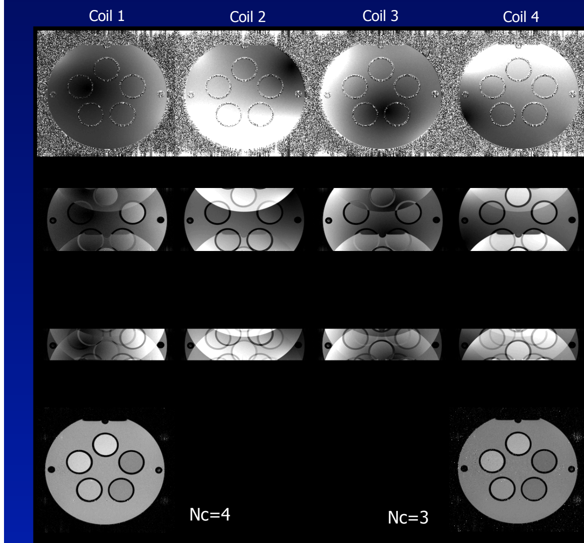
Multiple receiver coils

Coil sensitivity



- Multiple local receiver coils
- Coil sensitivities provide additional information for reconstruction
- Allows undersampling/aliasing in k-space

Klaas Pruessmann, ETH



Coil sensitivites

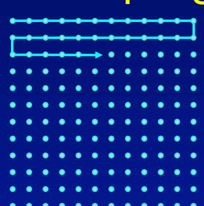
2X undersampling

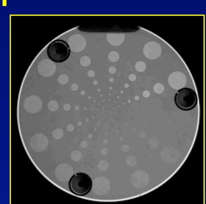
4X undersampling

Reconstructions

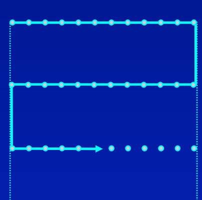
Roland Bammer

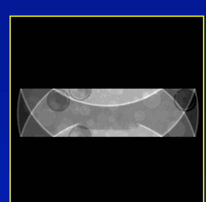
Parallel receive coils reduce sampling requirements





Standard k-space sampling

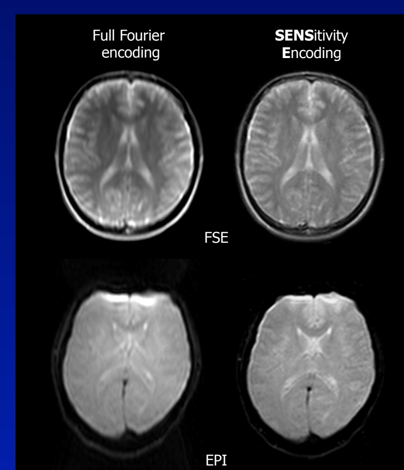


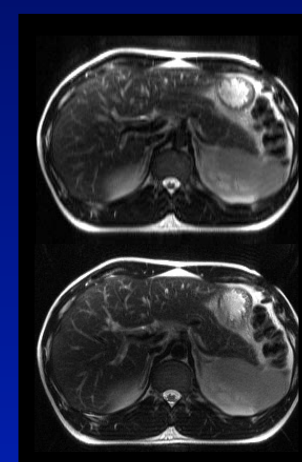


Reduced k-space sampling

Roland Bammer

Shorter readouts have less distortion





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Conclusions

MR imaging methods

- Determine contrast
- Define imaging volume
- Acquire imaging data

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MR imaging methods

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- Define imaging volume
- Acquire imaging data
- Many alternatives for each of these
- Most of these can be combined, for example
  - Spin-echo train
  - Multishot EPI
  - Parallel receiver coils