Acceptance and Quality Control Testing of Clinical MRI Scanners

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Acceptance Testing

I. Prior to MR system installation
- (A) Vibration measurements
- (B) RF shielding testing

II. Following system installation
- (A) Magnetic fringe field mapping
- (B) MR system inventory
- (C) General system checks
  1. Mechanical system checks
  2. Emergency system checks
  3. Patient monitoring, anesthesiology systems, gating systems and MR-compatible injectors
- (D) MR scanner system tests
  1. Static magnetic field subsystem tests
  2. RF subsystem tests
  3. Gradient subsystem tests
  4. Combined gradient/RF subsystem tests
  5. Global system tests
- (E) Advanced MR system tests
  1. Ultrafast imaging tests
  2. Spectroscopy tests

MRI system testing: phantoms

1. ACR phantom: general image quality
2. Home-made linearity phantom
3. Home-made slice thickness and spacing phantom
4. SNR phantoms: for difference coils, use oil for 3T
5. MRS phantom: w/ tissue-mimicking chemicals

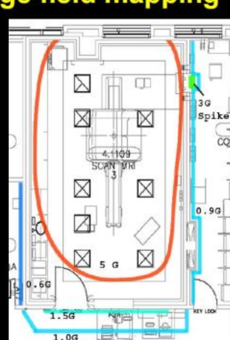
RF shielding

RF Leakage Testing

DC Isolation Test and Alarm

Ex: Magnetic fringe field mapping

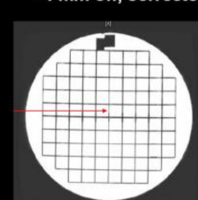
1.5 T

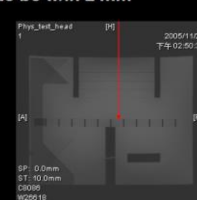


3 T

Ex: laser alignment and table positioning

1. Saggital laser:
   - 6 mm off, corrected to be w/in 2 mm
2. Axial laser (table):
   - 4 mm off, corrected to be w/in 2 mm



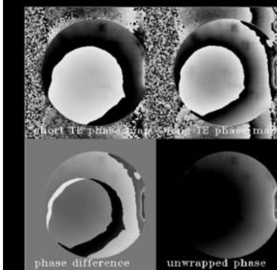


MRI system testing

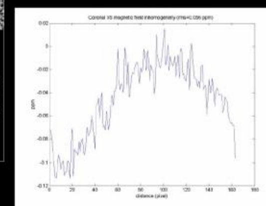
(D) MR scanner system tests
1. Static magnetic field subsystem tests
   (1) Magnetic field homogeneity
   (2) Magnetic field drift
2. RF subsystem tests
   (1) Transmitter and gain calibration
   (2) Transmitter gain stability
3. Gradient subsystem tests
   (1) Geometric accuracy and linearity
   (2) Eddy current compensation
4. Combined gradient/RF subsystem tests
   (1) Slice thickness and spacing
5. Global system tests
   (1) SNR
   (2) Percent image uniformity (PIU)
   (3) High contrast spatial resolution
   (4) Low contrast object detectability
   (5) Percent signal ghosting

(E) Advanced MR system tests
1. Ultrafast imaging tests
   (1) Ghosting
   (2) Geometric distortion
   (3) EPI stability
2. Spectroscopy tests
   (1) VOI location accuracy
   (2) Spectral quality tests

Magnetic Field Homogeneity



$$\Delta B_0 = \frac{\delta\varphi}{\gamma}\left(\frac{1}{TE_1} - \frac{1}{TE_2}\right)$$



Preparation of Acceptance Test

- Purchasing contract
  - Hardware / items list
  - Software / functionality
- Test Tools
  - ACR MRI QA Phantom
  - Gauss-meter
  - Etc…
- Operating Manuals

SIEMENS

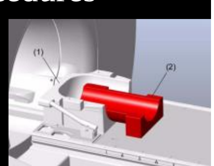
Item	Description
	MAGNETOM Espree
1	Magnet
2	I-class
3	Tim [76x18]
4	Z-engine Gradient System
5	RF Transmit and Receive System
6	Computer System
7	Standard Patient Matrix Table
8	PMU Wireless Physio Control
9	syngo MR Workplace
10	Head Matrix coil
11	Neck Matrix coil
12	Spine Matrix coil
13	Body Matrix Coil
14	Flex Coil Interface

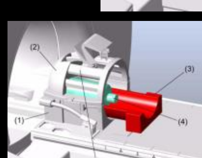
Acceptance Test Procedures

- Inventory check
- Manufacturer's check
  - Report about RF leakage test
  - Report from installation engineers
  - External RF coil tests
- ACR MRI QA Test
- Additional Test
  - Static field homogeneity

Annual Test Procedures

1. External RF Coil Tests
2. MRS Test
3. ACR MRI QA Test





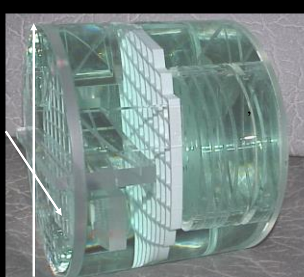
Phantom Test Guidance for the ACR MRI Accreditation Program

acr

OUTLINE

1. Geometric Accuracy
2. High Contrast Spatial Resolution
3. Slice Thickness Accuracy
4. Slice Position Accuracy
5. Image Intensity Uniformity
6. Percent Signal Ghosting
7. Low Contrast Object Detectability
8. Signal-to-Noise Ratio
9. Central Frequency Stability

Phantom positioning



setup of ACR phantom

- centered in coil & magnet
  - AP
  - SI
  - LR
- level
  - not rotated
  - not tilted
- view on localizer
- accurate, reproducible, easy
  - physicist assists with initial setup

setup of ACR phantom

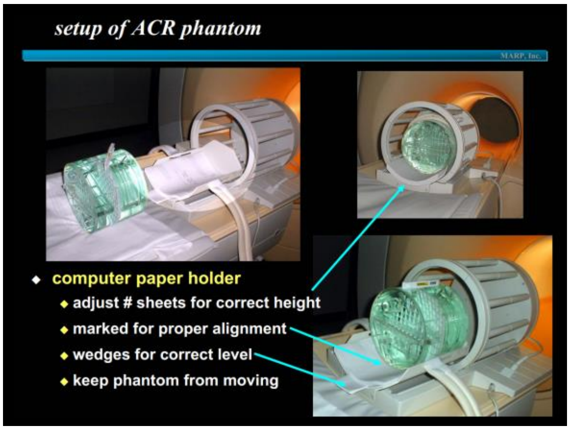
- manufacturer-supplied holders

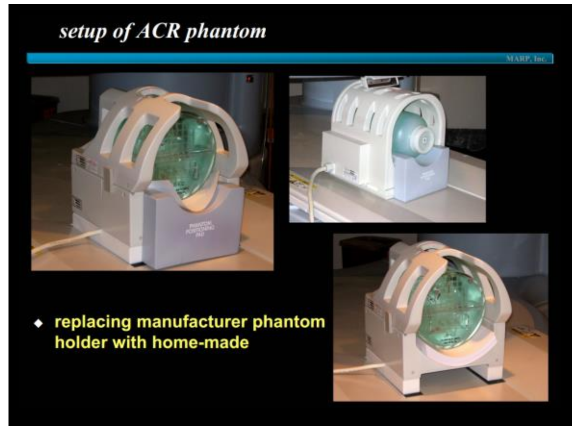
- available on site
  - designed for manufacturer's phantoms
    - not designed for ACR phantom
- imperfect alignment
  - not centered in head coil
  - may / may not be reproducible

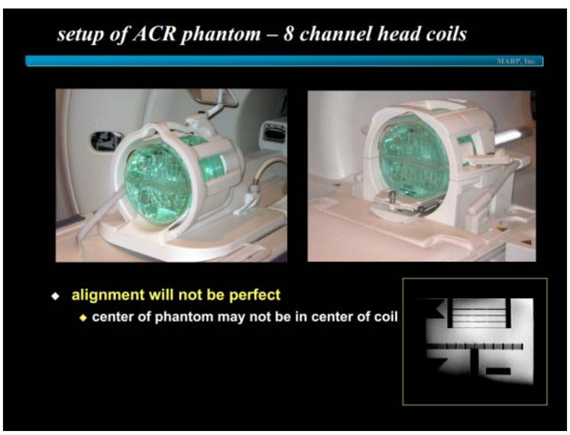
setup of ACR phantom

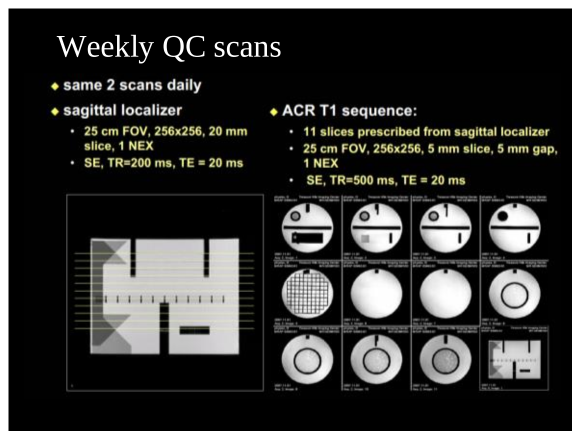
- 3rd party holders
  - designed for ACR phantom
  - designed for specific head coils
  - reproducible

- adjustable
  - alignment
  - centering ??
  - attached to ACR phantom
- ~ $700









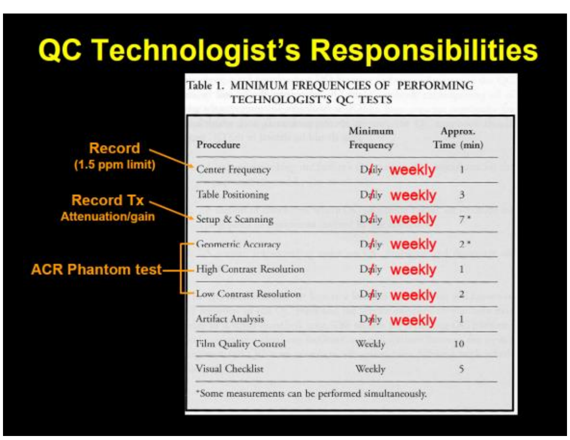
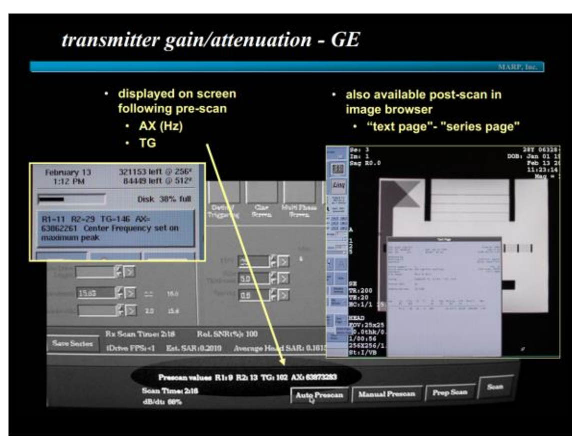


Table 1. MINIMUM FREQUENCIES OF PERFORMING TECHNOLOGIST'S QC TESTS

Procedure	Minimum Frequency	Approx. Time (min)
Center Frequency	Daily weekly	1
Table Positioning	Daily weekly	3
Setup & Scanning	Daily weekly	7*
Geometric Accuracy	Daily weekly	2*
High Contrast Resolution	Daily weekly	1
Low Contrast Resolution	Daily weekly	2
Artifact Analysis	Daily weekly	1
Film Quality Control	Weekly	10
Visual Checklist	Weekly	5

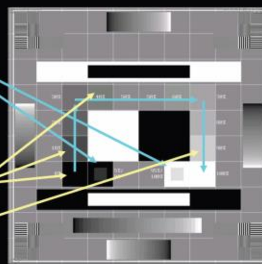
*Some measurements can be performed simultaneously.



laser film QC - setup

MARP, Inc.

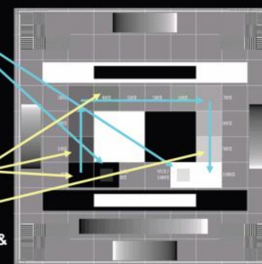
- verify monitor calibration
- view SMPTE pattern on console (default W/L)
  - verify gray levels
    - 0 / 5 % patch
    - 95 / 100 % patch
    - consistent gray-level changes
  - film 6 on 1
    - 4 on 1 if necessary
  - measure OD
    - 0% patch
    - 10% patch
    - 40% patch
    - 90% patch



laser film QC - weekly

MARP, Inc.

- view SMPTE pattern on console (default W/L)
  - verify gray levels
    - 0 / 5 % patch
    - 95 / 100 % patch
    - consistent gray-level changes
  - film 6 on 1
    - 4 on 1 if necessary
  - measure & plot OD
    - 0% patch
    - 10% patch
    - 40% patch
    - 90% patch
  - check film for artifacts & resolution

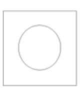


CGMH
Chang-Gung Memorial Hospital
MRI Survey

Facility:____________________ Make:______________________
Physicist:___________________ Model:_____________________
Date:_______________________Field Strength:_______________
Slices
Localizer:20mm single sagittal slice SE through center of phantom

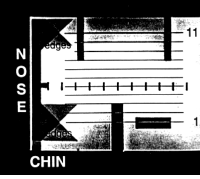
		TR	TE	slice Thick	slice Gap		matrix		Fov	
series	type	ms	ms	mm	mm	NEX	(v)	(Φ)	mm	Comment
ACRT1	SE	500	20	5	5	2	256	256		
ACRT2	dualSE	2000	20,80	5	5	2	256	256		use2nd echo

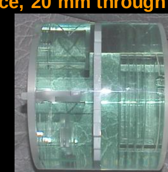
Incident orientation (A,P,L,R phase encoding direction):



ACQUISITION

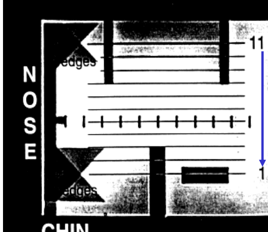
1. Phantom
   - Cylinder (10 mM $NiCl_2$ + 75 mM NaCl)
   - Length (inside) = 148 mm
   - Diameter (inside) = 190 mm
2. Localizer
   - Sagittal, SE, single slice, 20 mm through center

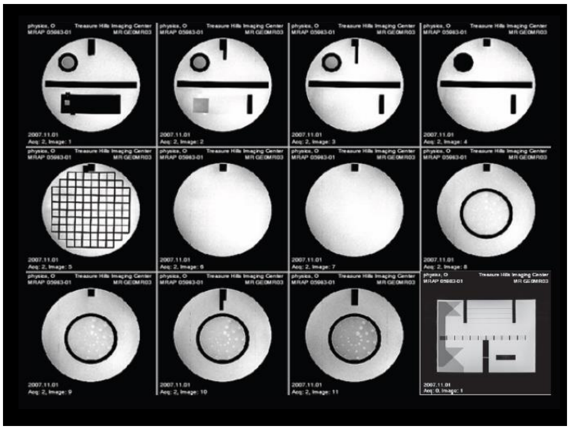




ACQUISITION

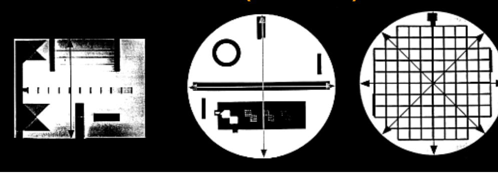
1. ACR T1
   - SE, TR = 500 ms, TE = 20 ms, NEX = 2
   - 11 slices, SW = 5 mm, Gap = 5 mm
   - pixel size = 1 mm x 1 mm
2. ACR T2
   - dual SE, TR = 2000 ms, TE = 20/80 ms, NEX = 2
   - 11 slices, SW = 5 mm, Gap = 5 mm
   - pixel size = 1 mm x 1 mm
   - use the 2nd echo images
3. Site T1 protocol
4. Site T2 protocol





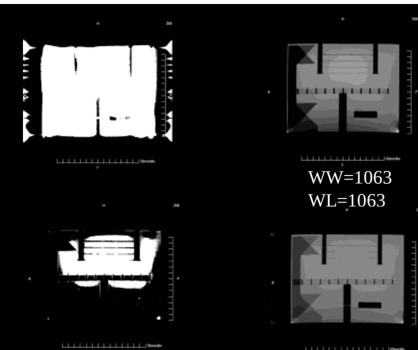
GEOMETRIC ACCURACY

1. Use Localizer
   - length
2. Use Slice 1 (ACR T1)
   - diameter (2 measures)
3. Use Slice 5 (ACR T1)
   - diameter (4 measures)

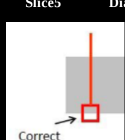


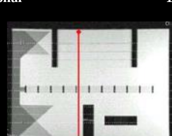
GEOMETRIC ACCURACY

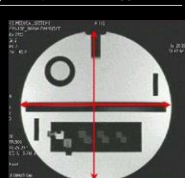
1. True length = 148 mm
2. True diameter = 190 mm
3. Criteria : +/- 2 mm
4. Measurement condition:
   - window ~ 0, level ~ 1/2 I_{water}(FWHM)
     (1) set window to 0 (or 1)
     (2) lower level : water all white
     (3) raise level : half water turn dark (=I_{water})

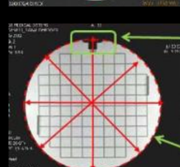


Slice	Measurement	Measured (mm)	Actual (mm)	Diff.	PASS
Localizer	End-end		148		
Slice1	Top-bottom		190		
Slice1	Left-right		190		
Slice5	Top-bottom		190		
Slice5	Left-right		190		
Slice5	Diagonal		190		
Slice5	Diagonal		190		



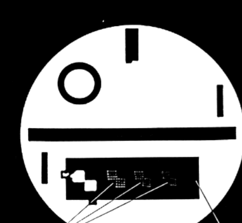


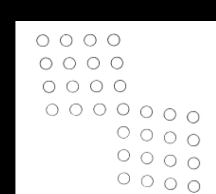




HIGH CONTRAST SPATIAL RESOLUTION

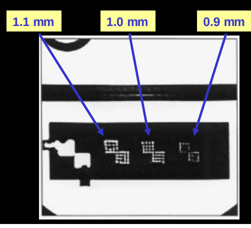
1. Use slice 1 of ACR T1 & ACR T2
   - magnify x 2 ~ 4, adjust window/level

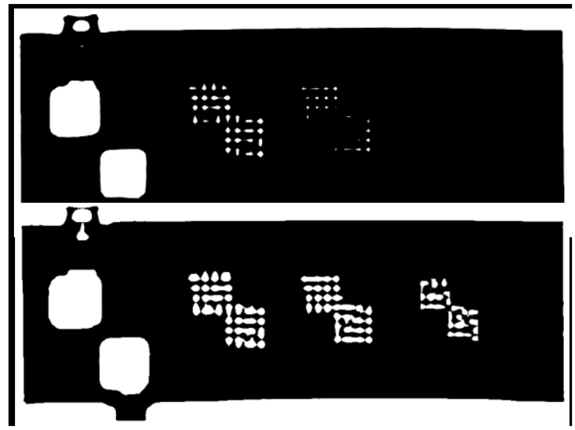




HIGH CONTRAST SPATIAL RESOLUTION

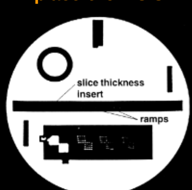
2. Observe UL holes for ↔ resolution
3. Observe LR holes for ↕ resolution
   - All 4 holes in a single row/column are distinguishable : resolved for that size
4. Criteria : 1.0 mm

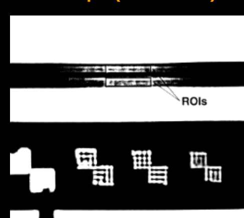




SLICE THICKNESS ACCURACY

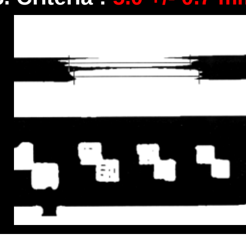
1. Use slice 1 of ACR T1 & ACR T2
   - magnify x 2 ~ 4
2. Adjust the window/level
   - adjust the level to see the ramps (window~0)
   - place the ROIs

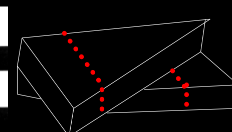


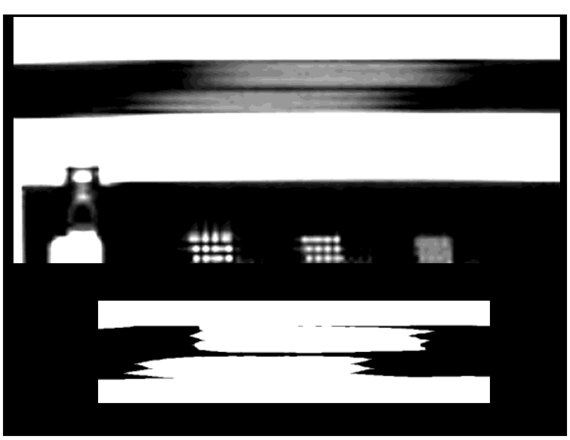


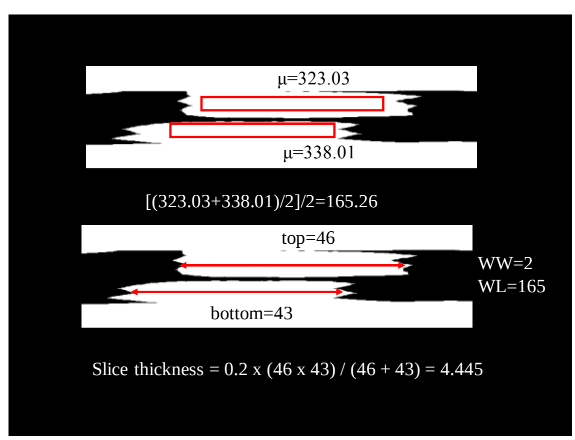
SLICE THICKNESS ACCURACY

3. Set window ~ 0, level = 1/2 mean(ROIs)
4. Measure the length of the top/bottom ramps
   - SW = 0.2 x (top x bottom) / (top + bottom)
5. Criteria : 5.0 +/- 0.7 mm



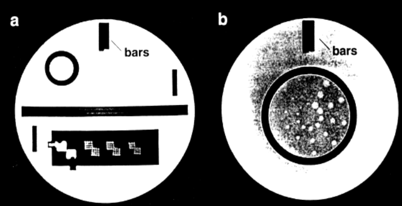






SLICE POSITION ACCURACY

1. Use slice 1 & 11 of ACR T1 & ACR T2
   - magnify x 2 ~ 4
2. Narrow window, level = 1/2 I_{water}



SLICE POSITION ACCURACY

3. Measure differences between bars
   - left longer : “-”
   - right longer : “+”
4. Criteria : each length difference <= 5.0 mm

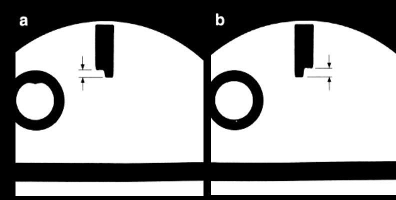


IMAGE INTENSITY UNIFORMITY

1. Use slice 7 of ACR T1 & ACR T2
2. Make a circular large ROI
   ~ 200 - 215 cm^2

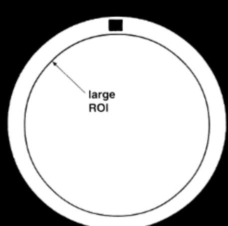
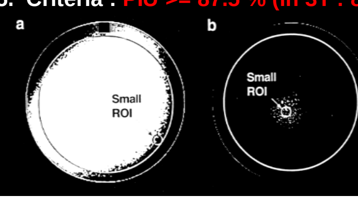
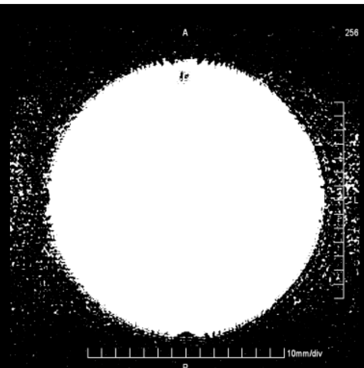


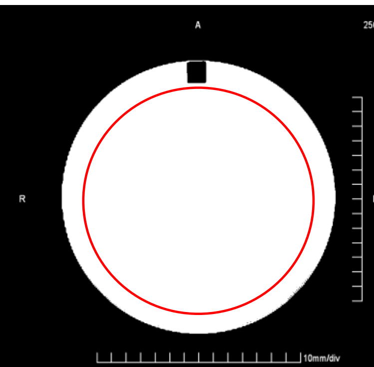
IMAGE INTENSITY UNIFORMITY

3. Adjust level to see highest / lowest signal in ROI (window ~ 0)
   - use 1 cm^2 small ROI, record mean
4. Percent Integral Uniformity (PIU) =
   100 x [1- (high - low) / (high + low)]
5. Criteria : PIU >= 87.5 % (in 3T : 82%)

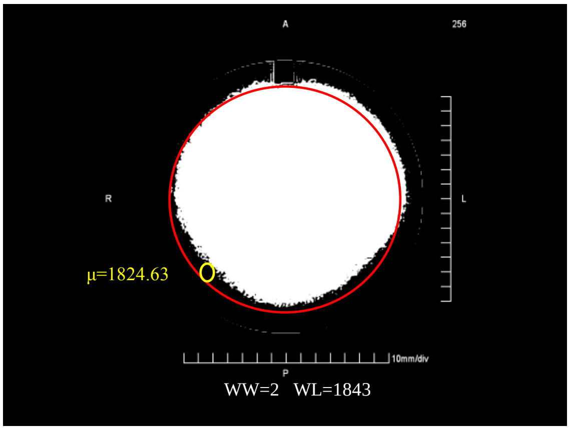


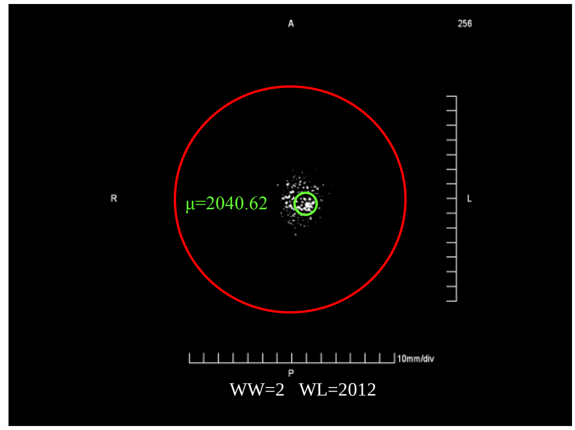


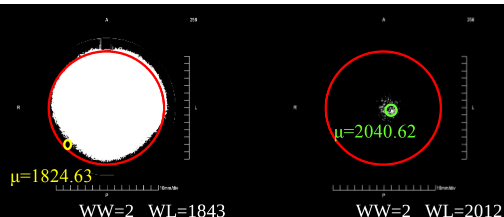
WW=2 WL=18



WW=2 WL=1266







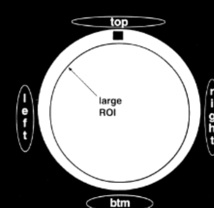
Percent Integral Uniformity (PIU) =

100 x [1- (2040.62 – 1824.63) / (2040.62 + 1824.63)]

= 94.412 %

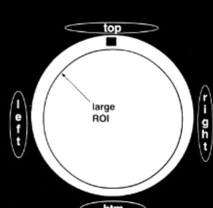
PERCENT SIGNAL GHOSTING

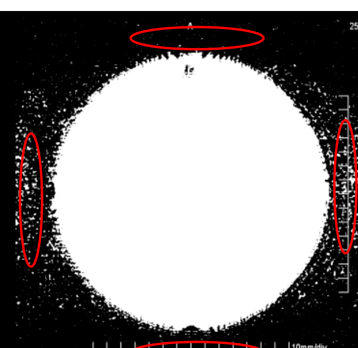
1. Use slice 7 of ACR T1
2. Make a circular large ROI, record mean
   ~ 200 - 215 cm^2
3. Make 4 elliptical ROIs, record mean of each
   ~ 10 cm^2 , with 4:1 ratio



PERCENT SIGNAL GHOSTING

4. Ghosting ratio =
   Abs {[(top + bottom) - (left + right)] / [2 x large ROI]}
5. Criteria : <= 0.025





Ghosting ratio =

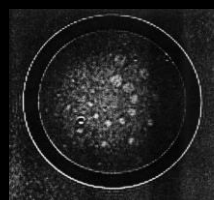
Abs {[(9.98 + 9.58) - (15.54 + 16.08)] / [2 x 1932.79]}

= 0.0030164

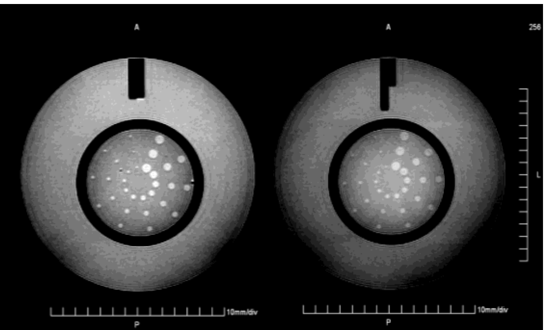
LOW CONTRAST OBJECT DETECTABILITY

1. Use slice 8, 9, 10 & 11 of ACR T1 & ACR T2
   - 1.4%, 2.5%, 3.6% & 5.1%
   - adjust window / level / mag. for optimum contrast

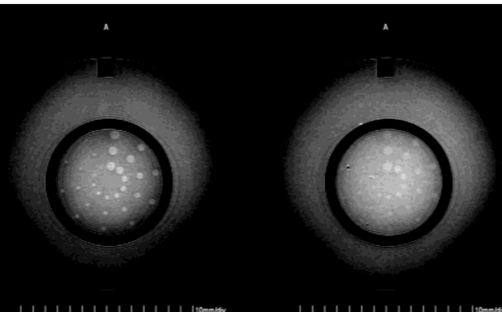
slice 11



magnified slice 8



WW=613 WL=1714 WW=303 WL=1493



WW=264 WL=1960 WW=270 WL=1922

LOW CONTRAST OBJECT DETECTABILITY

2. For each slice, count complete spokes
   - all 3 disks are discernible
   - from large to small
   - stop if one spoke incomplete
3. For each series, add total spokes from all four slices for the score
4. Criteria : score >= 9 (in 3T : 37)

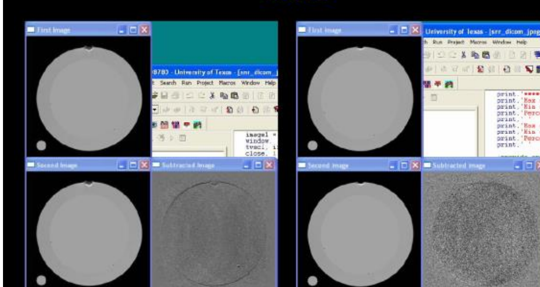
SNR

- Depends on RF coil selection and phantom positioning.
- Preferred method is NEMA:

$$SNR_{NEMA} = \frac{\sqrt{2}\bar{S}}{\sigma}$$

Acquire two images w/ a homogeneous phantom, measure in a ROI w/ at least 75% of the phantom area.

SNR



Head coil, BW = 3.6 kHz   Head coil, BW = 15.6 kHz

SNR

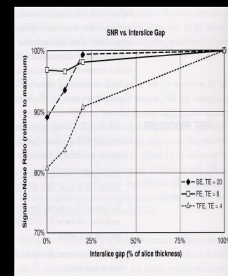
- If NEMA method is not practical, a single image can be used, assuming the background signal distribution is Rician:

$$SNR = \frac{\overline{S}}{\left[\sigma_{bkg} / \sqrt{2 - \frac{\pi}{2}}\right]} \approx \frac{0.655\,\overline{S}}{\sigma_{bkg}}$$

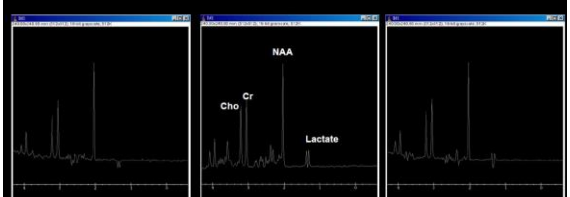
- SNR should be measured for ALL coils.
- For surface and phased-array coils, ROI should be showed in a film or digital image.
- For phased-array coils, SNR is better obtained for each coil element

Inter-slice RF Interference

1. Multi-slice imaging w/ slice gap = 0, 0.5, 1.0 and 5 mm gap.
2. Measure SNR
3. Limit: $SNR_0/SNR_{100\%} > 0.8$



MRS



TE = 144 ms   TE = 25 ms   TE = 80 ms

The Artifacts in MRI

新光吳火獅紀念醫院 放射診斷科
技術專員 李正輝

Introduction

- *All MRI images have artifacts in some degrees.*
- *Why and How ?*
- *How to remedy the artifacts encountered in MRI.*

Introduction

- *Motion artifacts*
  - *patient motion, physiological motion, flow*
- *Inhomogeneity artifacts*
  - *mental artifacts, zipper artifacts, cross talk*
- *Digital imaging artifacts*
  - *aliasing, truncation, partial volume, herring-bone artifacts, halo artifacts, Gradient nonlinearities, chemical shift*

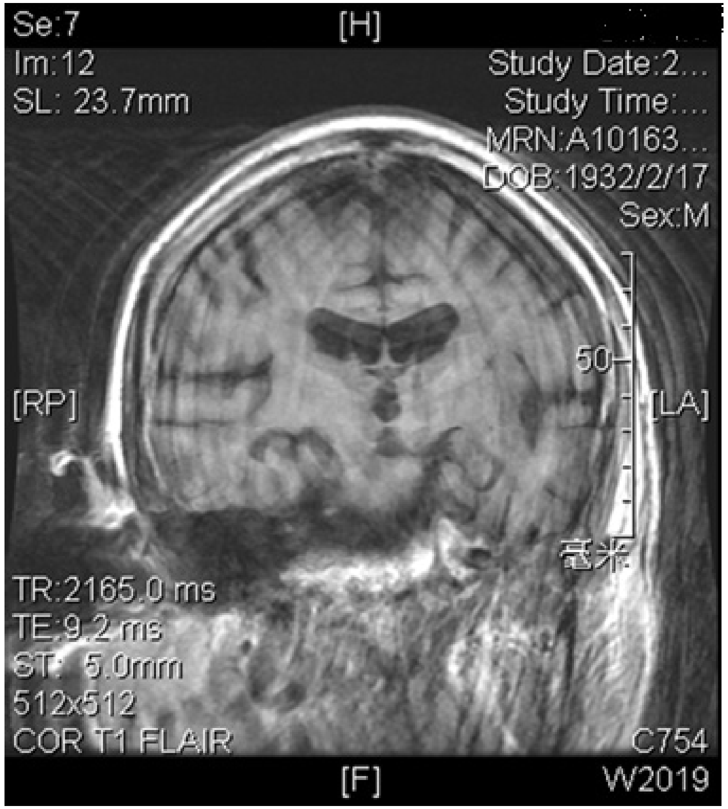
Motion Artifacts

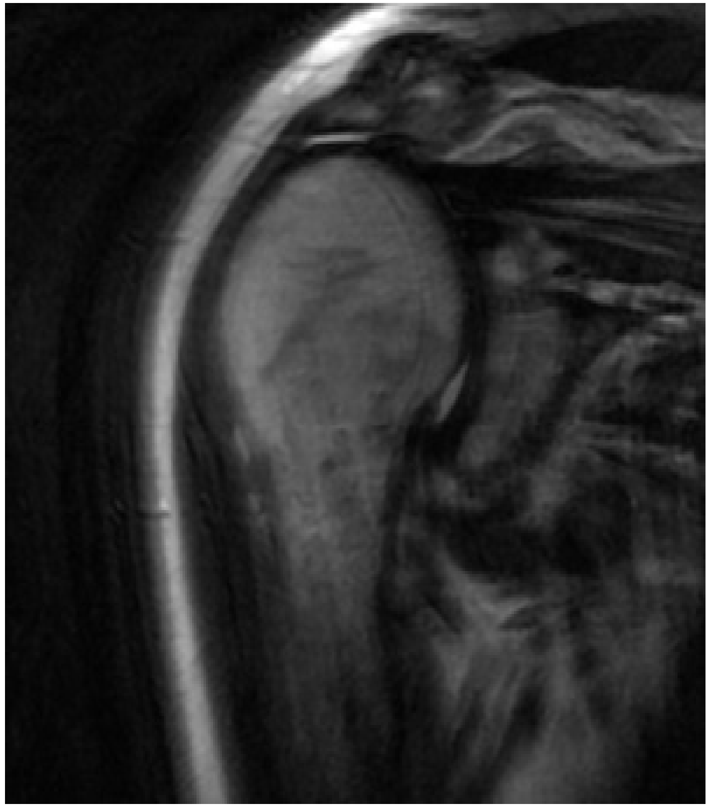
- *Patient motion*
  - *voluntary motion, involuntary motion*
- *Physiological motion*
  - *respiration, cardiac motion, peristaltic*
- *Occurring in phase encoding direction*

Motion Artifacts

- *Solution of patient motion*
  - *fixed patient, repeat scan, reduce scan time, drug-assisted*
- *Solution of physiological motion*
  - *hold on breath, respiration gating, respiratory compensation, ECG gating, fast scan technology, drug-assisted*

- *Patient motion*





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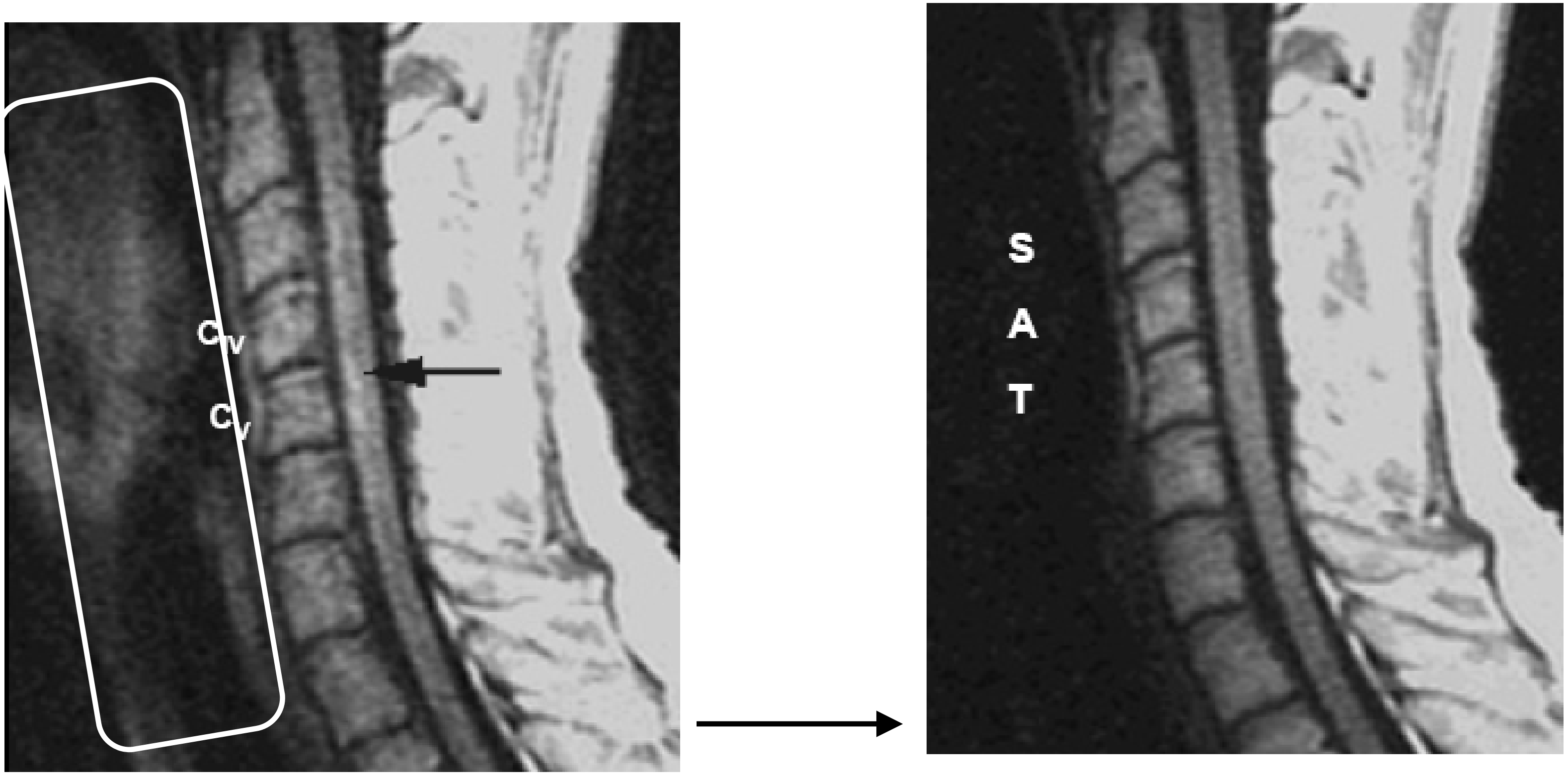
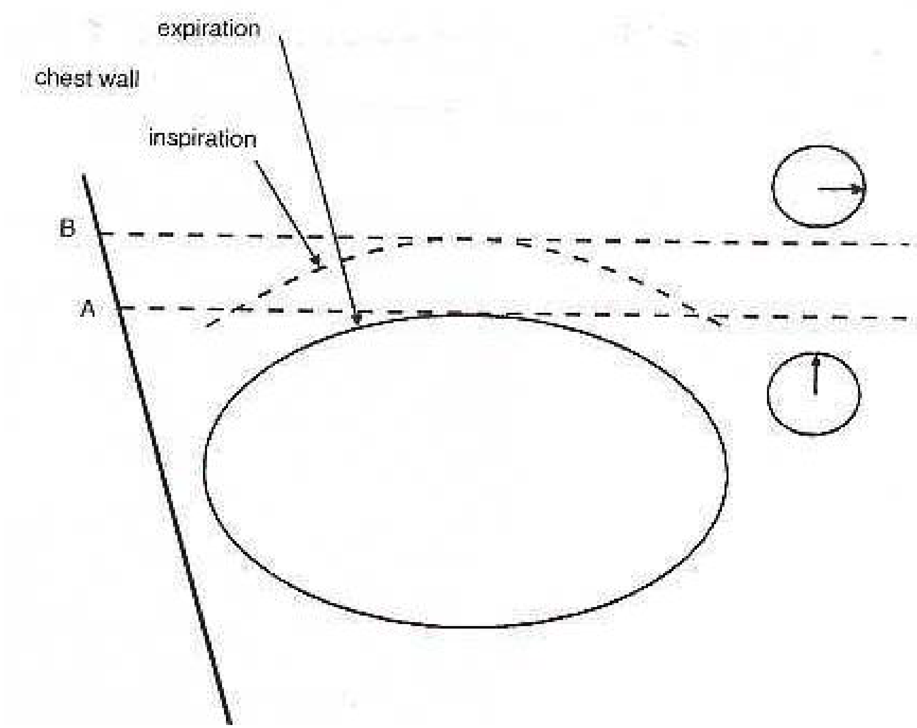
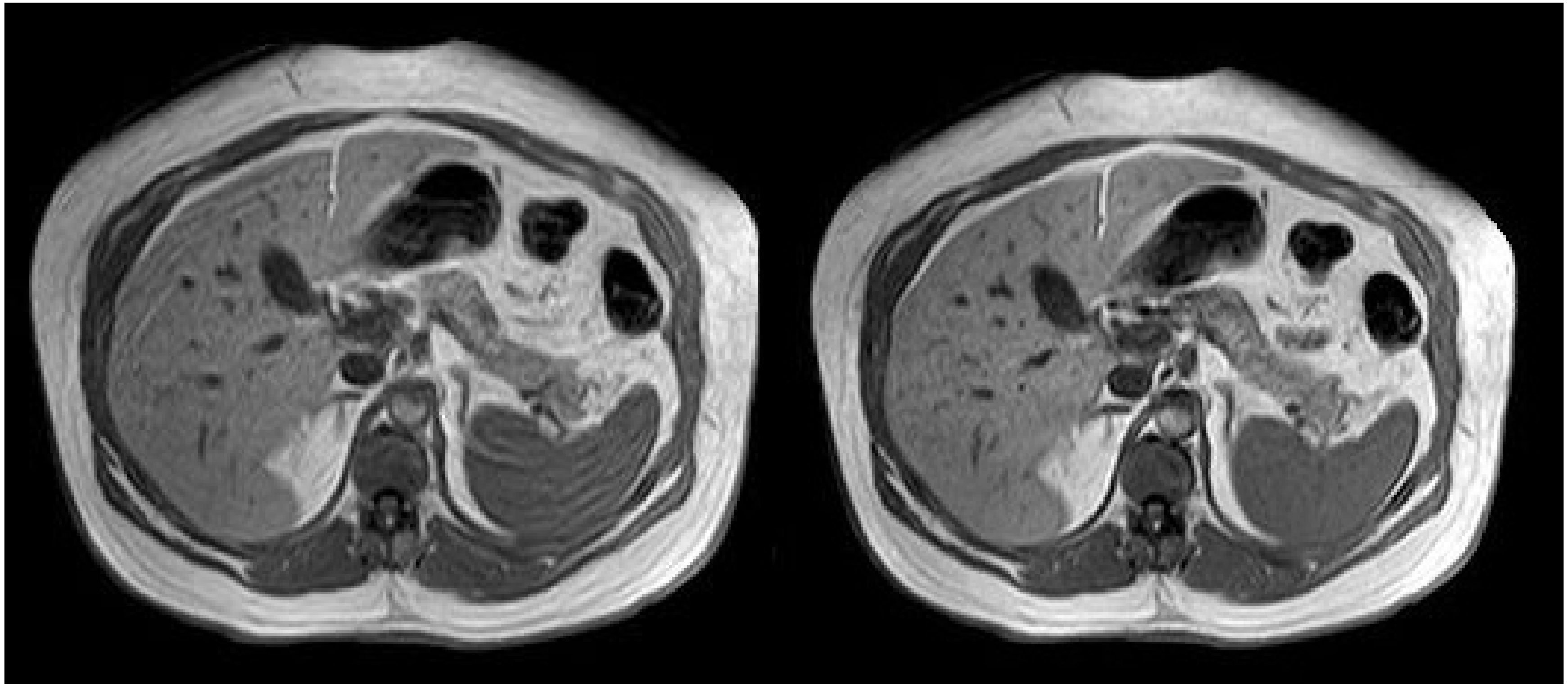


加□saturation band

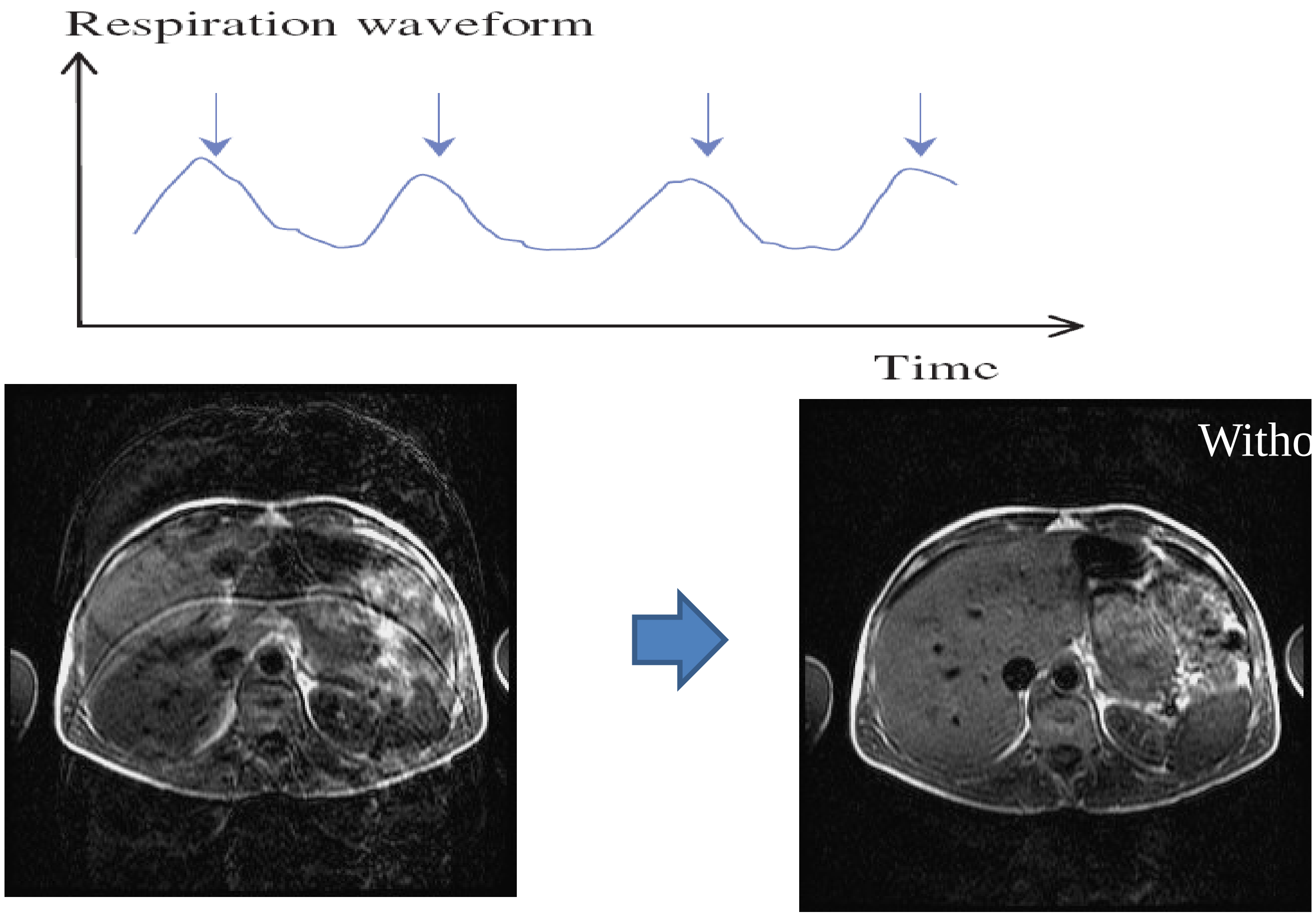
Motion Artifact(***Respiratory)***

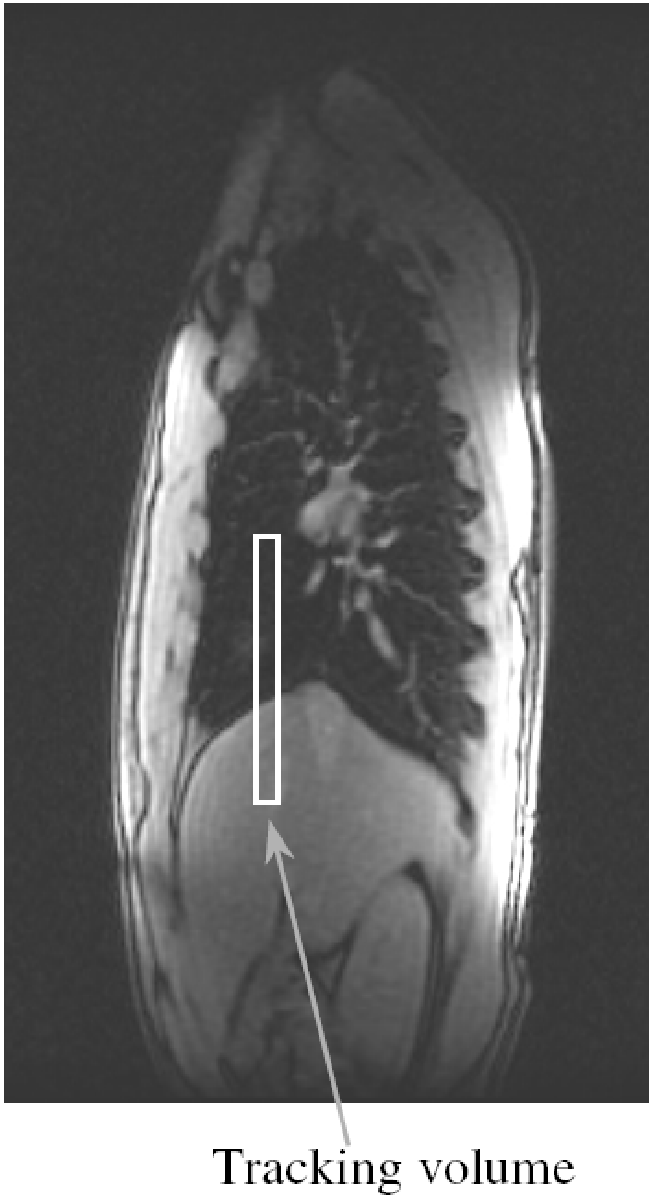




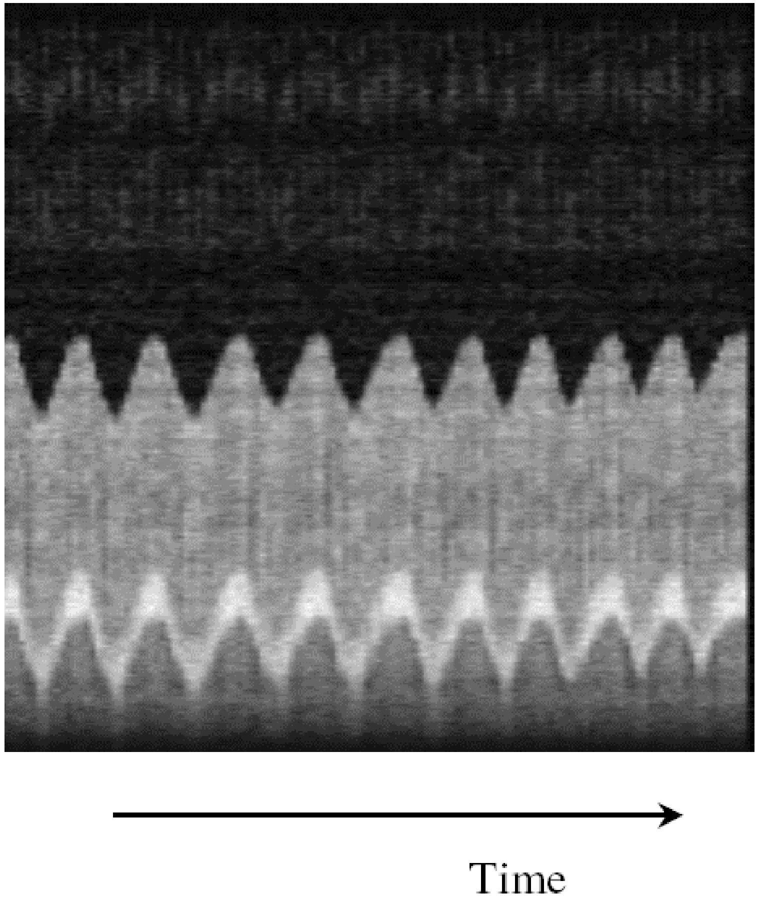
Respiration *Breath-hold*

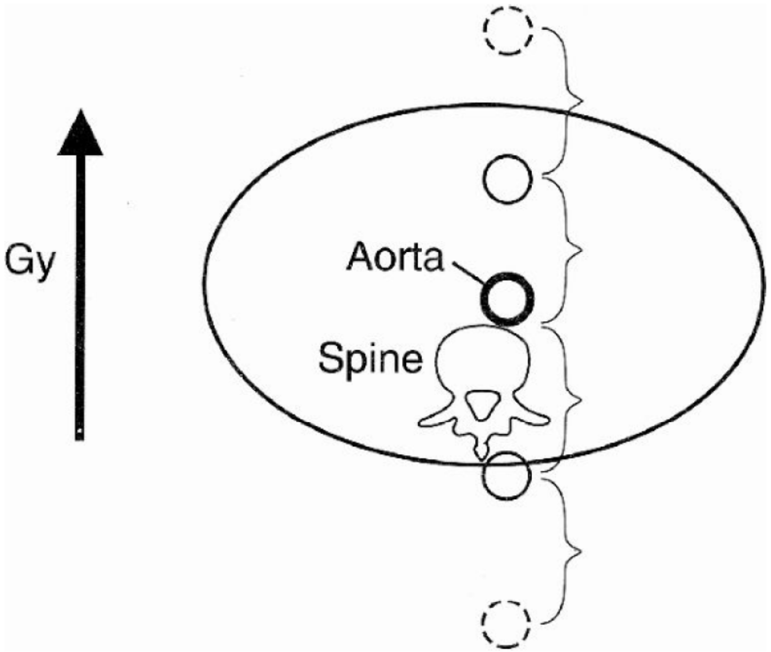
Respiration Gating

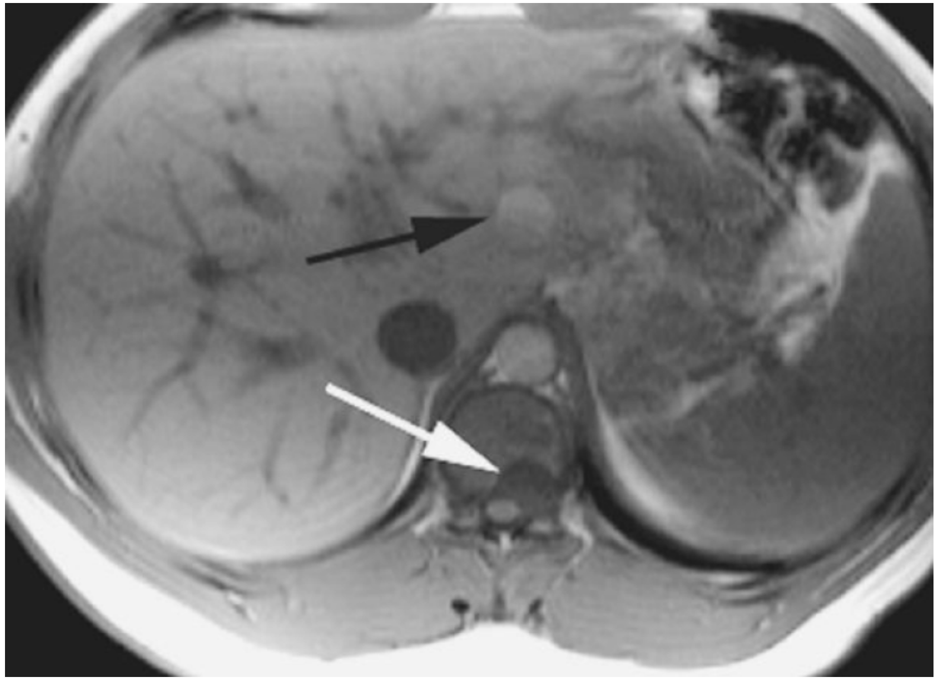




Navigator

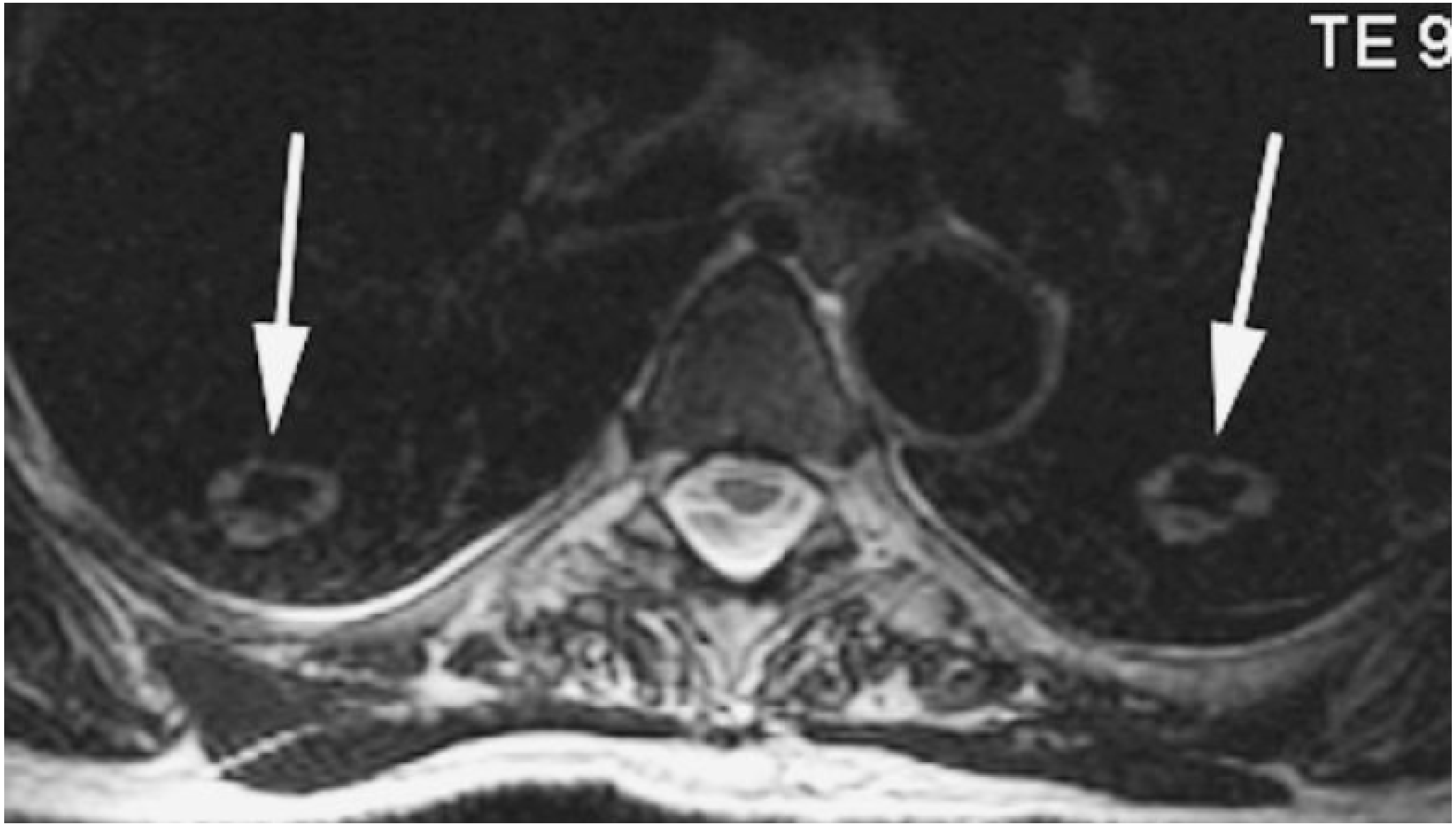




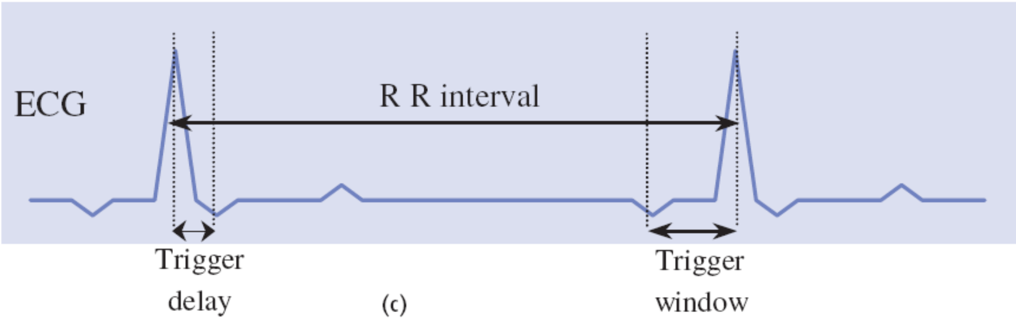


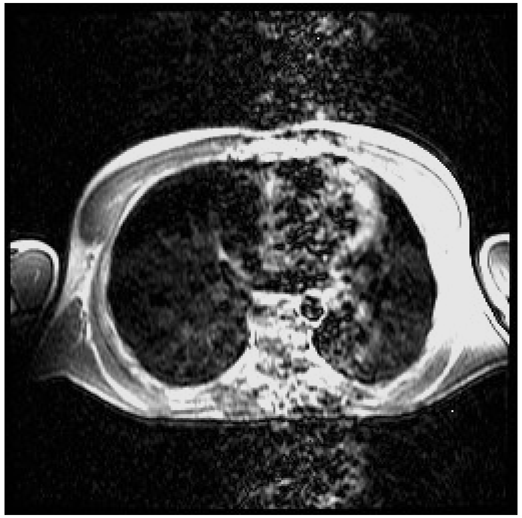
SEP = Acquisition time/T(motion)

???


TE 9

ECG Gating

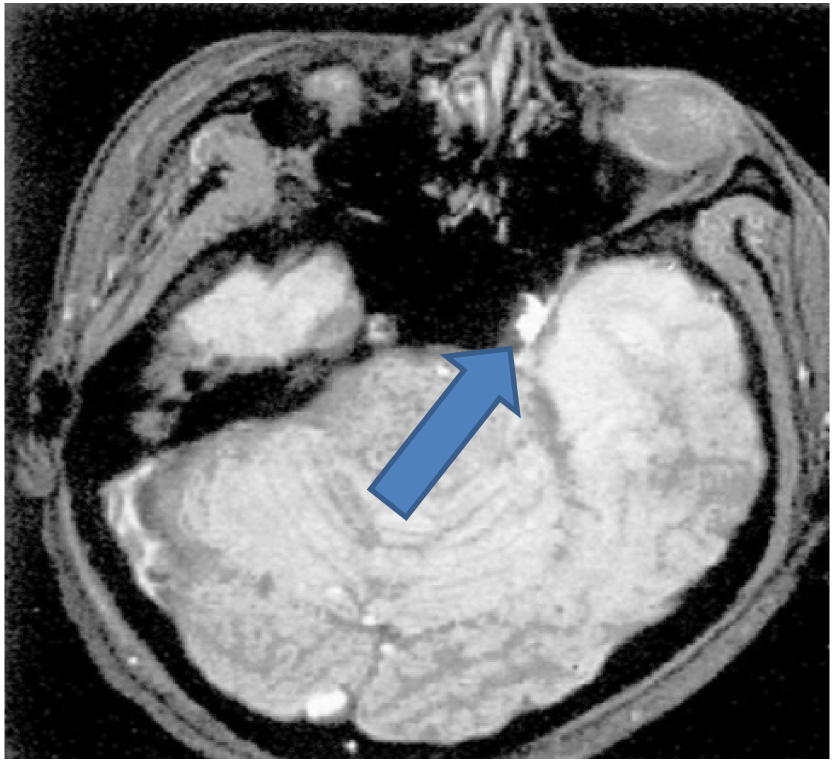




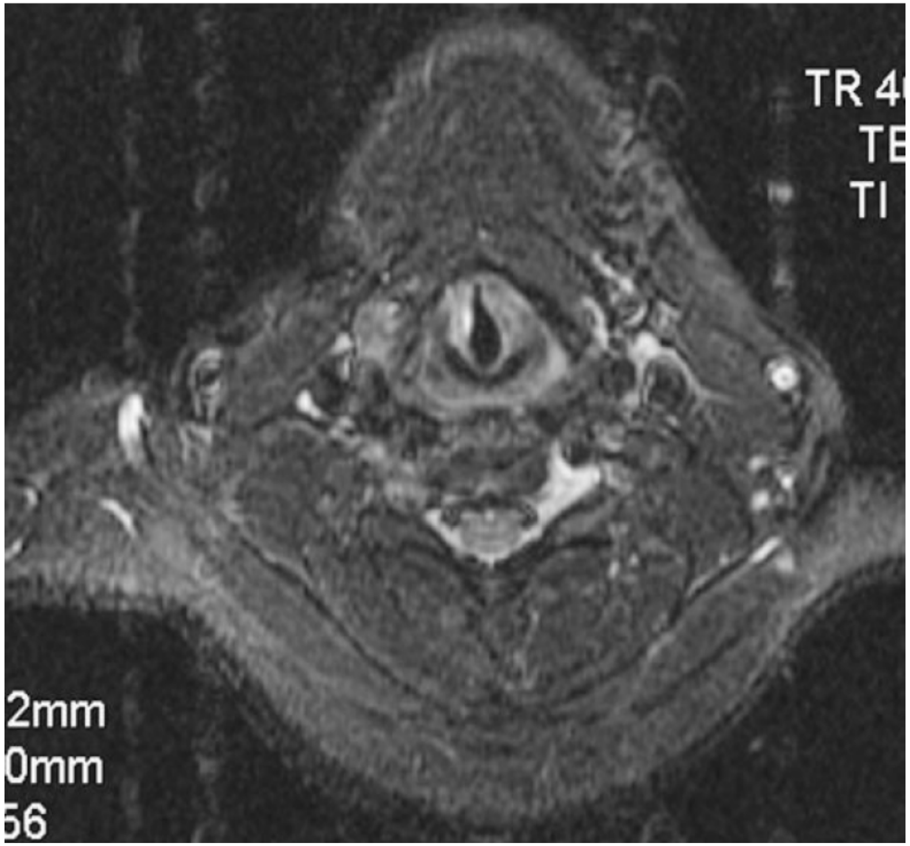
Flow Motion Artifact

- *Artifact or non artifact? There are two sides of same coin*
- *In-flow effect (flow related enhancement, FRE)*
  - *Spin echo: dark signal*
  - *Gradient echo: bright signal*
- *Velocity-induced phase effects*
  - *Resonant frequencies are changing continuously*
  - *Incorrect phase angle for their real position*
  - *Artifact on phase encoding direction*

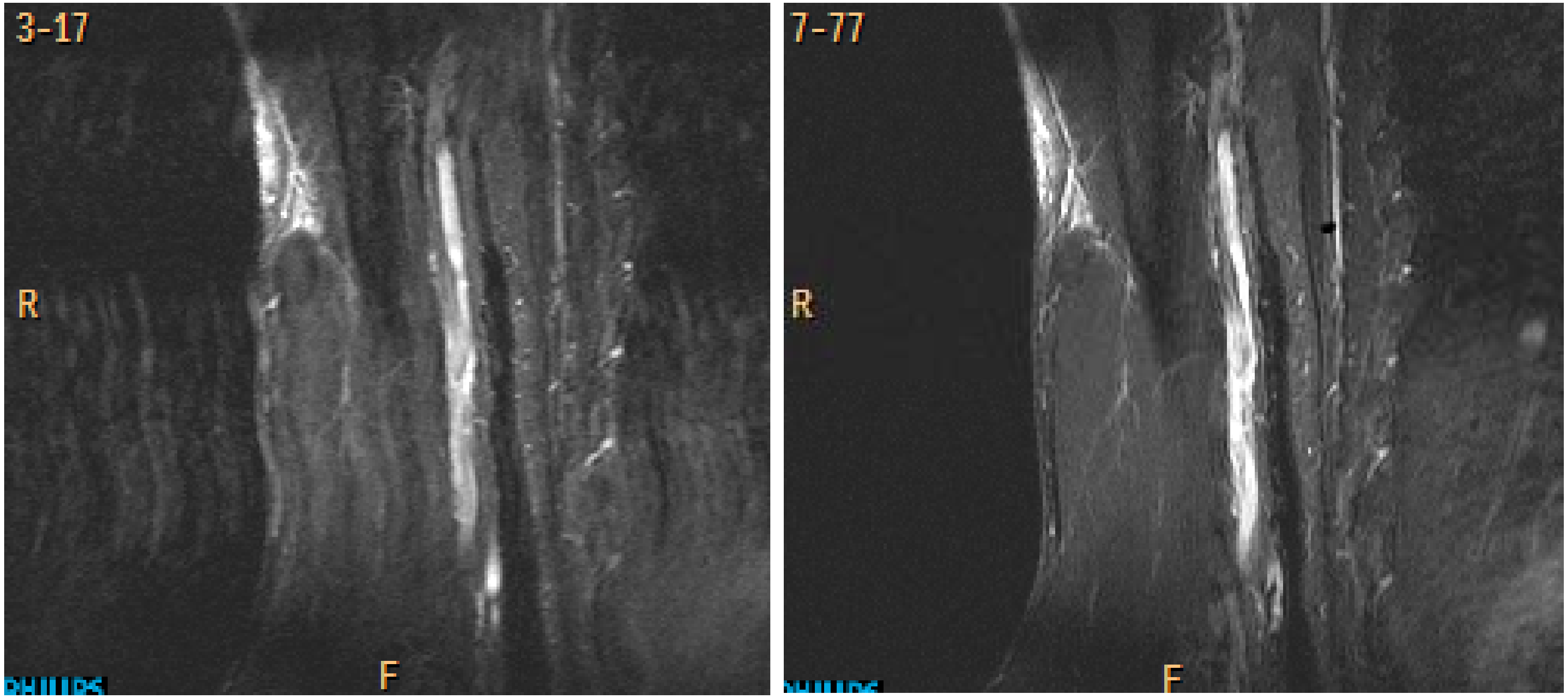
Dark & Bright Flow



Flow artifact

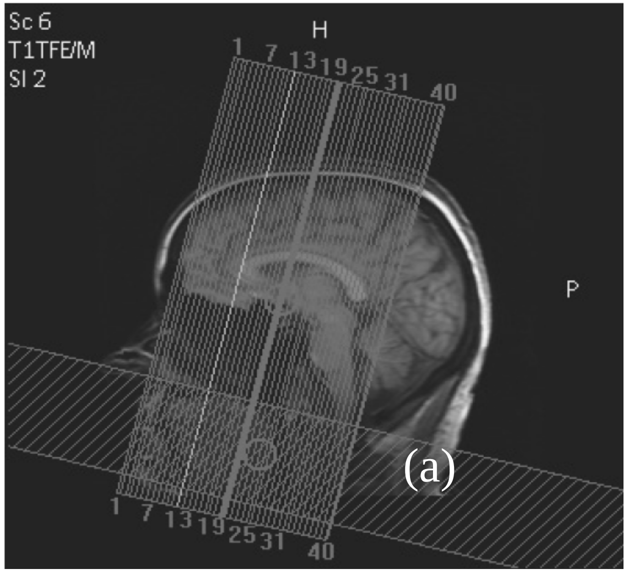


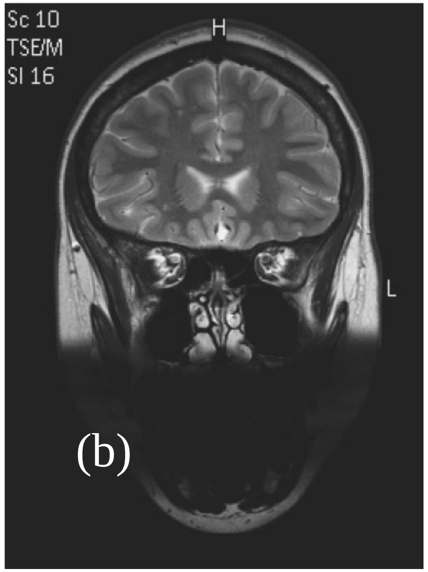
???


3-17
R
F
PHILIPS
7-77
R
F

Avoiding FRE Artifacts

- *Spatial saturation bands, also known as REST slabs or pre-sat bands, are simply slice selections, and can be used in many ways*





Inhomogeneity artifacts

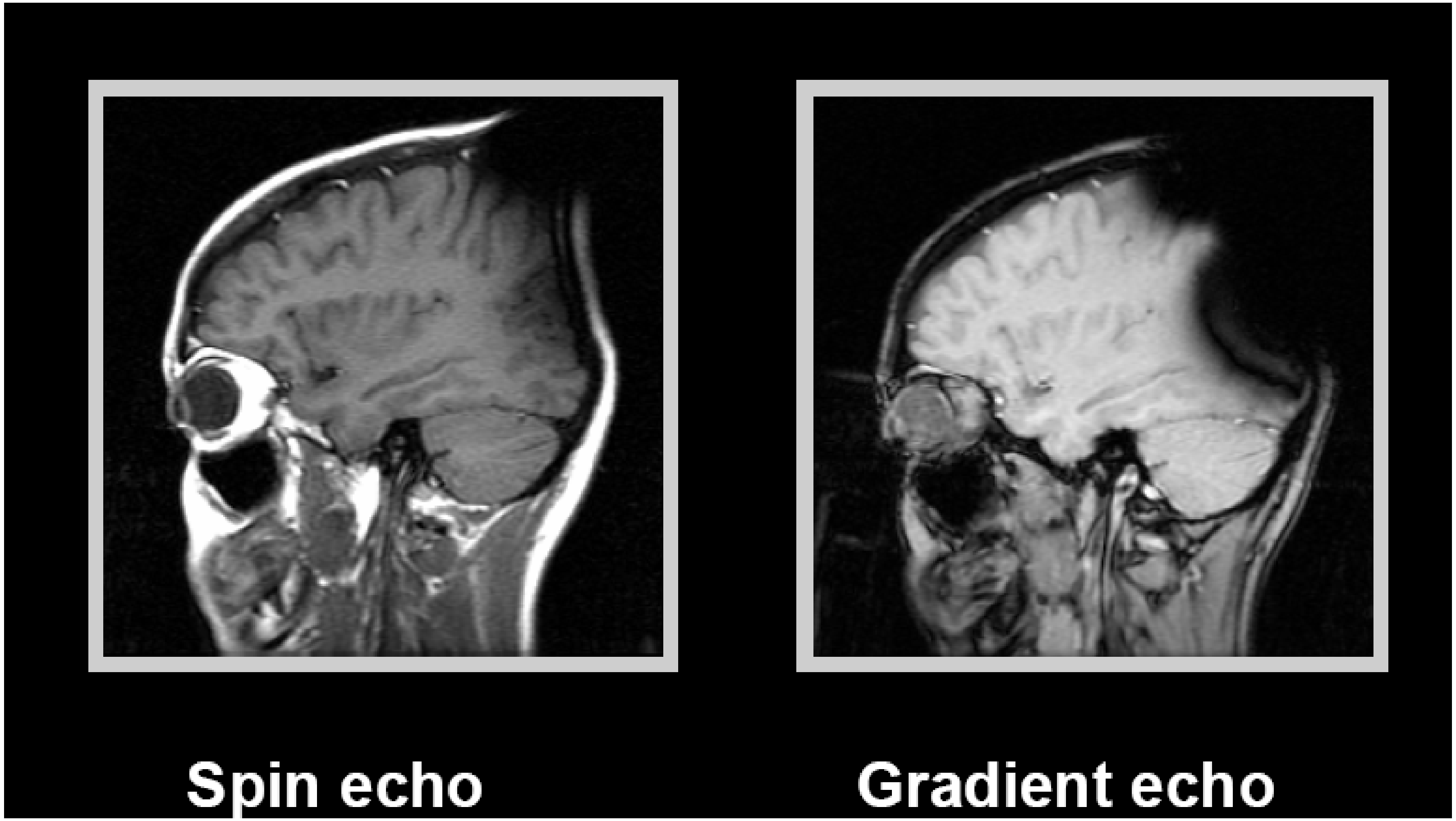
Susceptibility artifacts

- *Susceptibility artifacts in MRI occur at interfaces of differing magnetic susceptibilities, such as at tissue-air and tissue-fat interfaces (examples include paranasal sinuses, skull base, and sella)*

- *There are caused by inhomogeneities , susceptibility artifacts are generally worse on gradient-echo images than spin-echo images.*

Mental Artifacts

- *Metals caused homogeneity change*



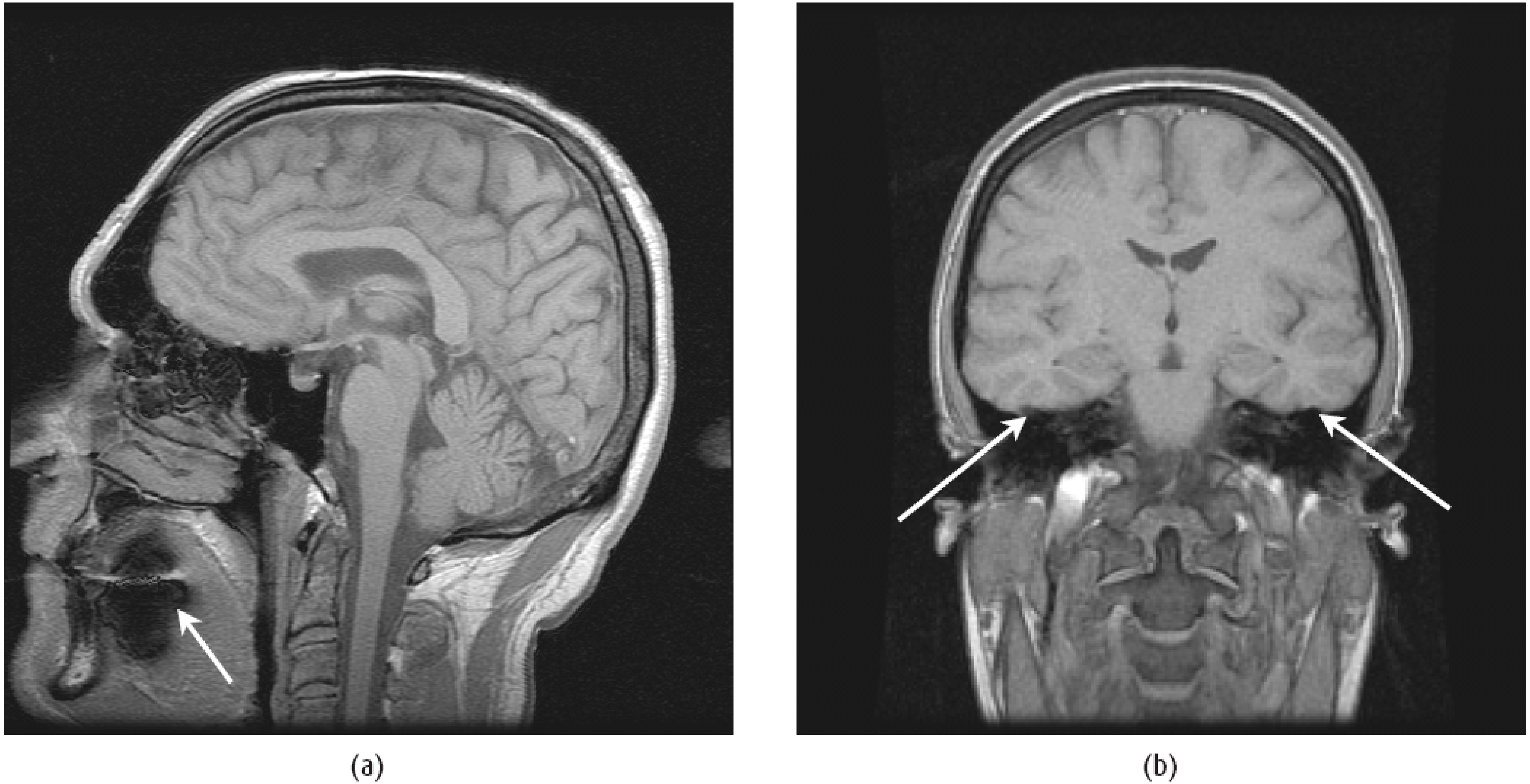
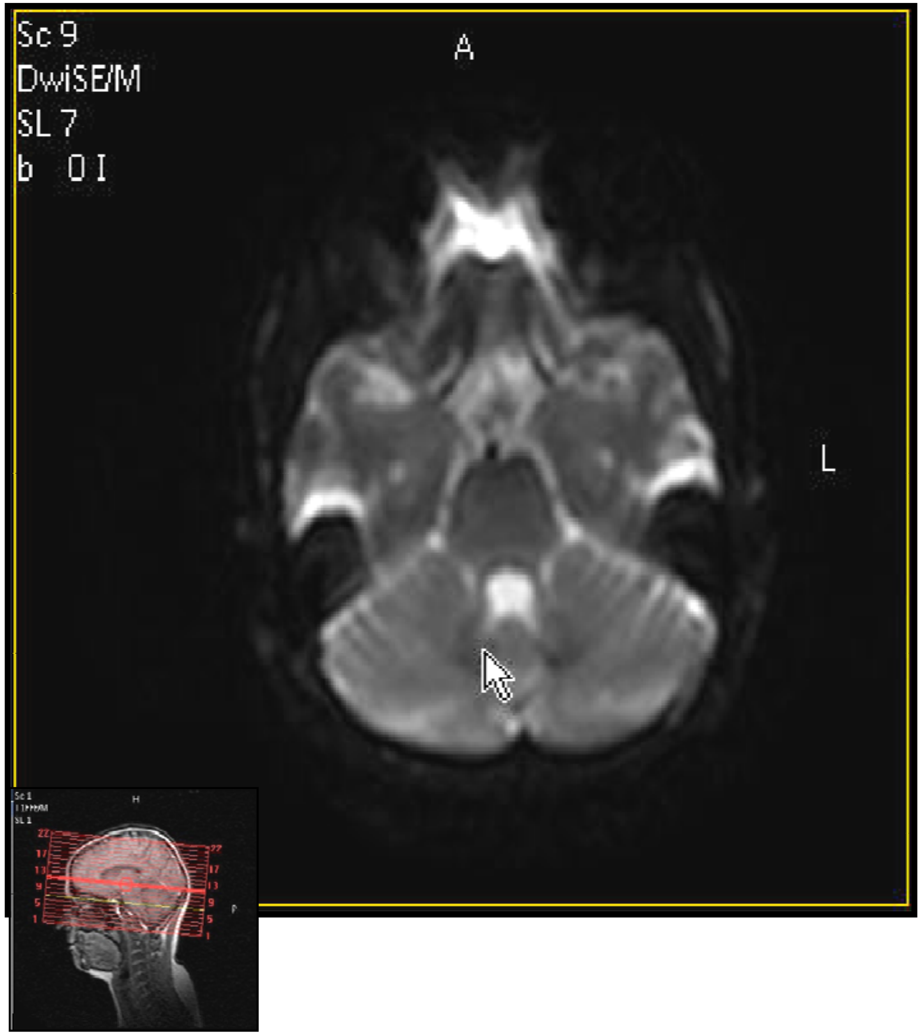
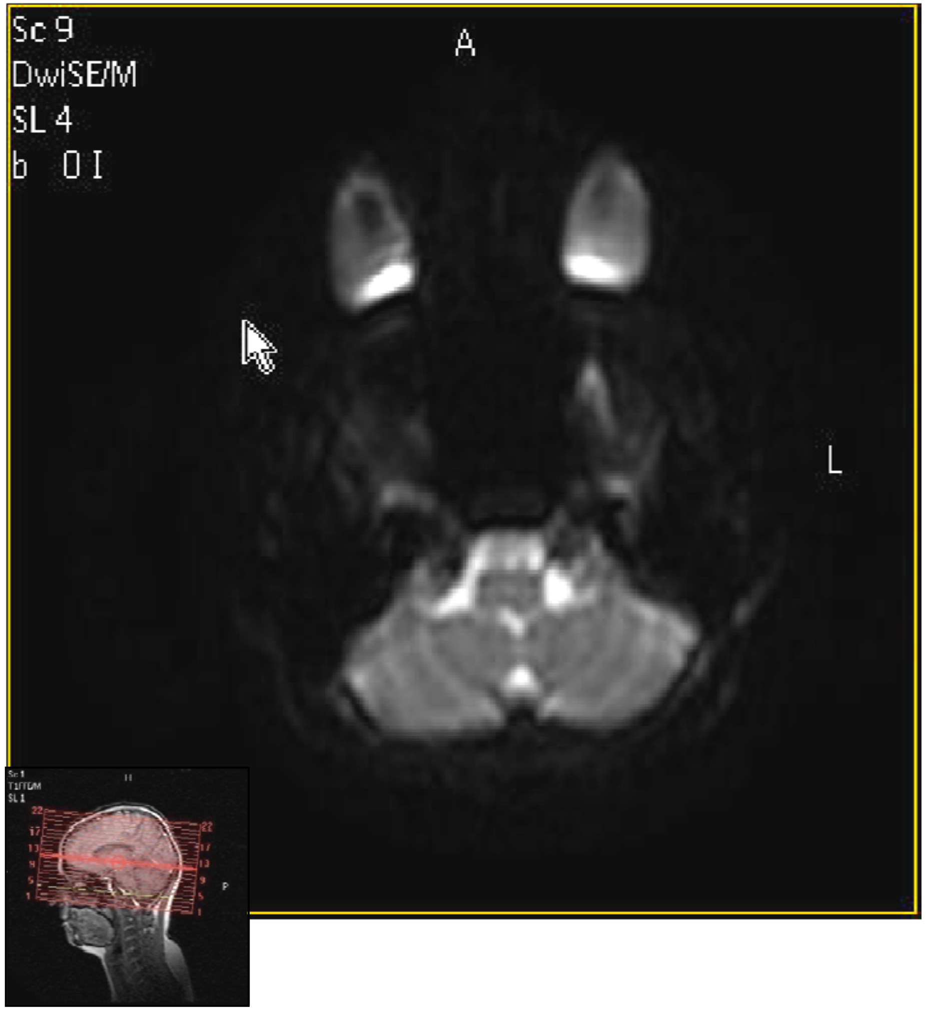


Figure 6.19 (a) Metal artefact from dental work on a spin-echo image. (b) Susceptibility artefact in the temporal lobes on a gradient-echo image.


Sc 9
DwiSE/M
SL 7
b 0 I
A
L

Sc 9
DwiSE/M
SL 4
b 0 I
A
L

???

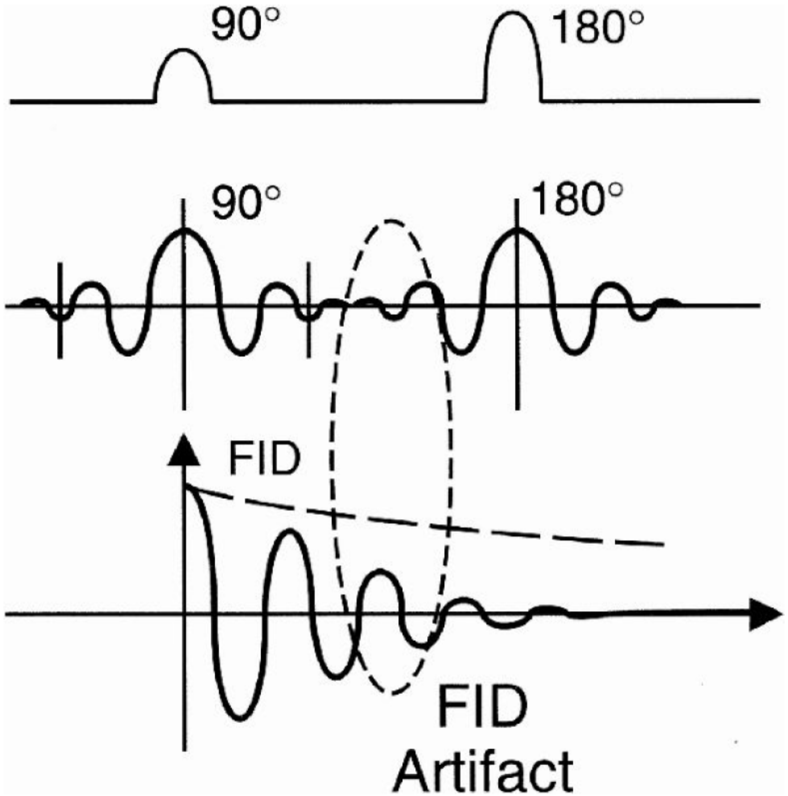
Zipper artifact (RF)

- *This artifact is one form of* ***central artifacts***
- *Most of zipper artifacts result from inhomogeneities of the magnetic field caused by interferences with radio frequency from various sources.*
- *Software and equipment problems can also cause zipper lines in both directions*

FID Artifacts

- *Free induction decay (FID) artifacts occur due to overlapping of side lobes of the 180^0 pulse with the FID before it has had a chance to completely decay. This overlapping causes a "zipper" artifact*
- *Along the frequency -encode direction.*

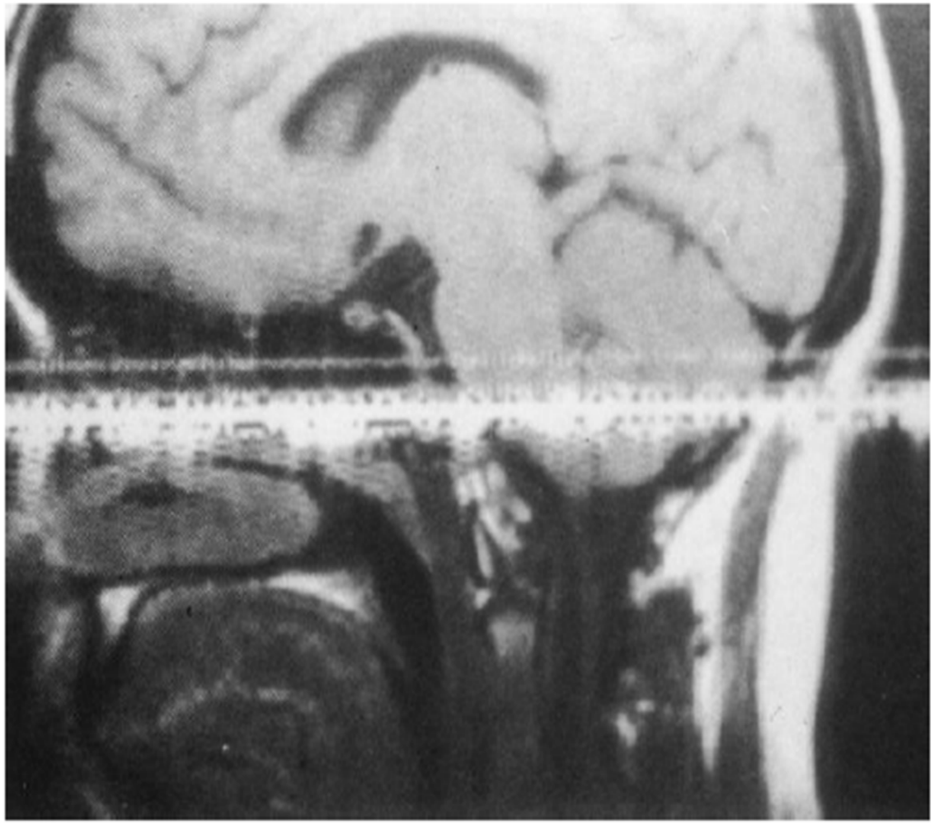
FID Artifacts



Remedy

- *Increase the TE (increases the separation between the FID and the 180^0 RF pulse).*
- *Increase slice thickness. This in effect results from selecting a wide RF BW , which narrows the RF signal in the time domain, thus lowering chances for overlap.*

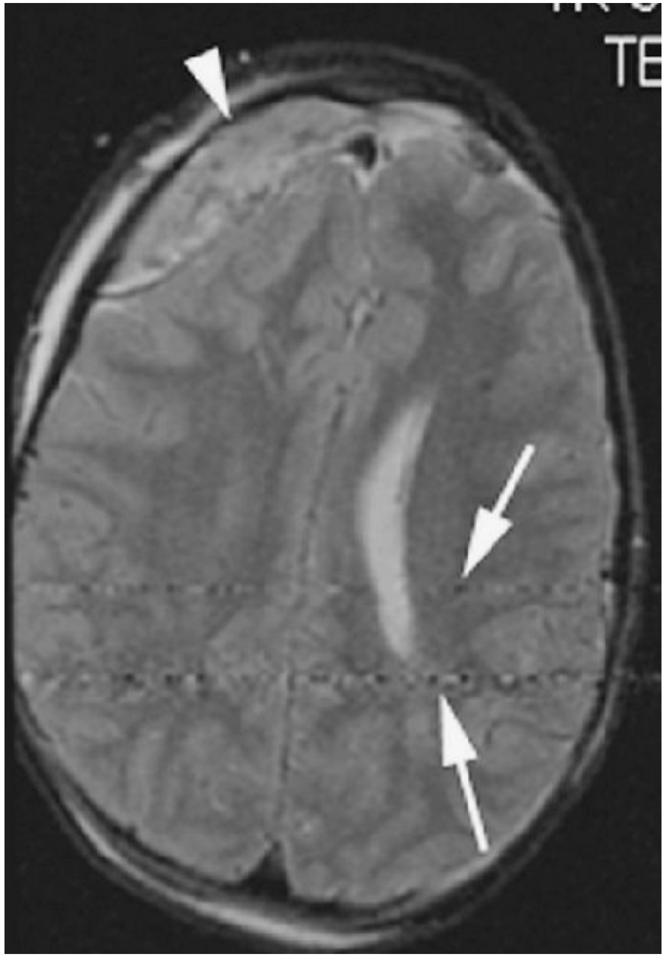
Zipper artifact



RF Feedthrough Zipper Artifact

- *This artifact occurs when the excitation RF pulse is not completely gated off during data acquisition and "feeds" through the receiver coil. It appears as a "zipper" stripe along the phase-encoding axis at zero frequency*

RF Noise

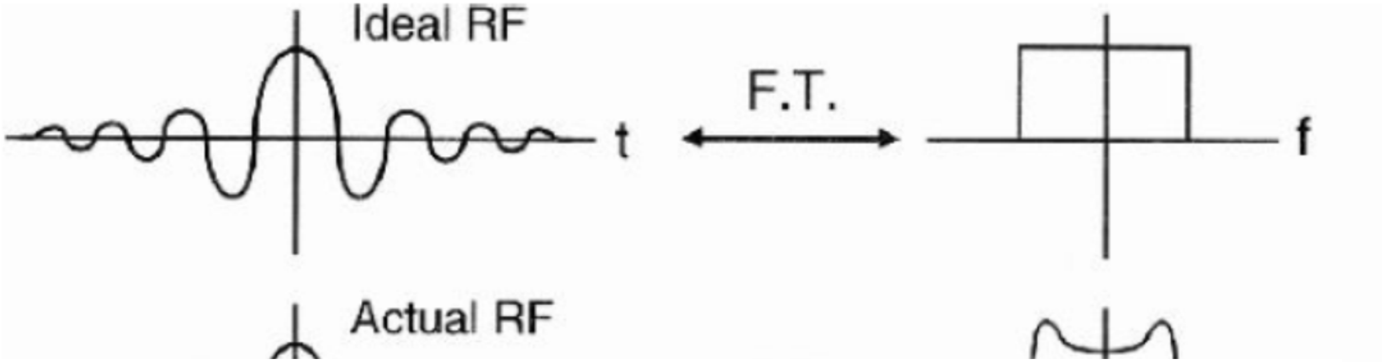


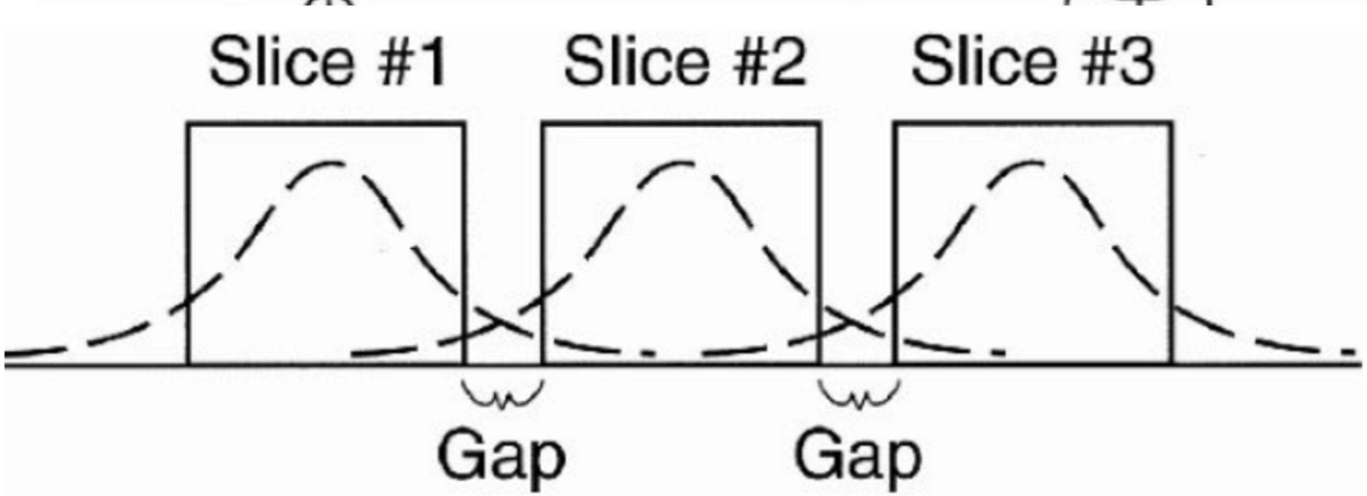
- *RF noise is caused by unwanted external RF noise (e.g., TV channel, a radio station, a flickering fluorescent light, patient electronic monitoring equipment). It is similar to RF feedthrough except that it occurs at the specific frequency (or frequencies) of the unwanted RF pulse(s) rather than at zero frequency*

Remedy for Zipper Artifact

- *Improve RF shielding.*
- *Remove monitoring devices if possible.*
- *Shut the door of the magnet room!*

Cross-talk



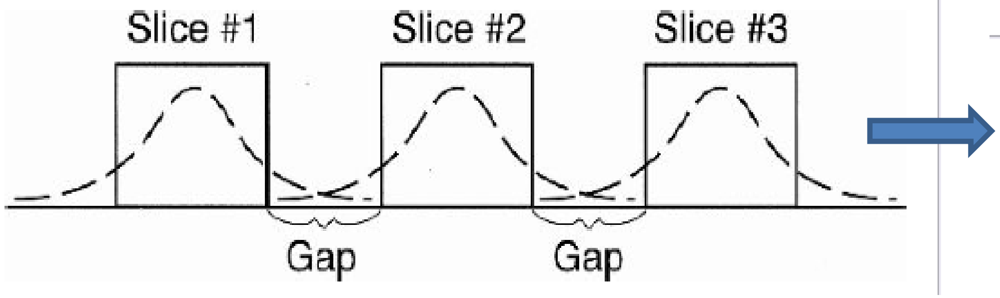


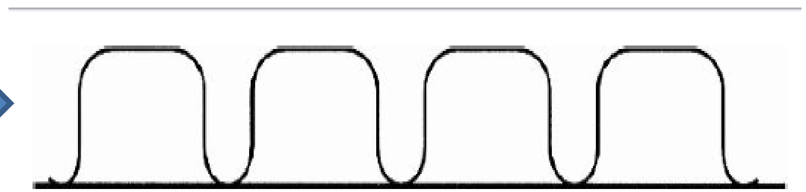
The remedy of cross talk

- *At least a 30% gap between the slices.*
- *Excite alternate slices (interleaved) during the acquisition.*

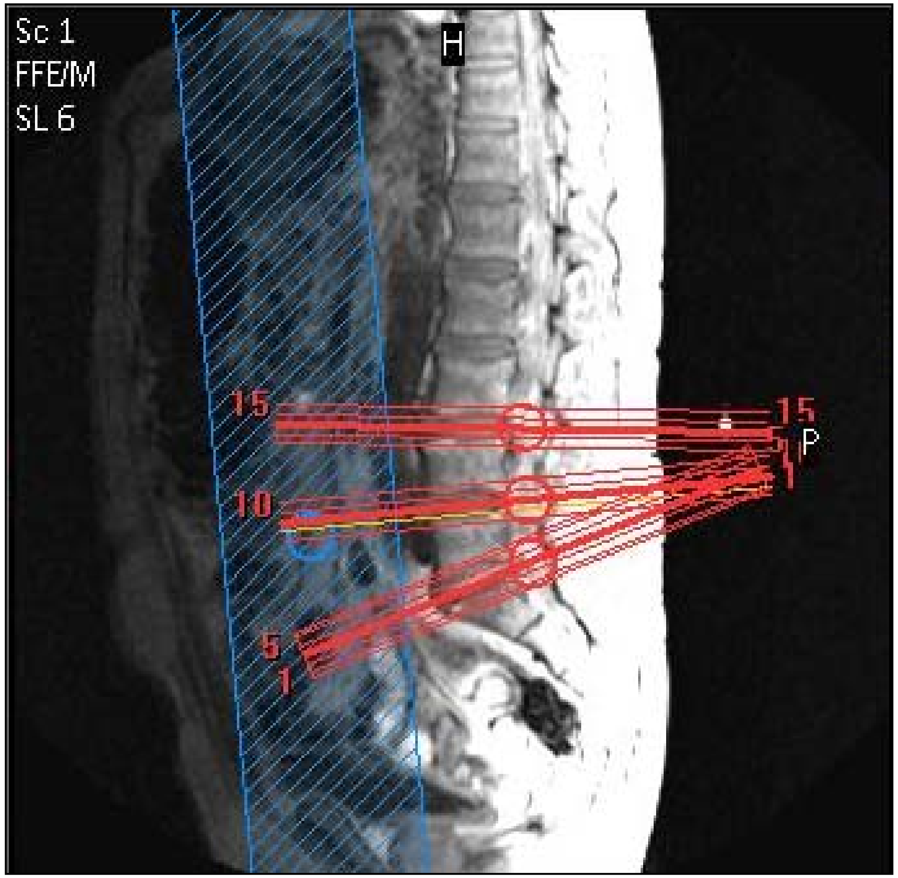
--- First sequence: odd slices 1,3,5,7, …

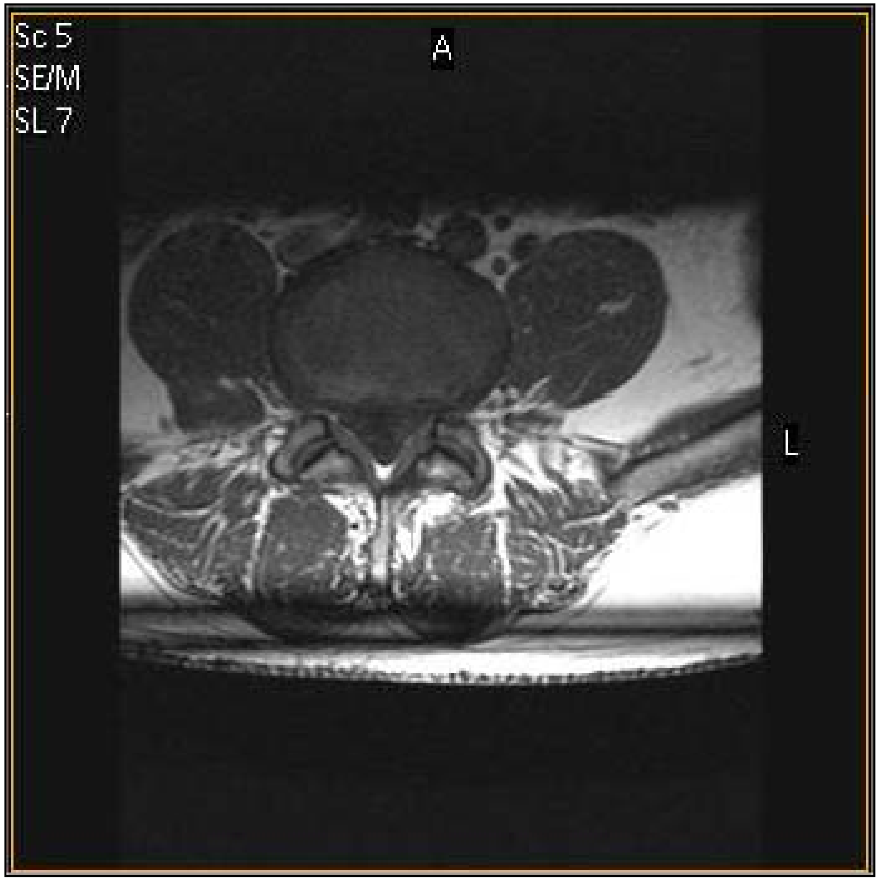
--- Next sequence: even slices 2,4,6,8,





Multi-stack artifact

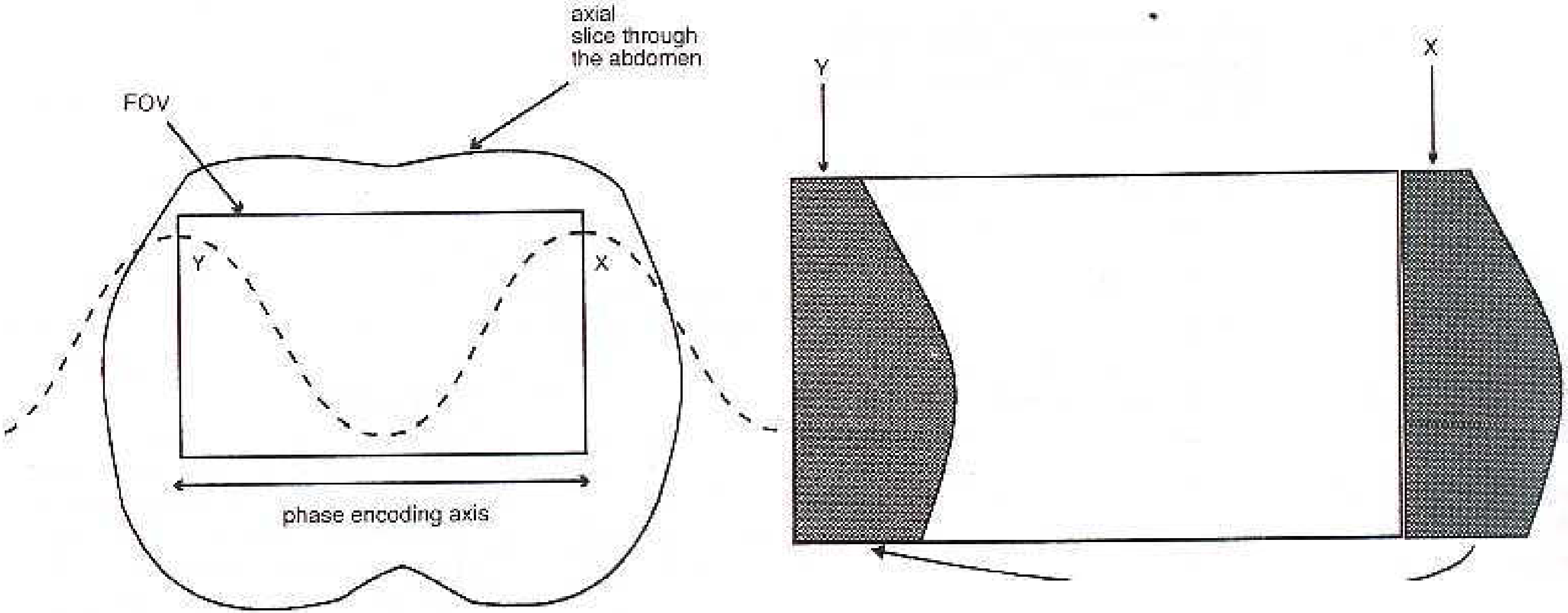




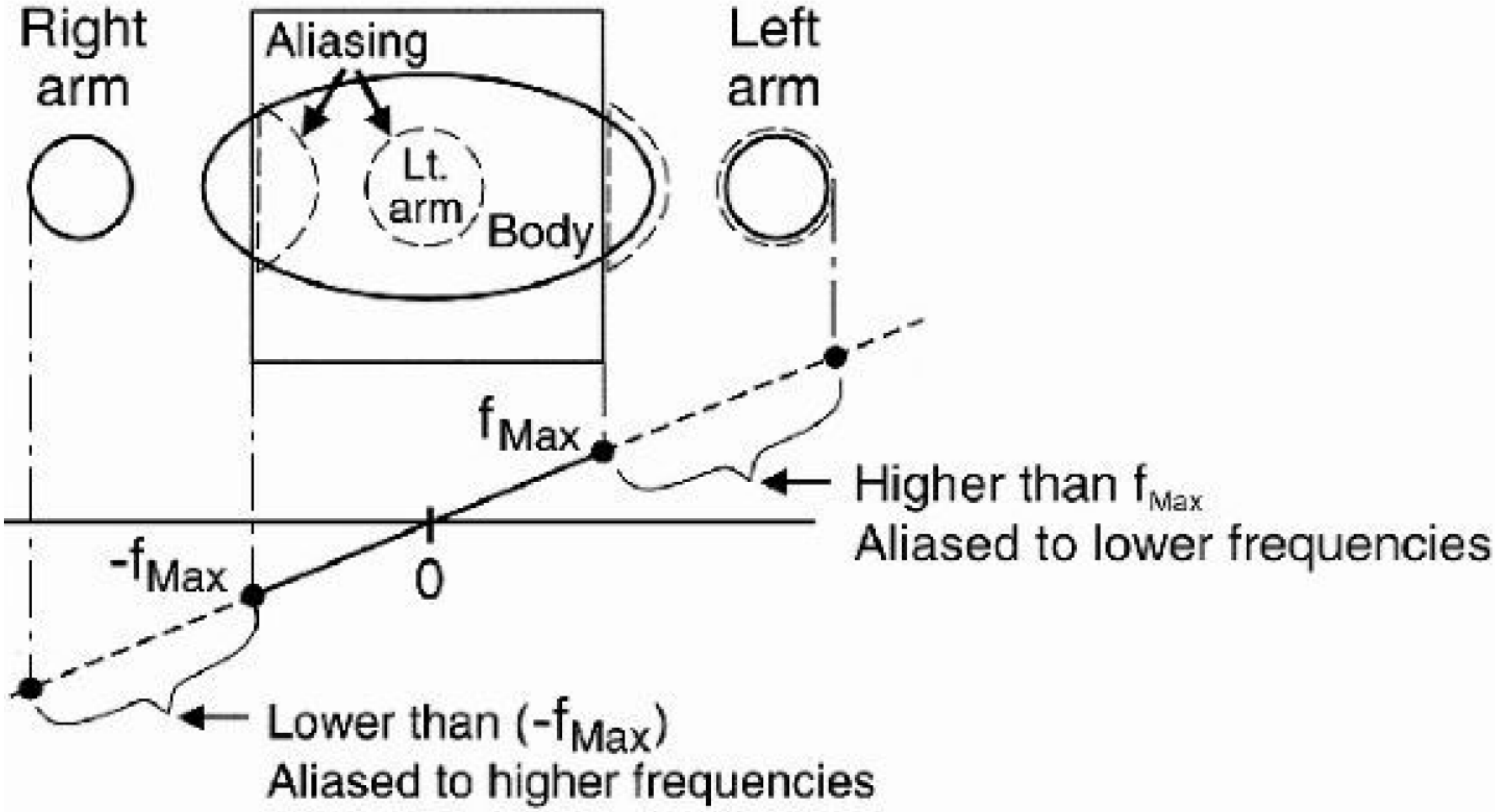
Digital imaging artifacts

Aliasing Artifacts

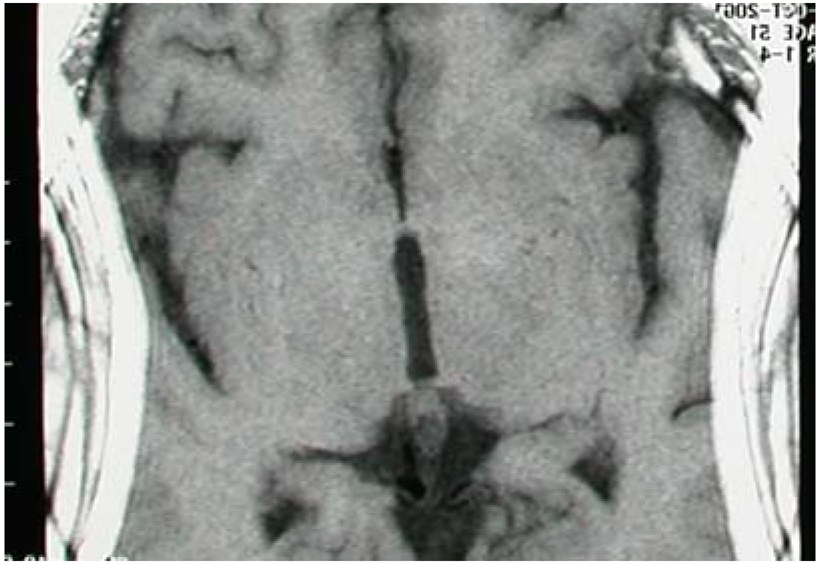
- *Aliasing artifacts, also called wrap-around artifacts*
- *Arises whenever the anatomy bigger than field of view (FOV)*

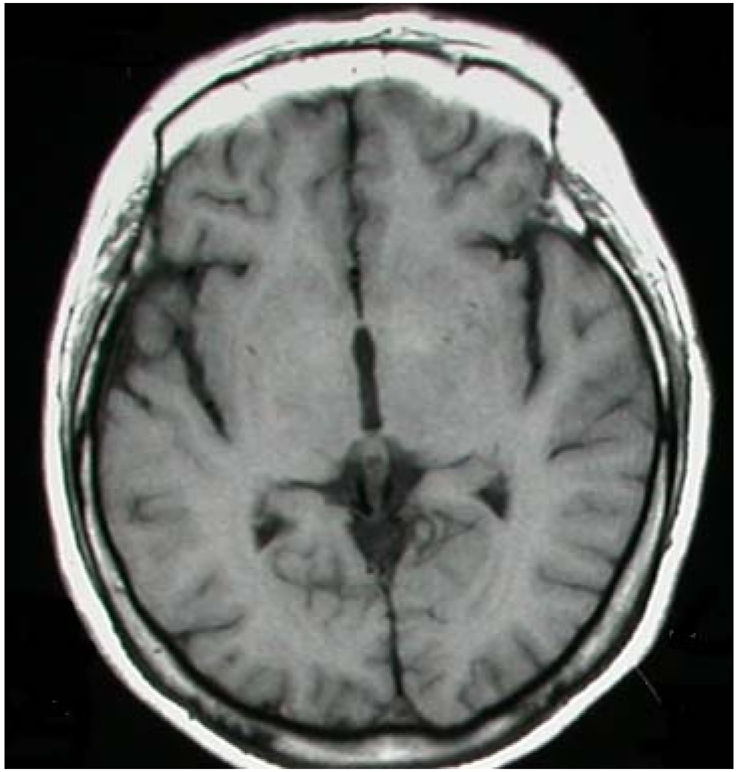


axial
slice through
the abdomen
FOV
Y
X
phase encoding axis
Y
X


Right arm
Aliasing
Left arm
Lt. arm
Body
f_{Max}
Higher than f_{Max}
Aliased to lower frequencies
$-f_{Max}$
0
Lower than $(-f_{Max})$
Aliased to higher frequencies

Aliasing Artifacts



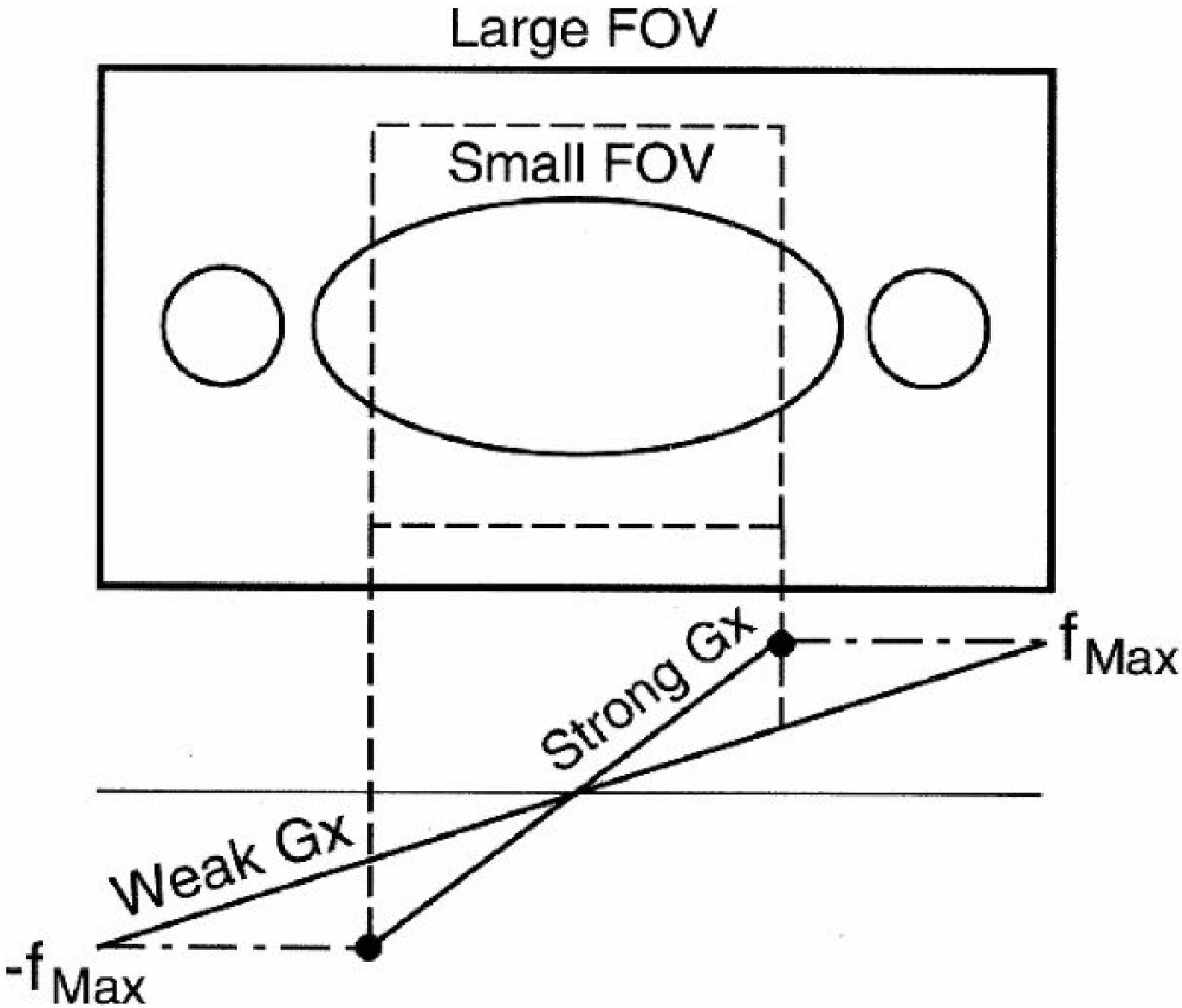


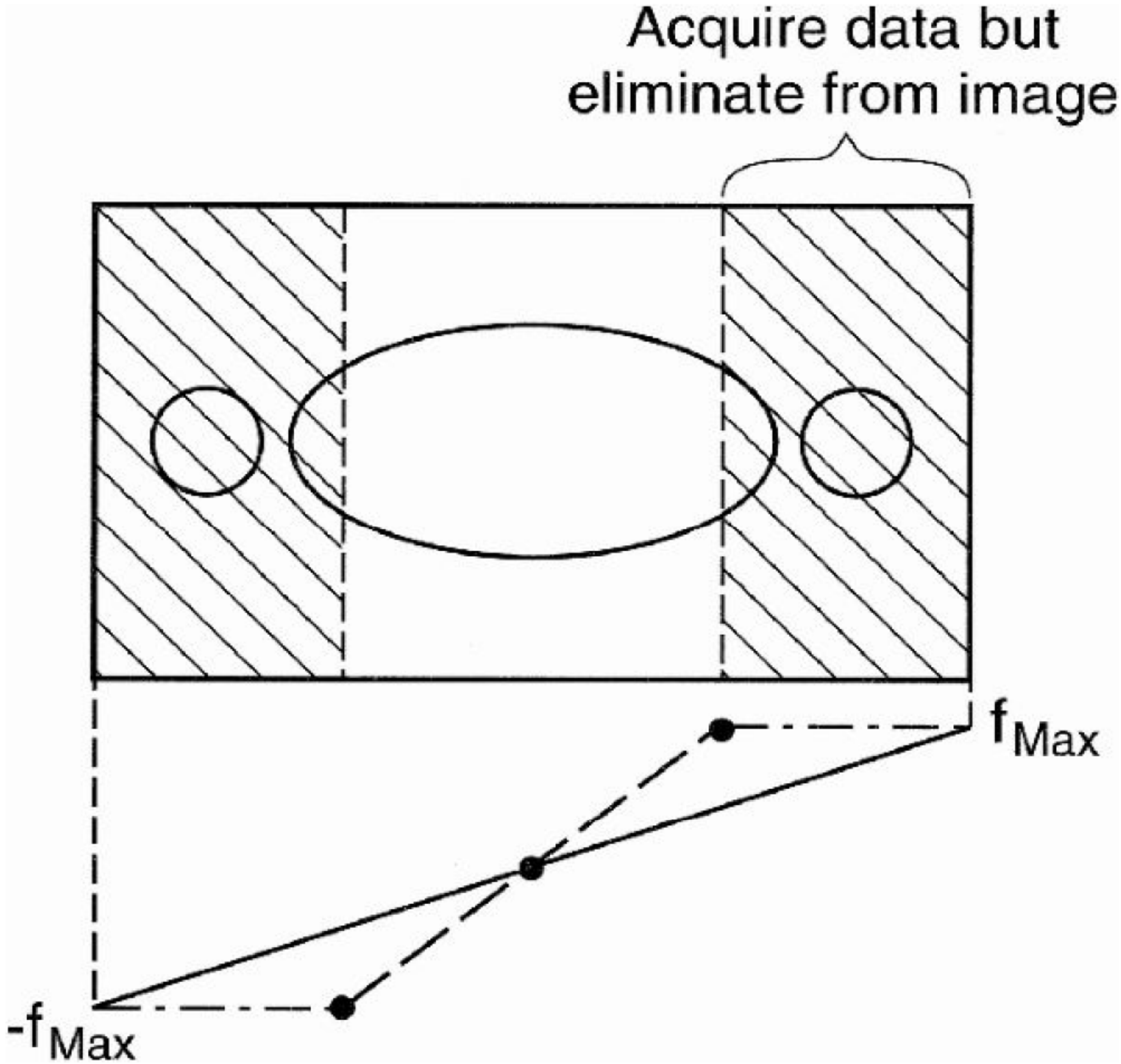
Anti-aliasing along the phase axis

- *Surface coil*
- *Increase FOV*
- *Over samples along the phase encoding axis.*

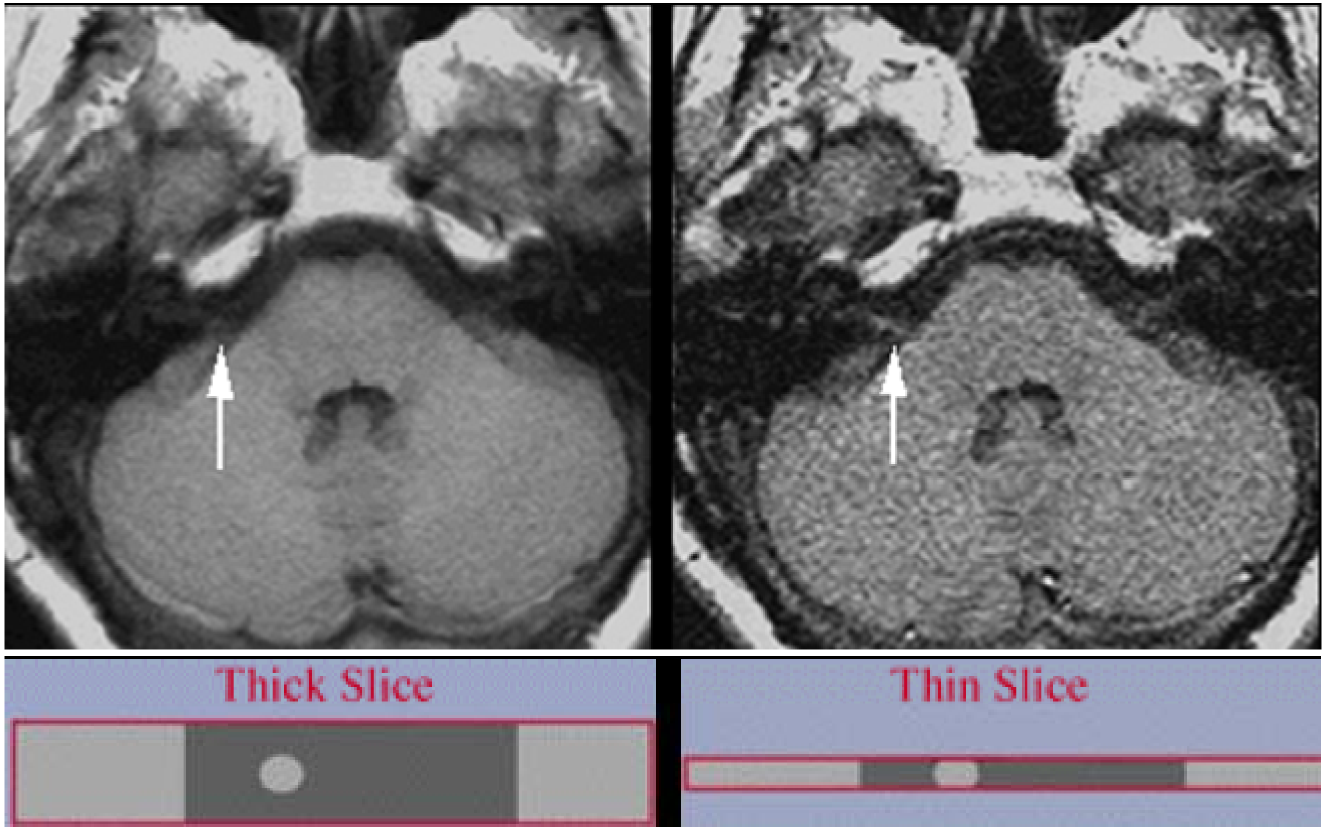
--- *To increasing the number of the phase encoding,the scan time has be prolonged. So, the motion artifact may be more apparent.*

- *Saturation pulse*


Large FOV
Small FOV
Strong Gx
Weak Gx
f_{Max}
$-f_{Max}$


Acquire data but
eliminate from image
fMax
-fMax

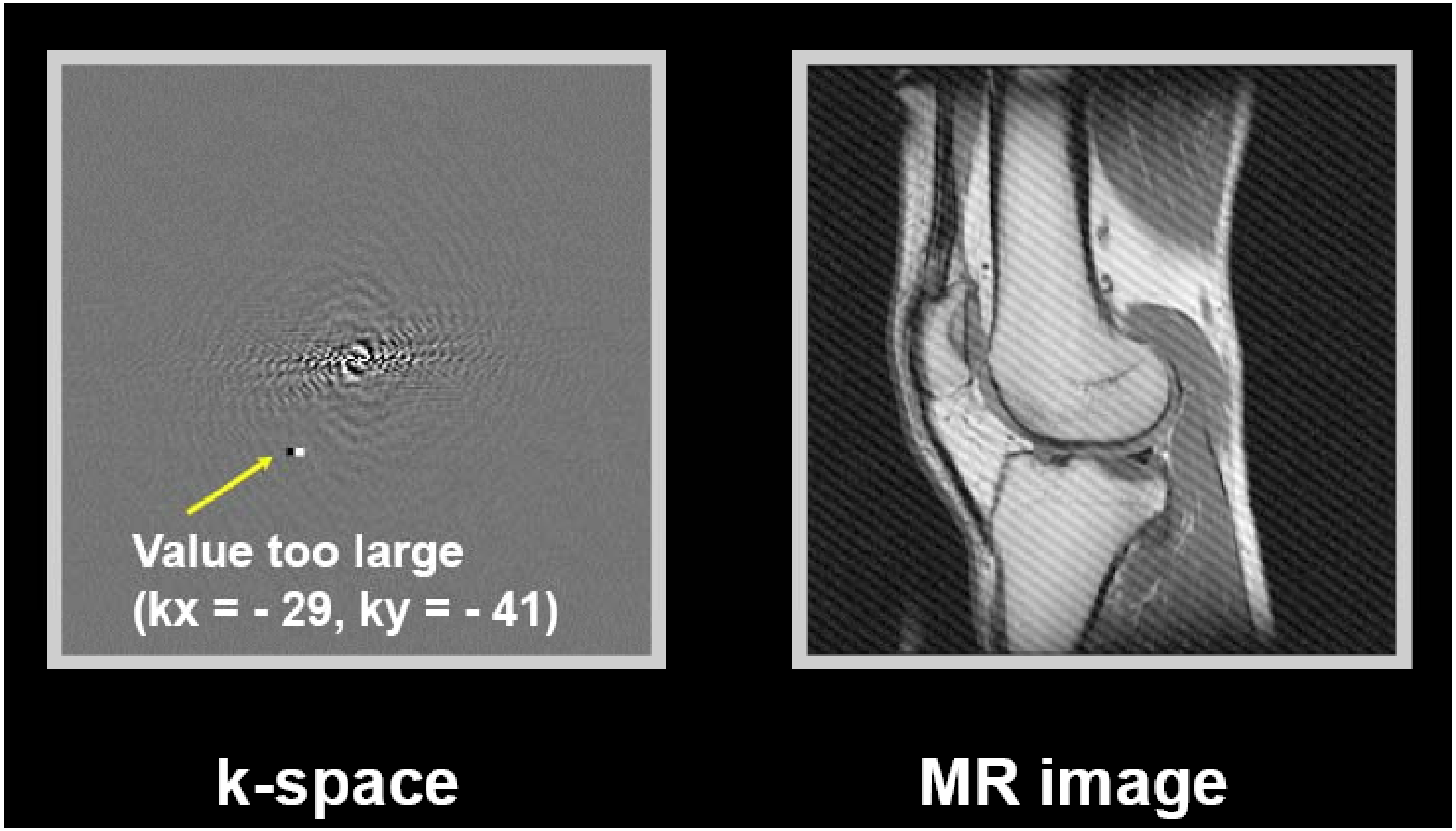
Partial volume artifact

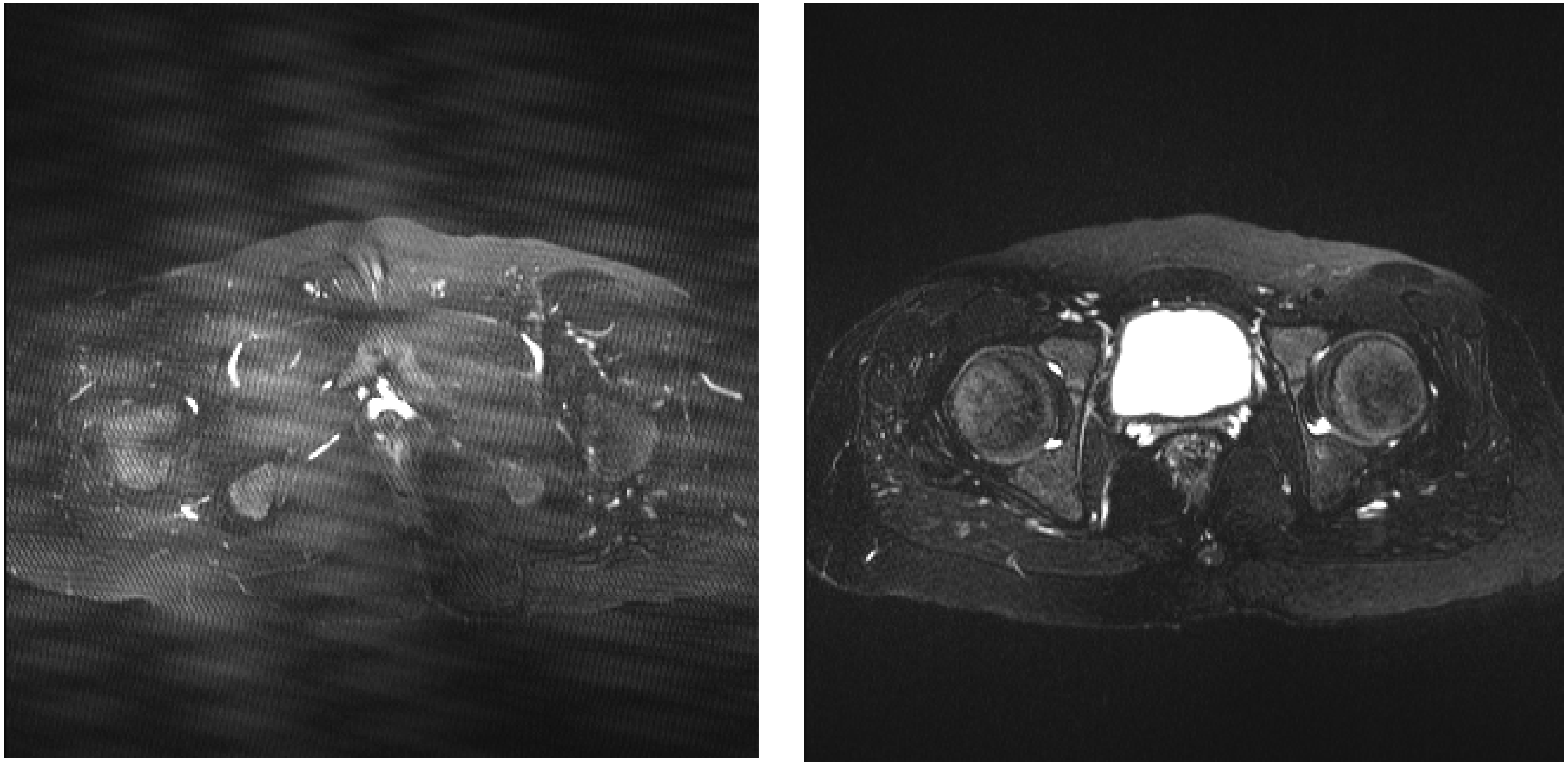


Herring-bone artifact

- *A regular series of high- and low-intensity stripes extending right across the image*
- *It is caused by spike noise in the raw data, whose Fourier transform is then convolved with all the image information*

Herring-bone artifact

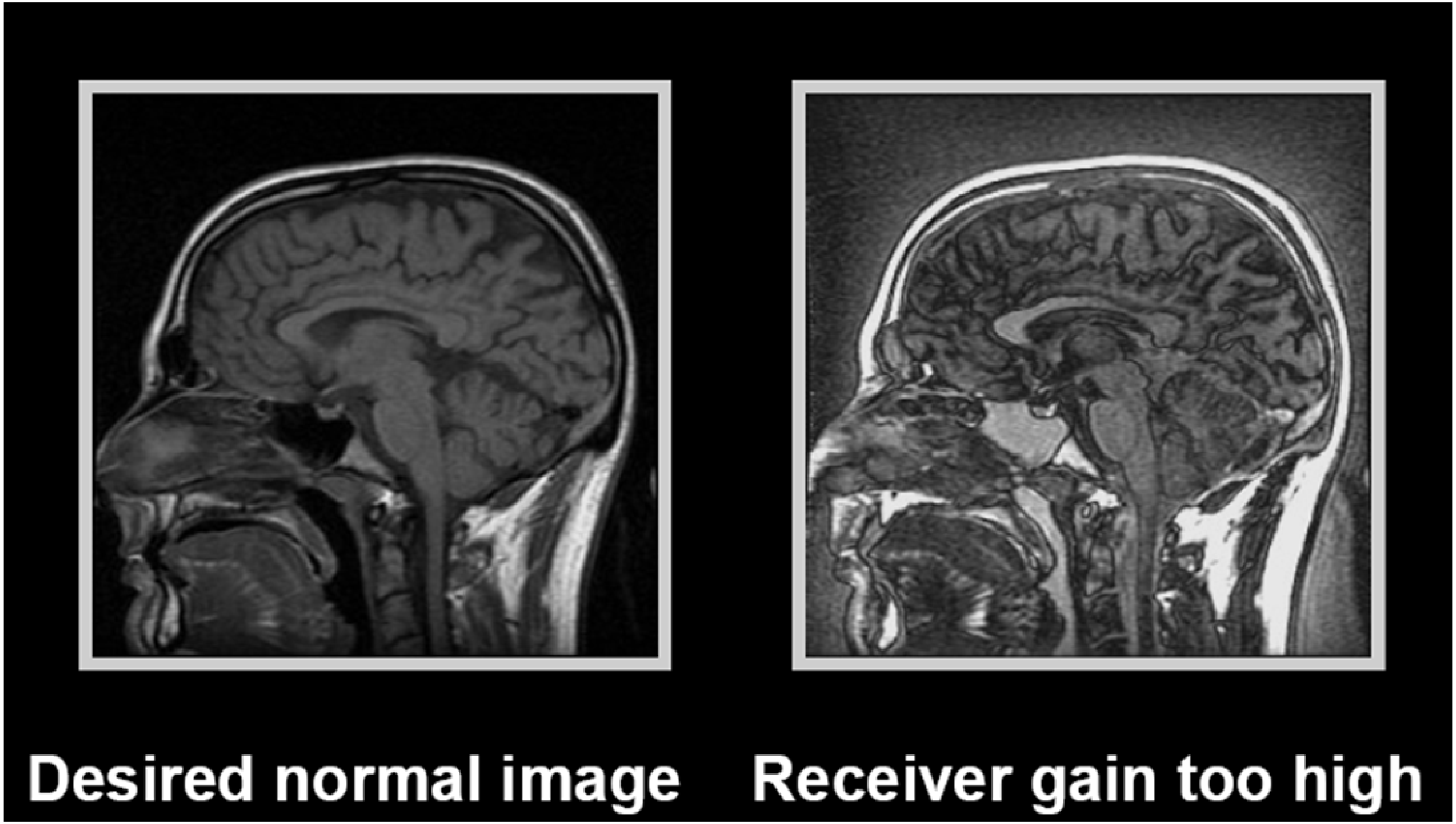




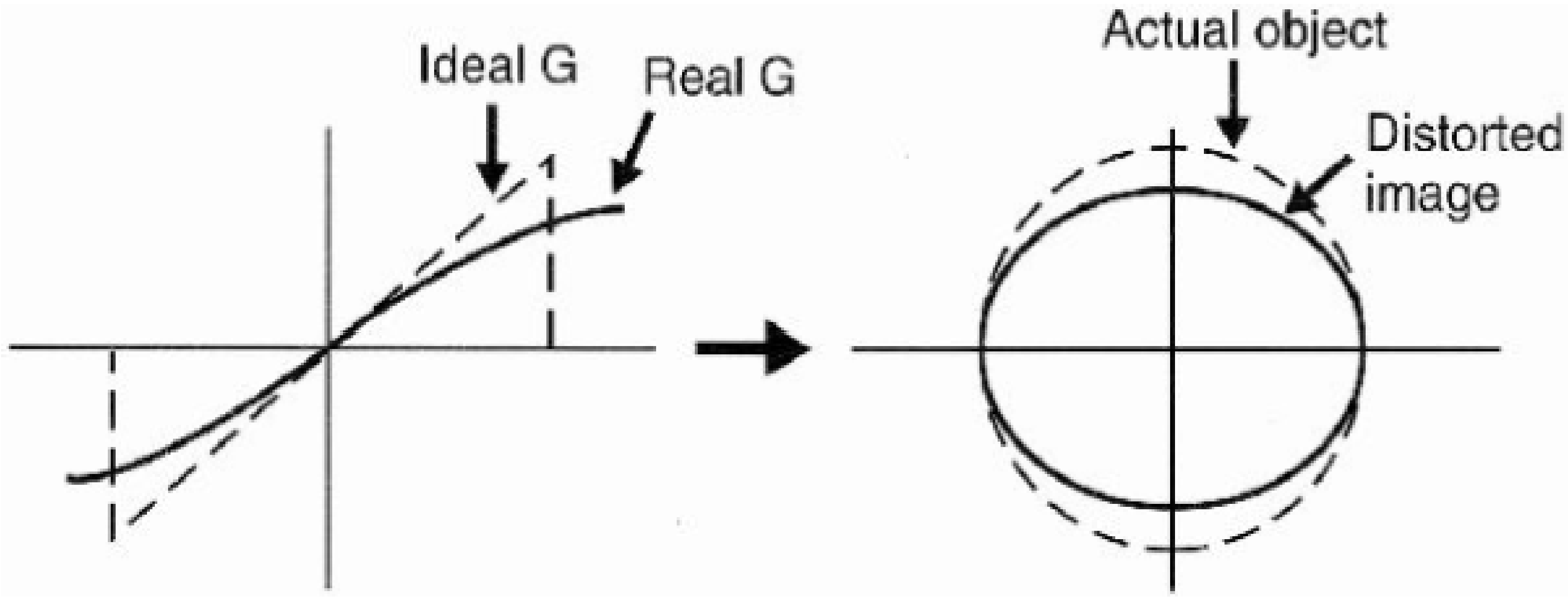
Halo artifact

- *A halo effect can be produced if the receiver gains are incorrectly set.*
- *When this happens the signal is too large for the range of the digitizer and information in the center of k-space is lost*
- *It is a rare artifact with modern automatic pre-scan systems, and is more likely to occur when receiver gains are manually set*

Halo artifact



Gradient nonlinearities

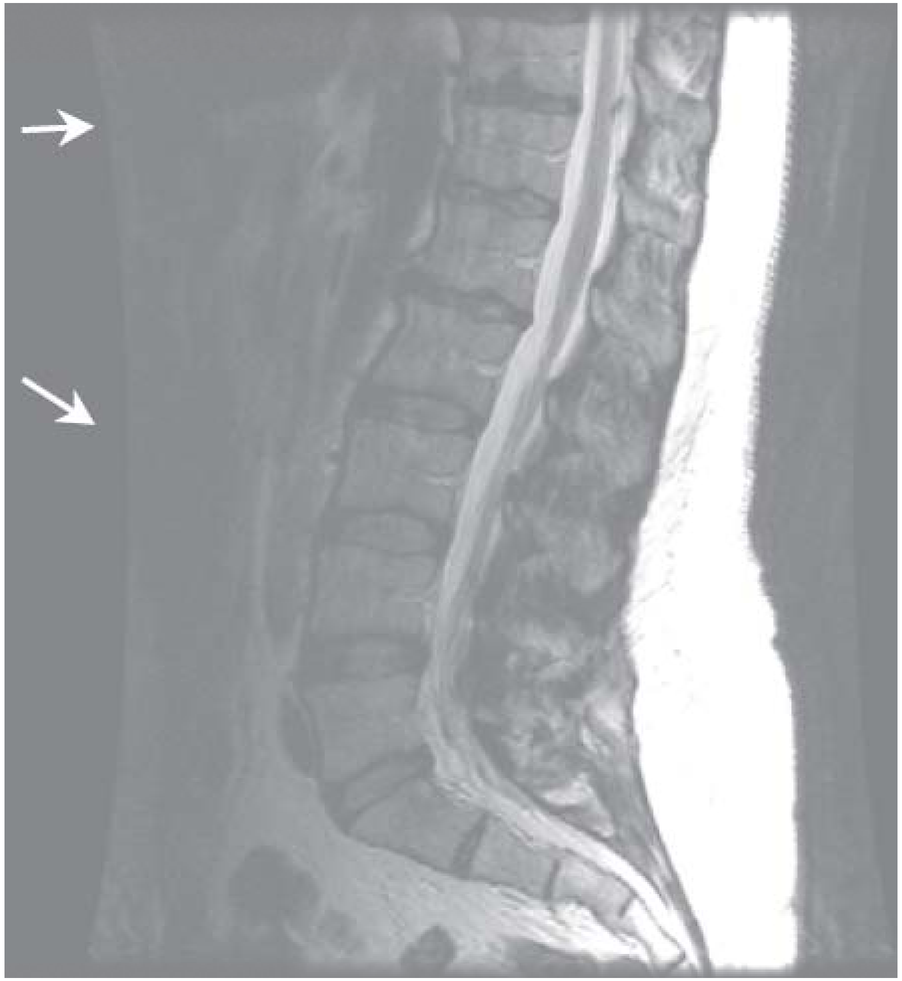


Nonlinearities in the gradient cause distortion in the image. For instance, a circle may appear elliptical.

Gradient nonlinearities

- *The effect of nonlinearities is to distort the image, tending to compress the image information at the edges of the FOV.*
- *Many systems apply a correction to the images to stretch out the pixels, and on rectangular FOV a curved edge can be seen*
- *This is quite normal and also unavoidable; if necessary the area should be re-imaged using a smaller FOV.*

Gradient nonlinearities

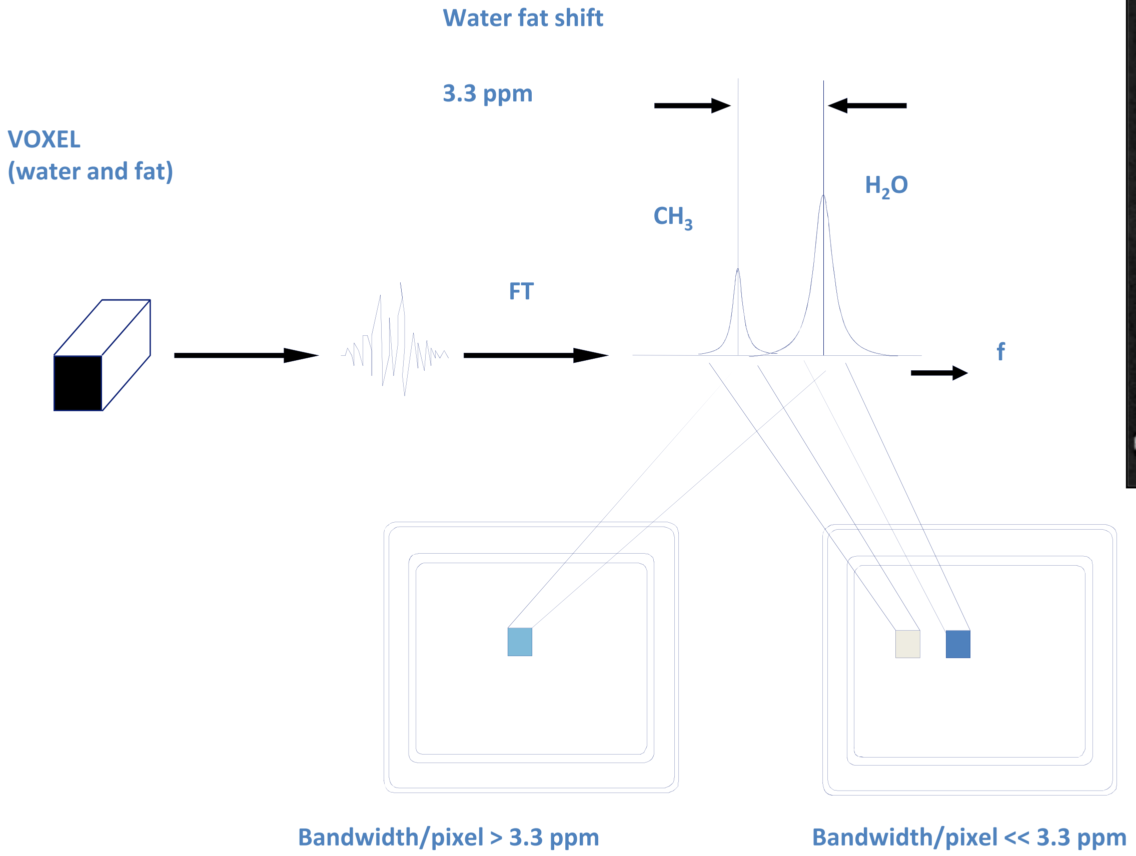


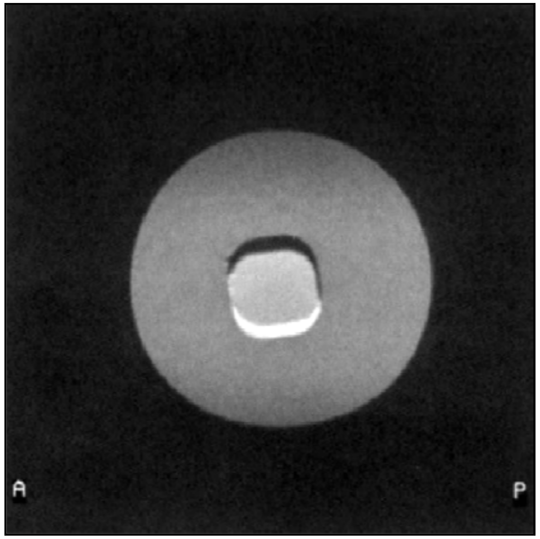
Chemical shift artifact

- *Caused by the different chemical environment of fat and water.*
- *The precessional frequency of fat＜water （depend on the main magnetic field strength）*

  ex. At 1.5T the different of precessional frequency is 220 Hz;at 1.0T is 147 Hz.But at lower field strength （o.5T or less）,it is usually insignificant.

Chemical shift

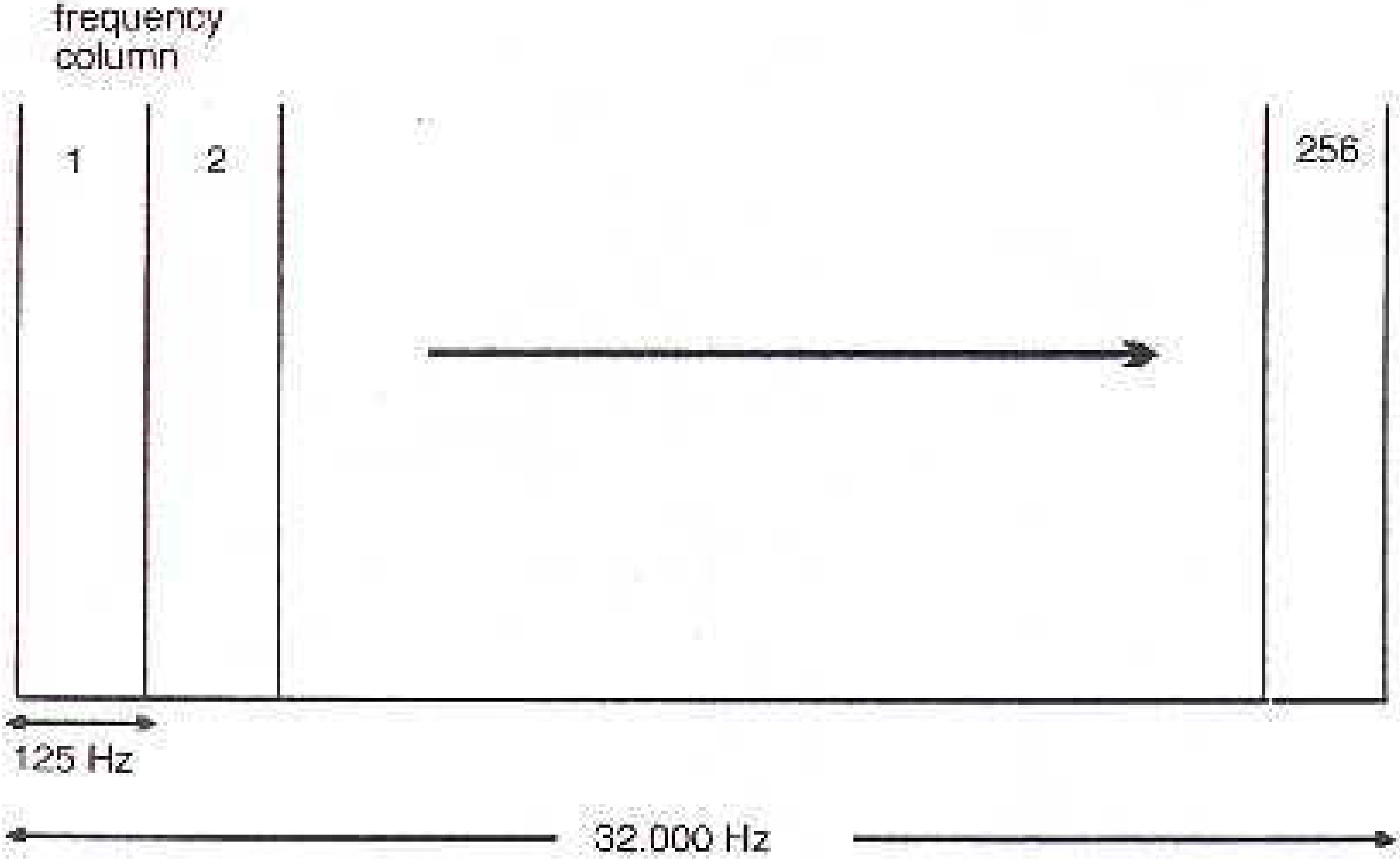


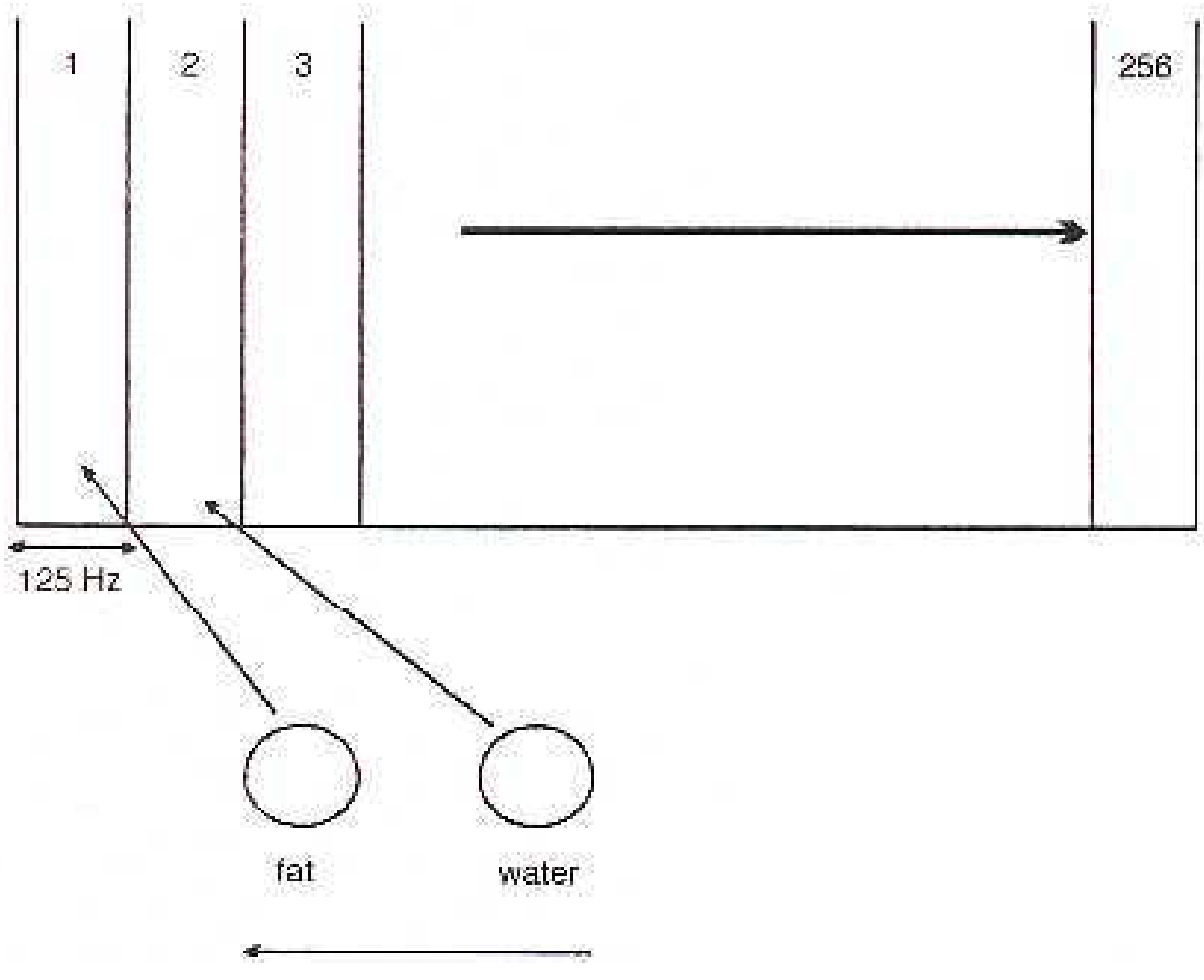


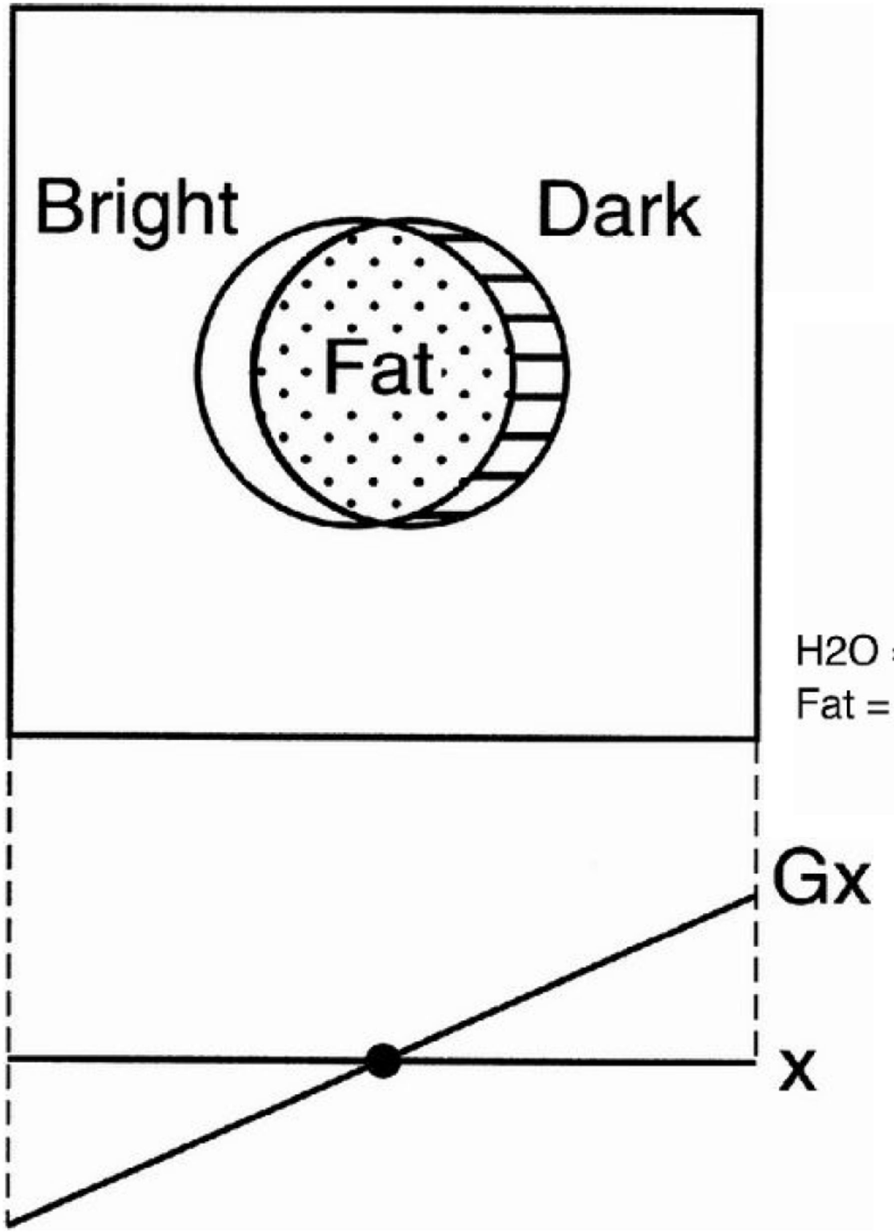
chemical shift artifact

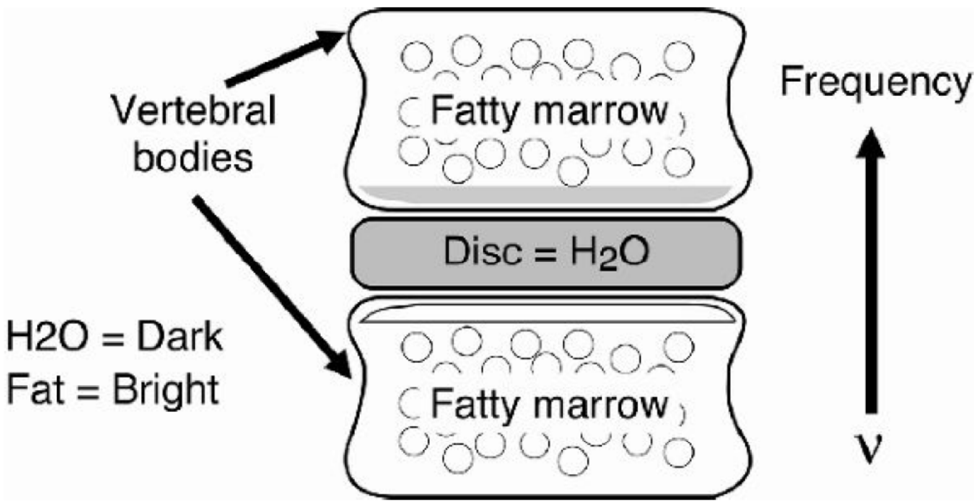
- *For example :*

  The frequency mapped across the FOV is 32000 Hz;256 frequency samples are selected,each pixel has an individual frequency range of 125Hz （32000/256Hz）.At 1.5T,fat and water existing adjacent has a shift about 1.76 pixel which called chemical shift


frequency
column
1
2
256
125 Hz
32.000 Hz


1
2
3
256
125 Hz
fat
water


Bright
Dark
Fat
Gx
x


Vertebral
bodies
Fatty marrow
Disc = H₂O
Fatty marrow
H2O = Dark
Fat = Bright
Frequency
ν

chemical shift artifact

- *It depend on the size of FOV as this determines the size of each pixel.*
- *Causes a dark edge at the interface between fat and water.*
- *It occurs along the frequency encoding axis only.*

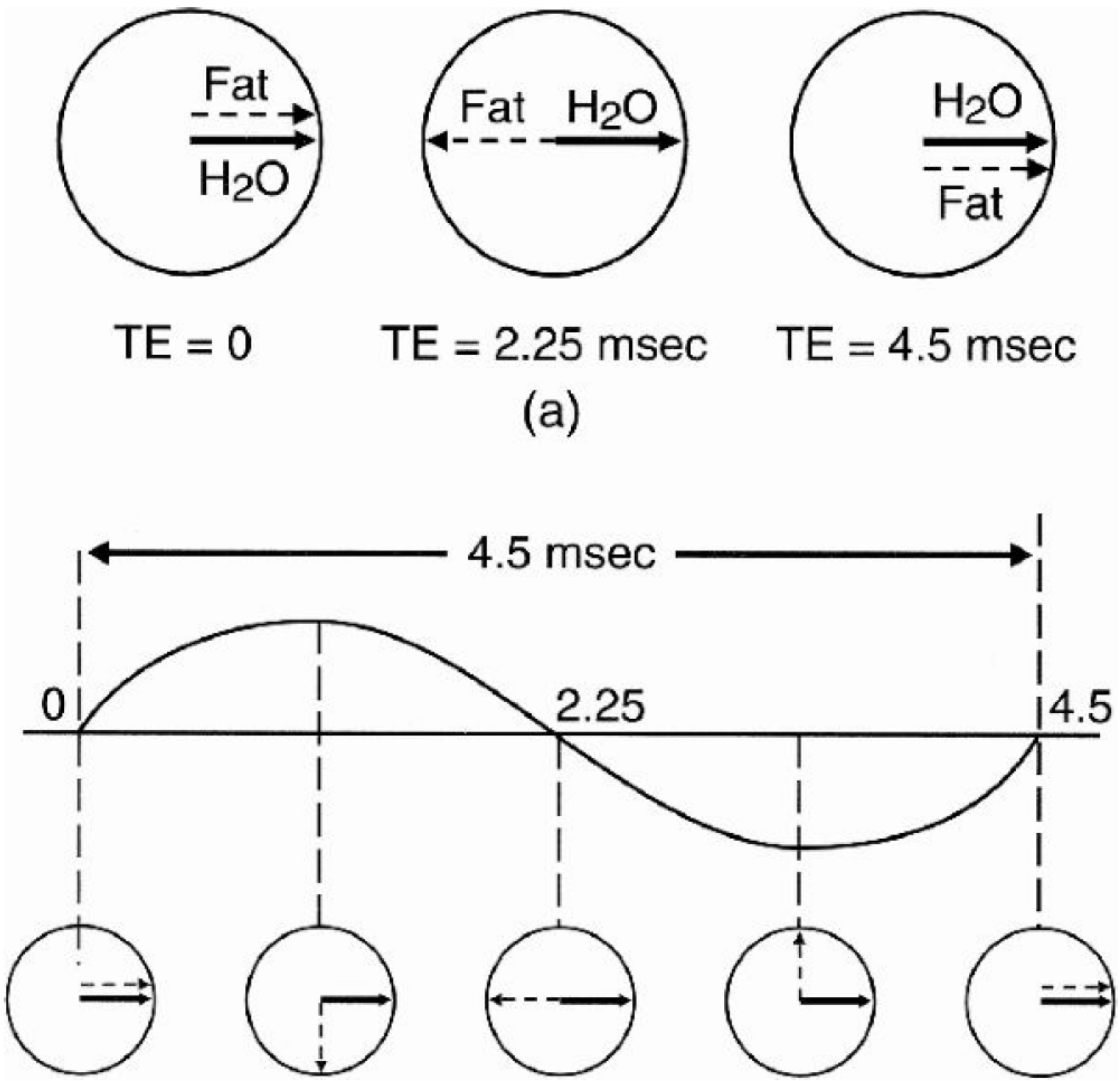
The remedy of chemical shift artifact

- *Using fat suppression.*
- *Scanning at lower filed strengths.*
- *Increase bandwidth (trade-off: lowers SNR)*
- *Switch phase and frequency directions.*
- *Use a long TE (causes more dephasing and less signal from fat).*

Chemical misregistration

Chemical Shift of the "Second Kind"

- *Also produced as a result of the precessional frequency different between fat and water.*
- *Caused because fat and water are in phase at certain times and out of phase at others.*



Fat
H_2O
Fat
H_2O
H_2O
Fat
TE = 0
TE = 2.25 msec
TE = 4.5 msec
(a)
4.5 msec
0
2.25
4.5

- *When fat & water are in phase:*

  ➡ *signals add constructively.*

- *When fat & water are out phase:*

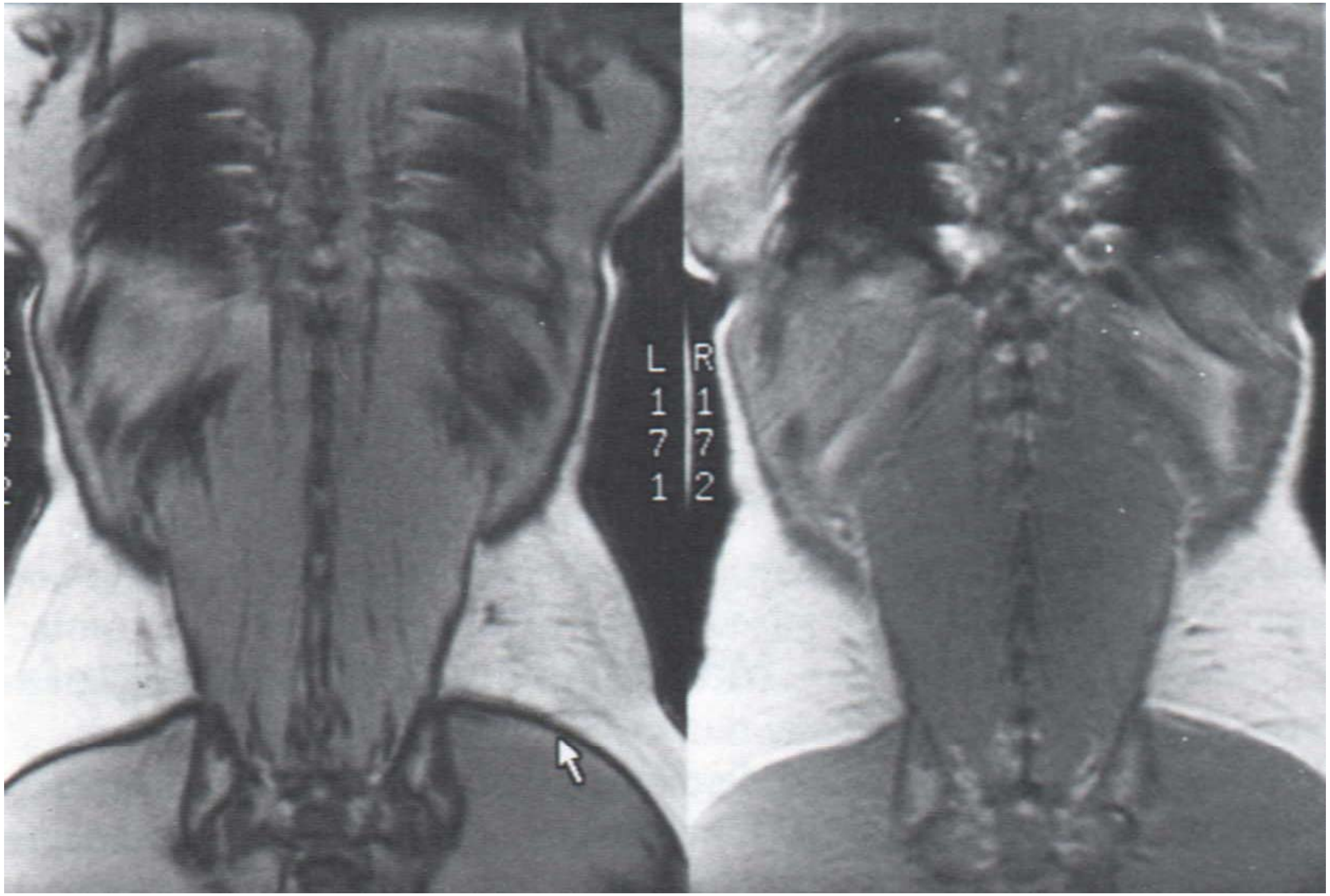
  ➡ *signals cancel each other out.*

Which called ---- Chemical misregistration

- *Cause a ring of dark signal around certain organs where fat and water interfaces occur within the same voxel.*

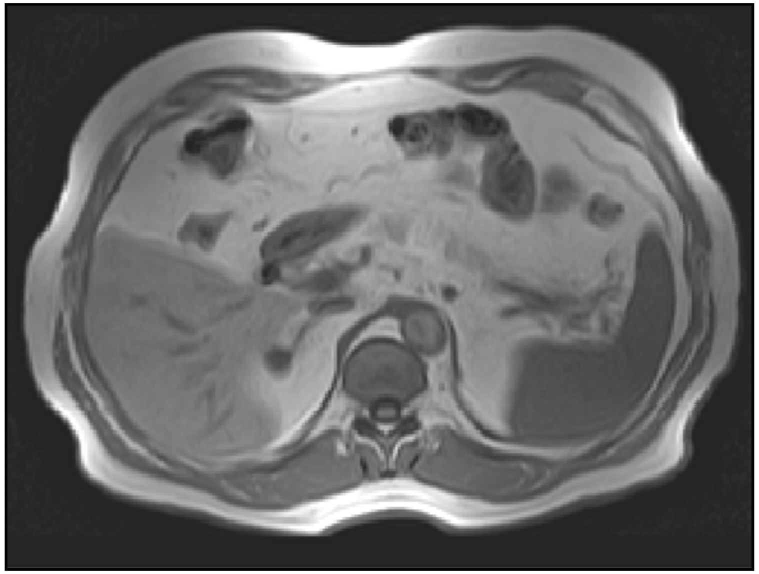
The remedy of Chemical misregistration

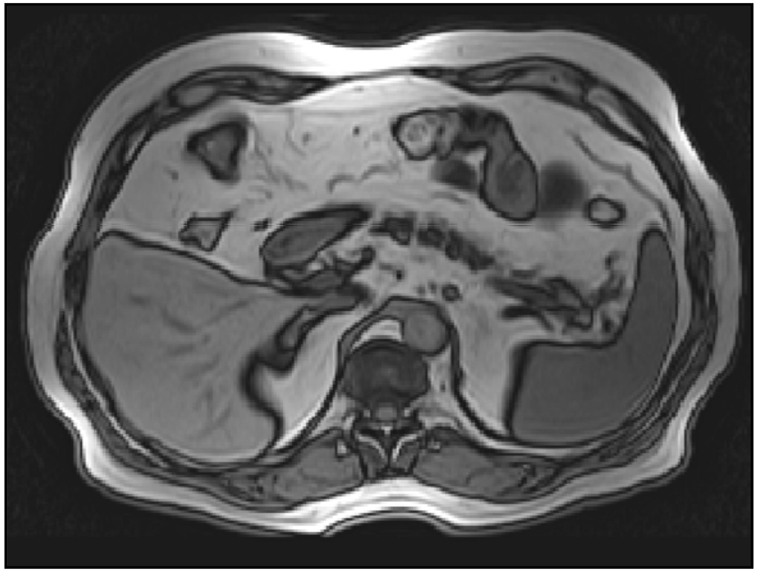
- *Use a spin echo sequence to reduce the artifact.*
- *Select a TE generates an echo when fat and water are in phase. （at 1.5T the TE is a multiple of 4.2ms）*



※ T1W GE coronal image ,left image TE=2.8ms ;right image TE=4.2ms

Chemical shift for in-out phase

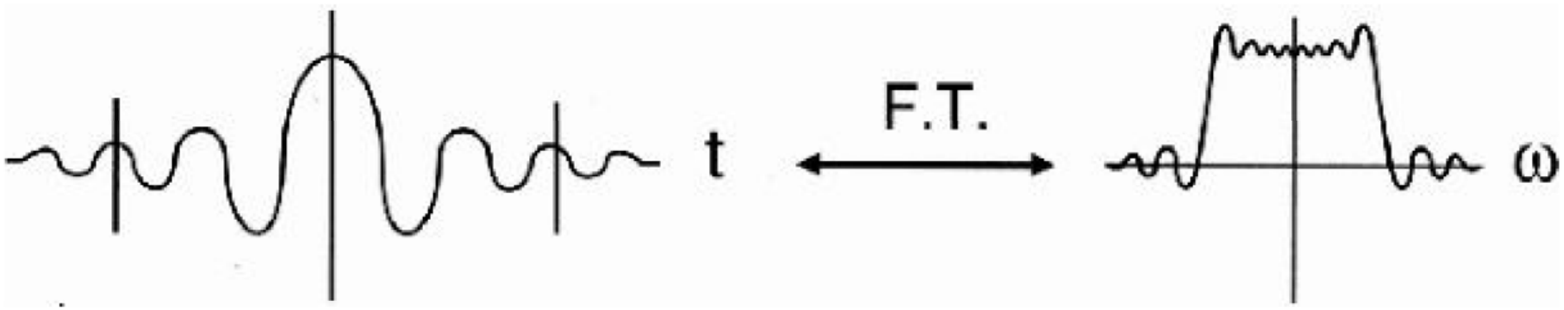


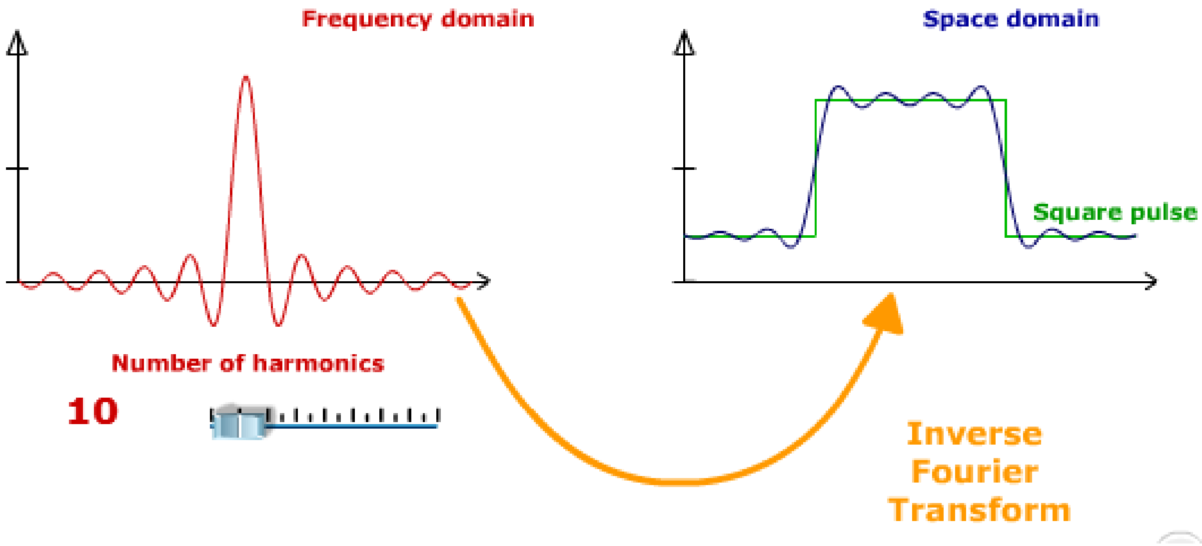


FIELD STRENGTH	In	Out	In	Out	In	Out	In
0.5 T	0	6.8 ms	13.6 ms	20.4 ms	27.2 ms	34 ms	40.8 ms
1.0 T	0	3.4 ms	6.8 ms	10.2 ms	13.6 ms	17 ms	20.4 ms
1.5 T	0	2.2 ms	4.4 ms	6.8 ms	9 ms	11.2 ms	13.4 ms
3.0 T	0	1.1 ms	2.2 ms	3.4 ms	4.5 ms	5.6 ms	6.7 ms

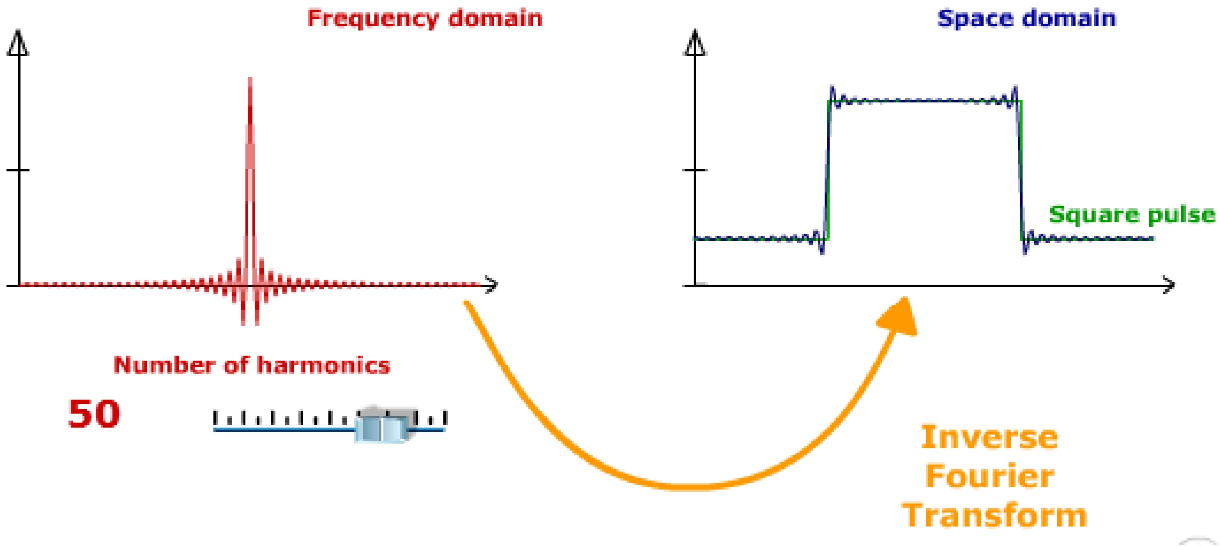
Truncation artifact

- *Caused by under sampling of data so that interfaces of high and low signal are incorrectly represented on the image.*
- *Occurs in the phase direction only.*
- *Produces a low intensity band running through a high intensity area.*


t
F.T.
ω

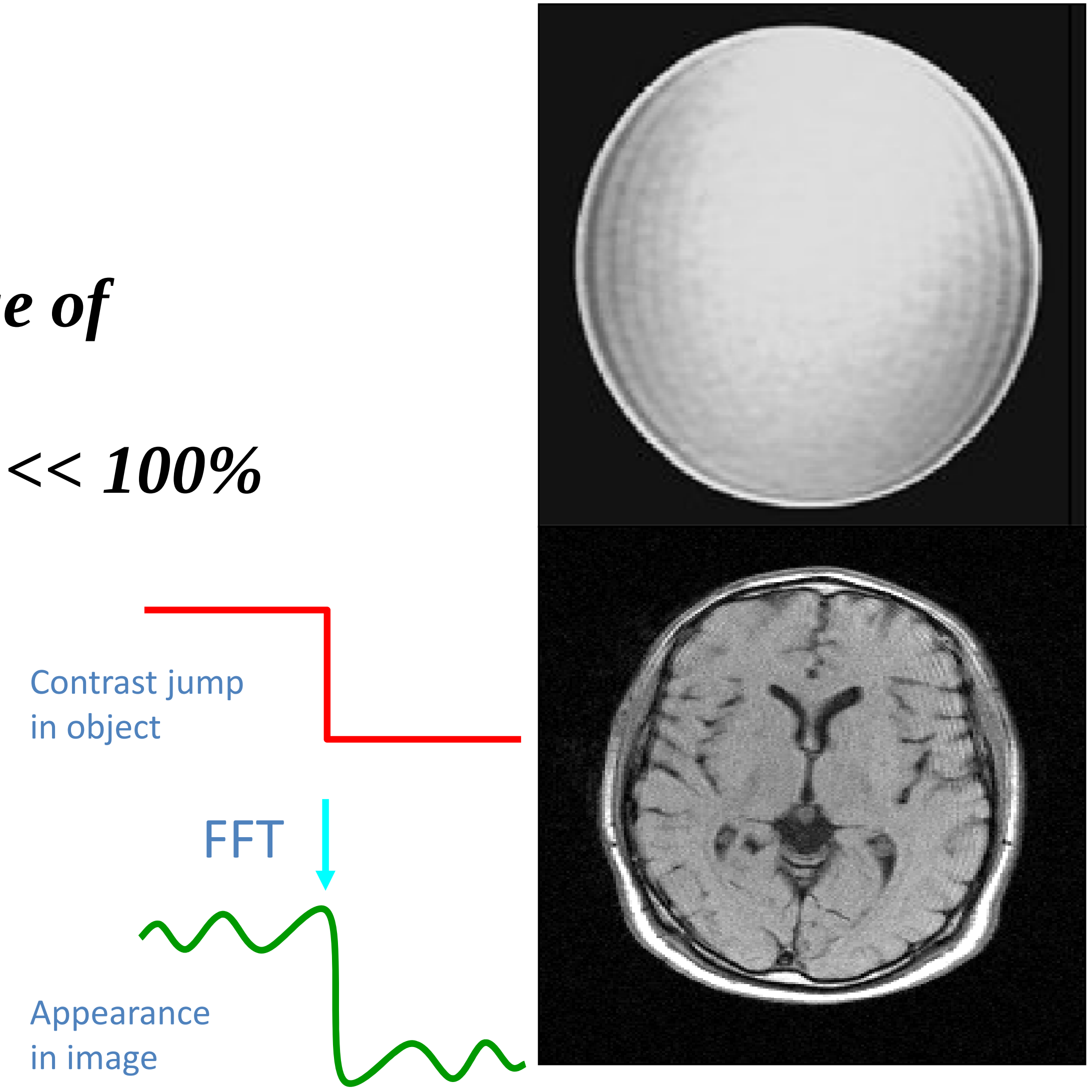


Frequency domain
Space domain
Square pulse
Number of harmonics
10
Inverse
Fourier
Transform



Frequency domain
Space domain
Square pulse
Number of harmonics
50
Inverse
Fourier
Transform

- ***Also called:***
  - ***Gibbs artefact***
  - ***Ringing***
  - ***Spectral leakage***
- ***Predominant in case of***
  - ***low matrix***
  - ***scan percentage << 100%***



The remedy of truncation artifact

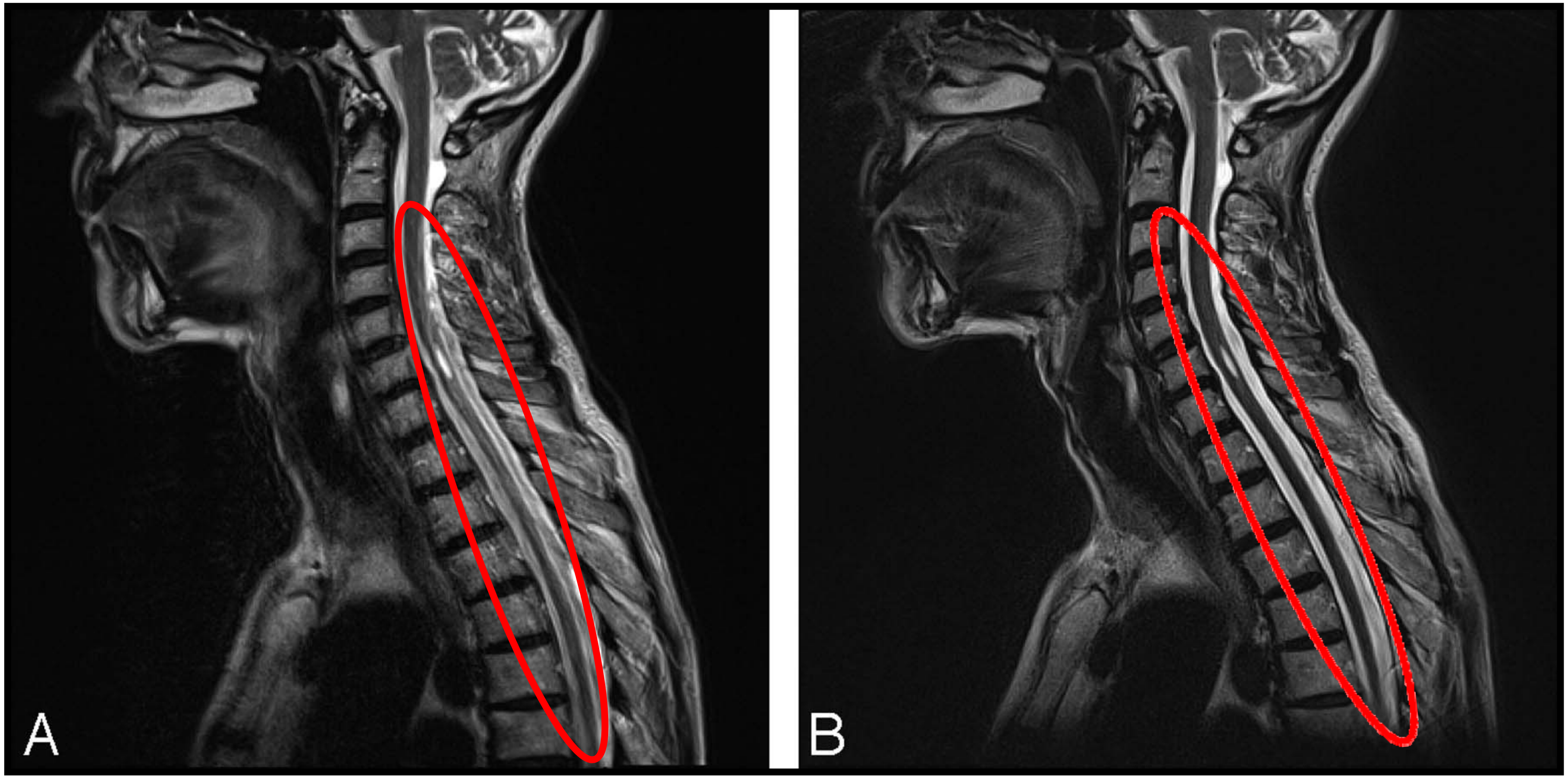
- *Increase sampling time (BW)*
- *Decrease pixel size:*

---*The under sampling of data must be avoided.*

→ *increase the number of phase encoding steps.*

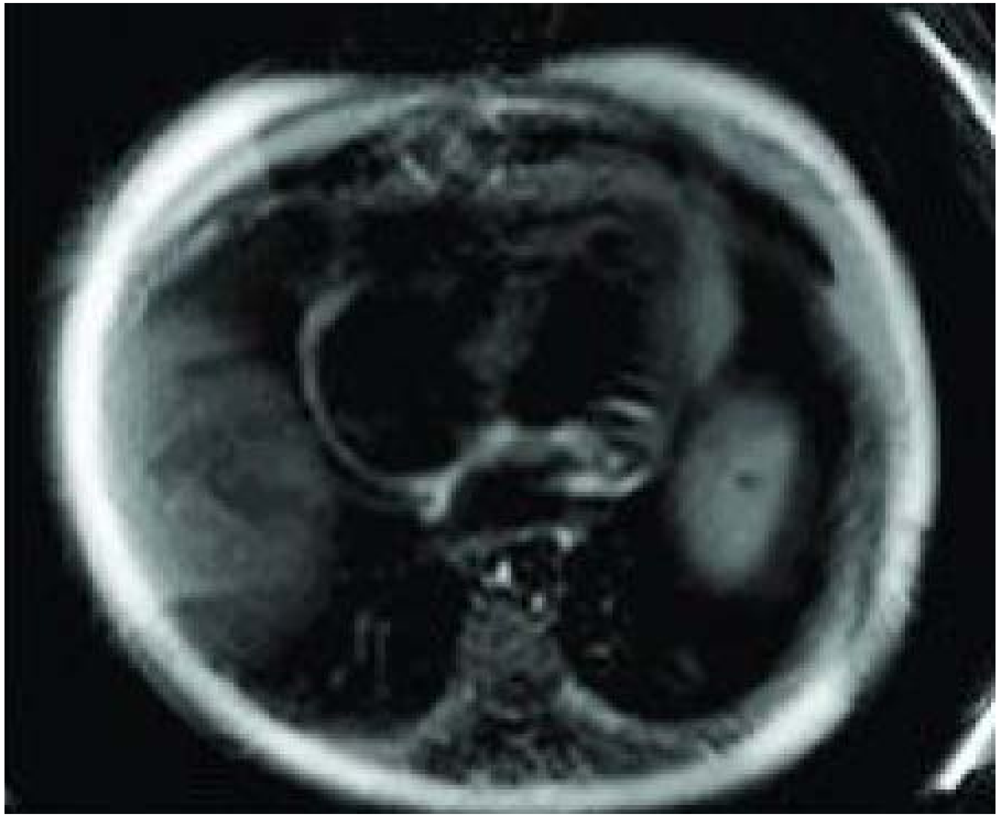
---*Decreasing the FOV*

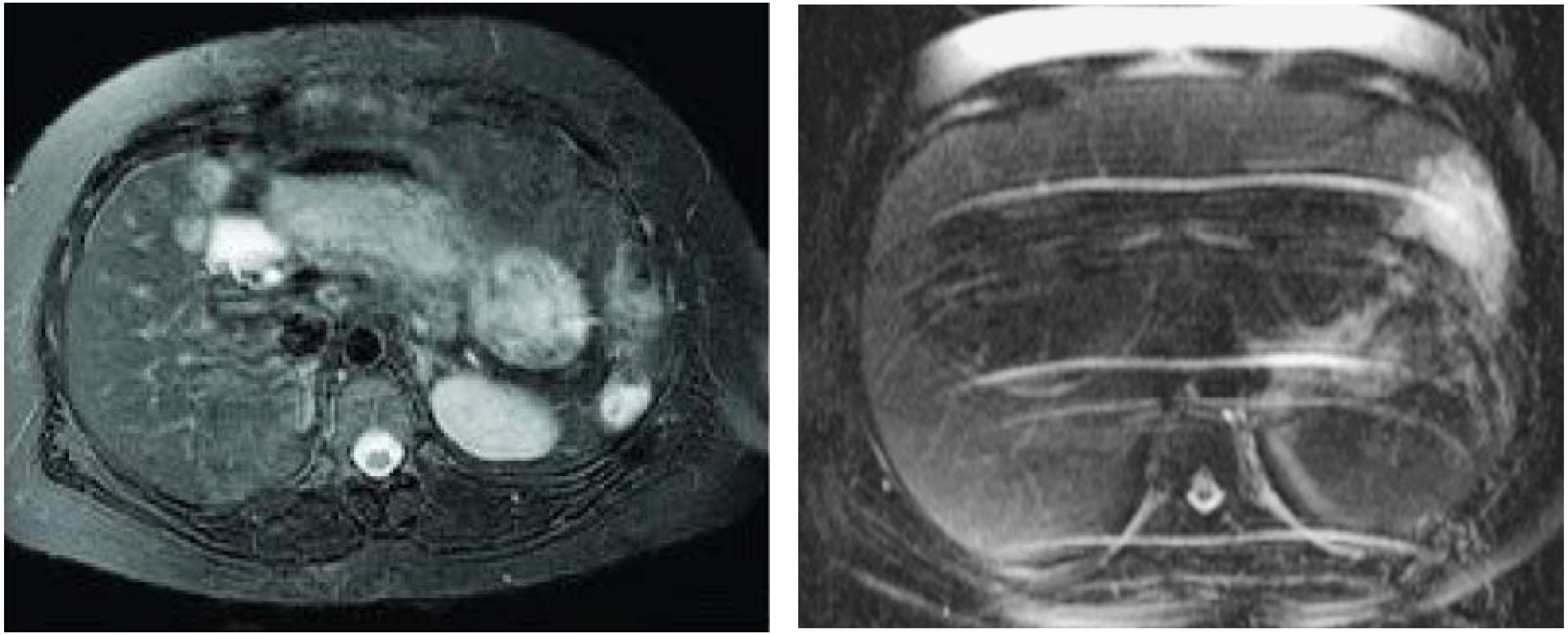
Gibbs' artifact(truncation artifacts)

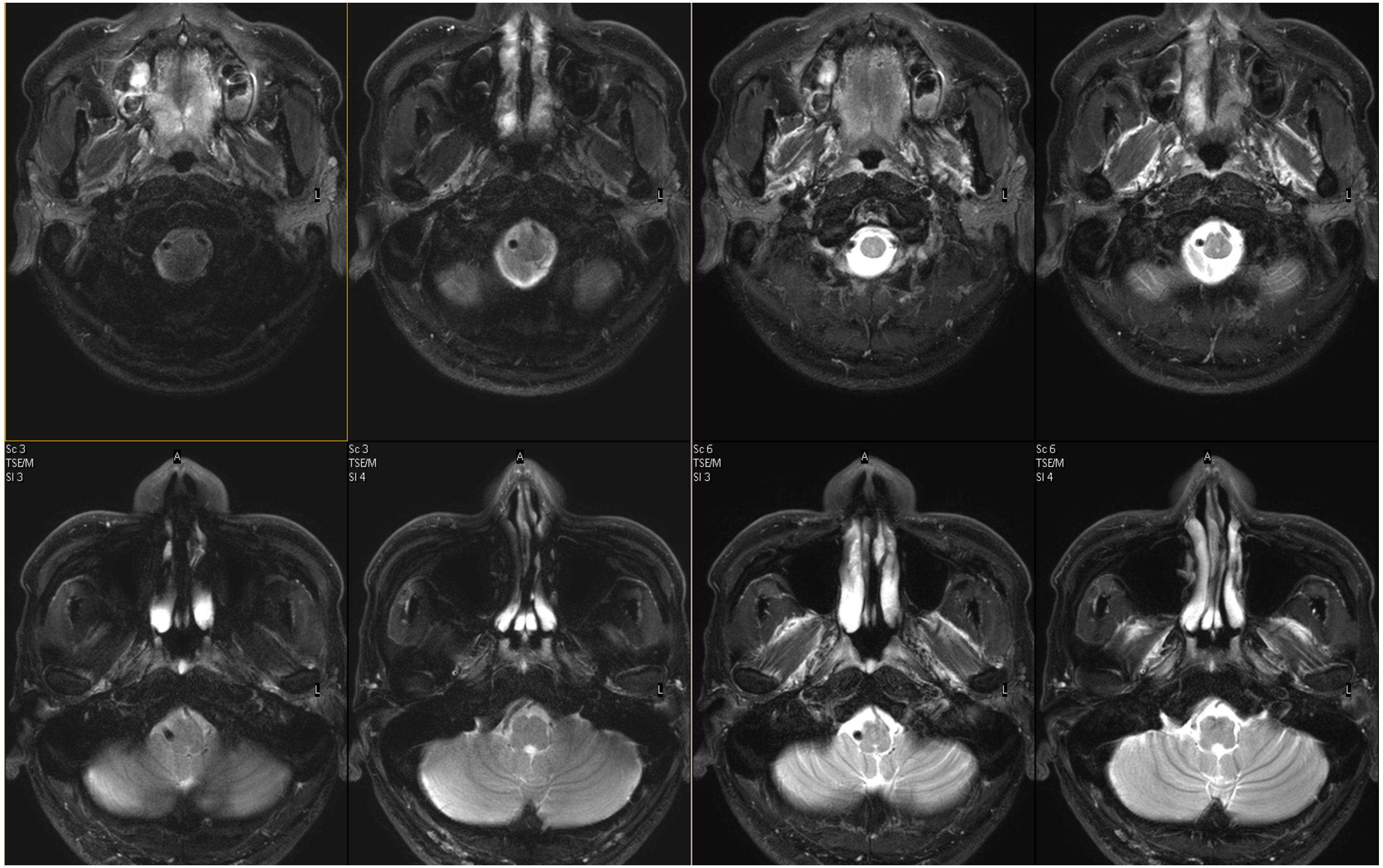


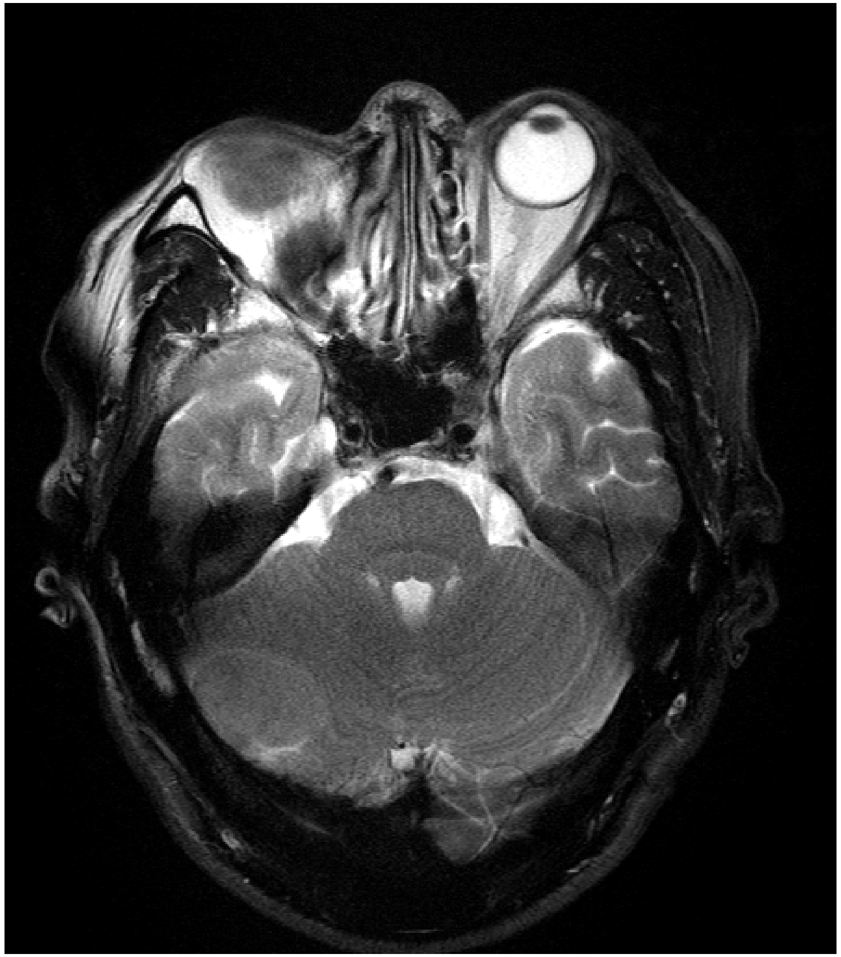
External Magnetic Field Artifacts

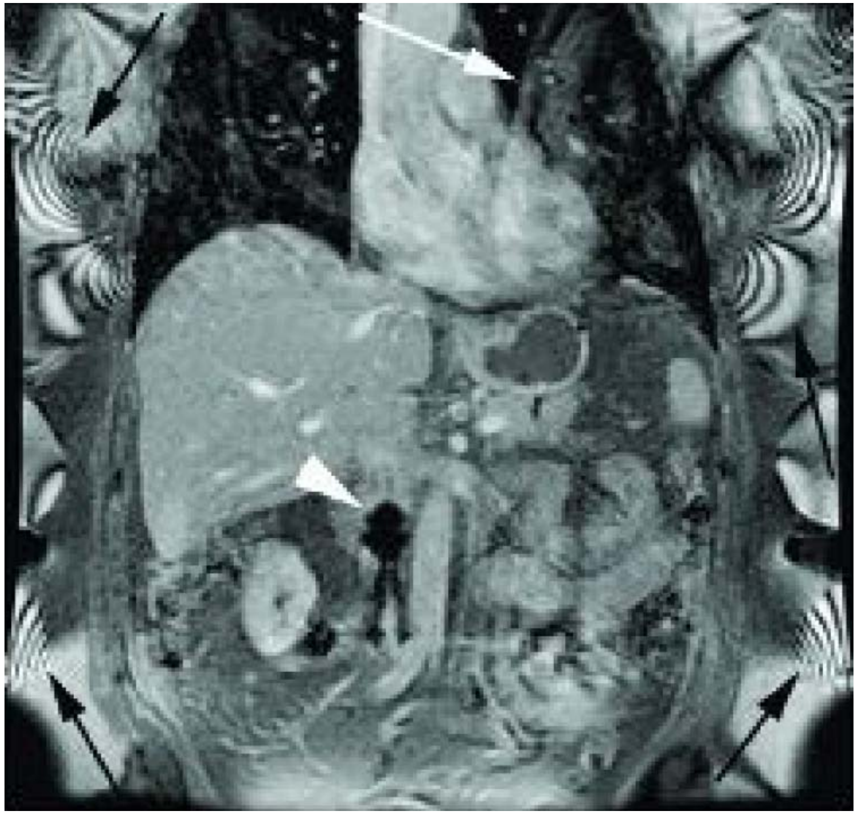
- *Artifacts related to B0 are usually caused by magnetic inhomogeneities.*
- *These nonuniformities are usually due to improper shimming, environmental factors, or the far extremes of newer short bore magnets.*
- *This can lead to image distortion*
- *They can be reduced in SE and FSE imaging by using 180^0 refocusing pulses.*
- *They can be a source of image inhomogeneity when a fat suppression technique is used*






L
L
L
L
Sc 3
TSE/M
Sl 3
A
L
Sc 3
TSE/M
Sl 4
A
L
Sc 6
TSE/M
Sl 3
A
L
Sc 6
TSE/M
Sl 4
A
L





Coronal post gadolinium spoiled gradient T1 image with chemical (spectral) fat saturation

Single-shot FSE (SSFSE) T2W

Thanks for your attention

磁振造影影像最佳化的設定

新光吳火獅紀念醫院 放射診斷科
技術專員 李正輝

Primary parameters

TR
TE
TI
FA (flip angle)
} contribute to *image contrast*

Δz = slice thickness
Interslice gap
} contribute to *coverage*

- FOV$_x$
- FOV$_y$
- N$_x$: # of frequency-encoding steps
- N$_y$: # of phase-encoding steps

} Contribute to *resolution:*
Δx : spacing in x direction
Δy : spacing in y direction

- NEX
- Bandwidth

} Contribute to *S/N ratio* (all of the above: FOV$_x$, FOV$_y$, N$_x$, N$_y$, NEX, Bandwidth)

overview

- Scan time
- Contrast
- SNR
- Resolution
- coverage

什麼是波序？

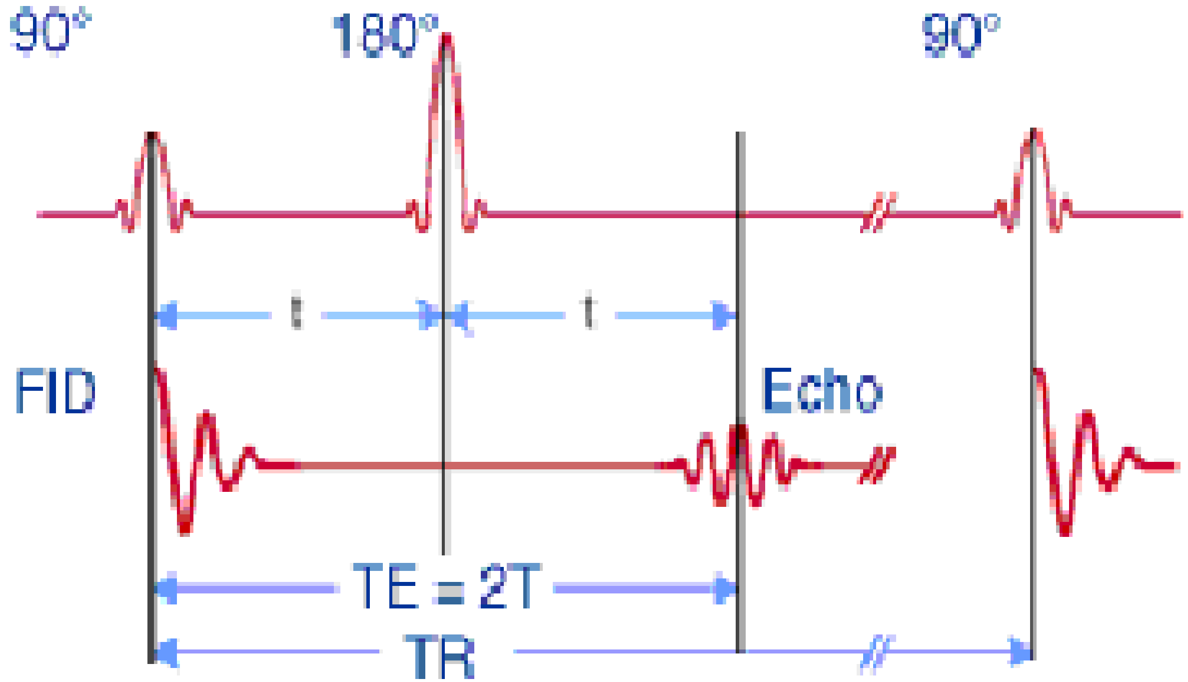
- 在MRI成像中，為了擷取不同組織對比的影像，所安排在以時間為主的軸位上，一連串訊號激發與擷取的磁場序列。

MRI訊號的產生

- 在適當的時間點施加梯度回訊磁場並接收訊號。
- 專有名詞：

1. **重複時間(TR)：**施加兩次相同RF中間的時間。
2. **回訊時間(TE) ：**從施加RF到擷取回訊之間的時間。
3. **偏轉角度(FA) ：**將縱軸向量偏轉至橫軸向量的角度。

MRI訊號的產生--- TR &TE



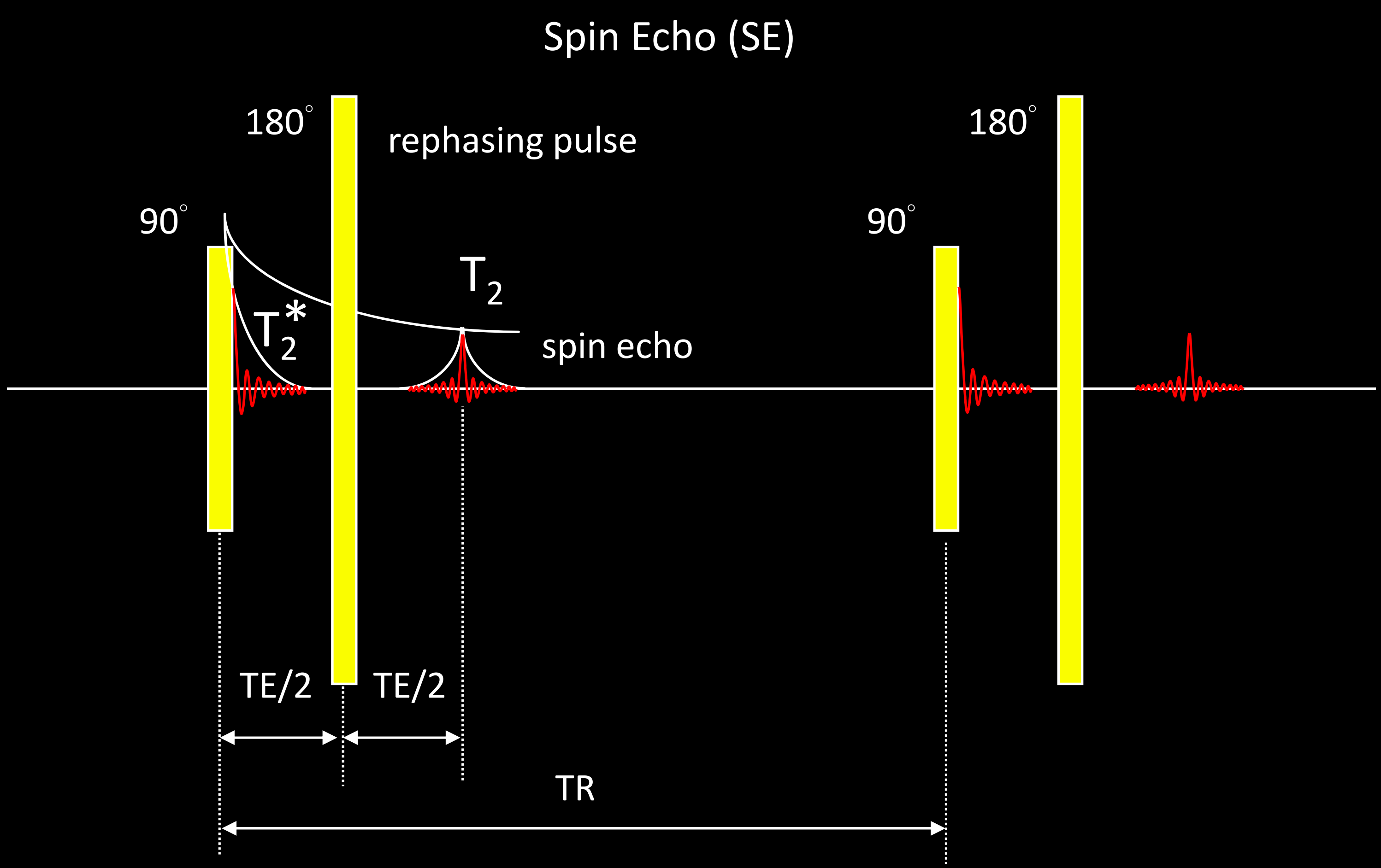
MRI常用的波序

- **Spin echo**
- **Gradient echo**
- **Inversion Recovery**

Spin echo

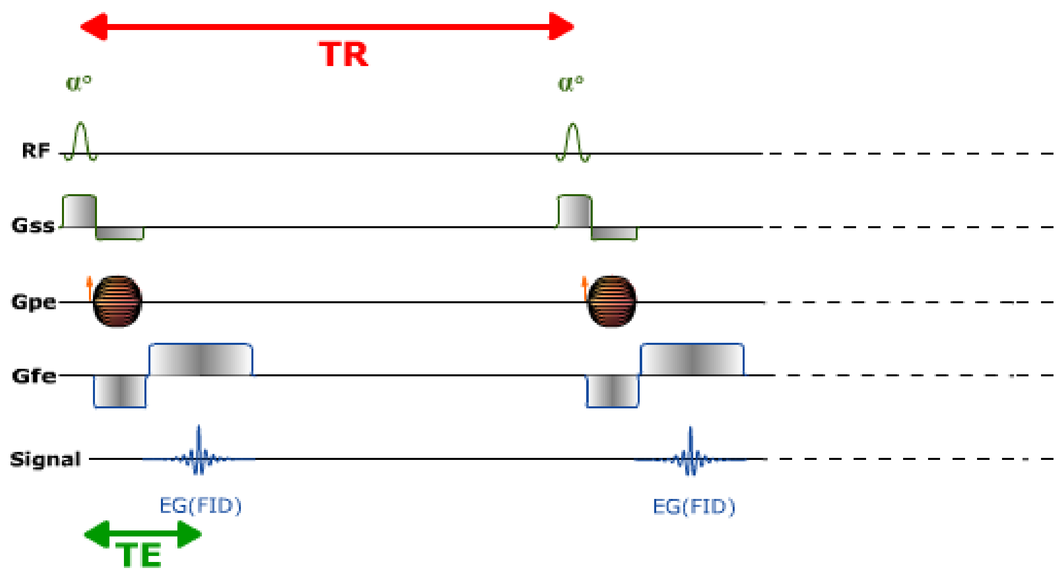
- 90^{0} -180^{0} - TE
- Gold standard for MR imaging quality.
- Minimize the noise by 180^{0} rephasing.
- Higher SNR
- Take much more time to imaging.
- Tuber spin echo (TSE or FSE)

Spin Echo
pulse sequence



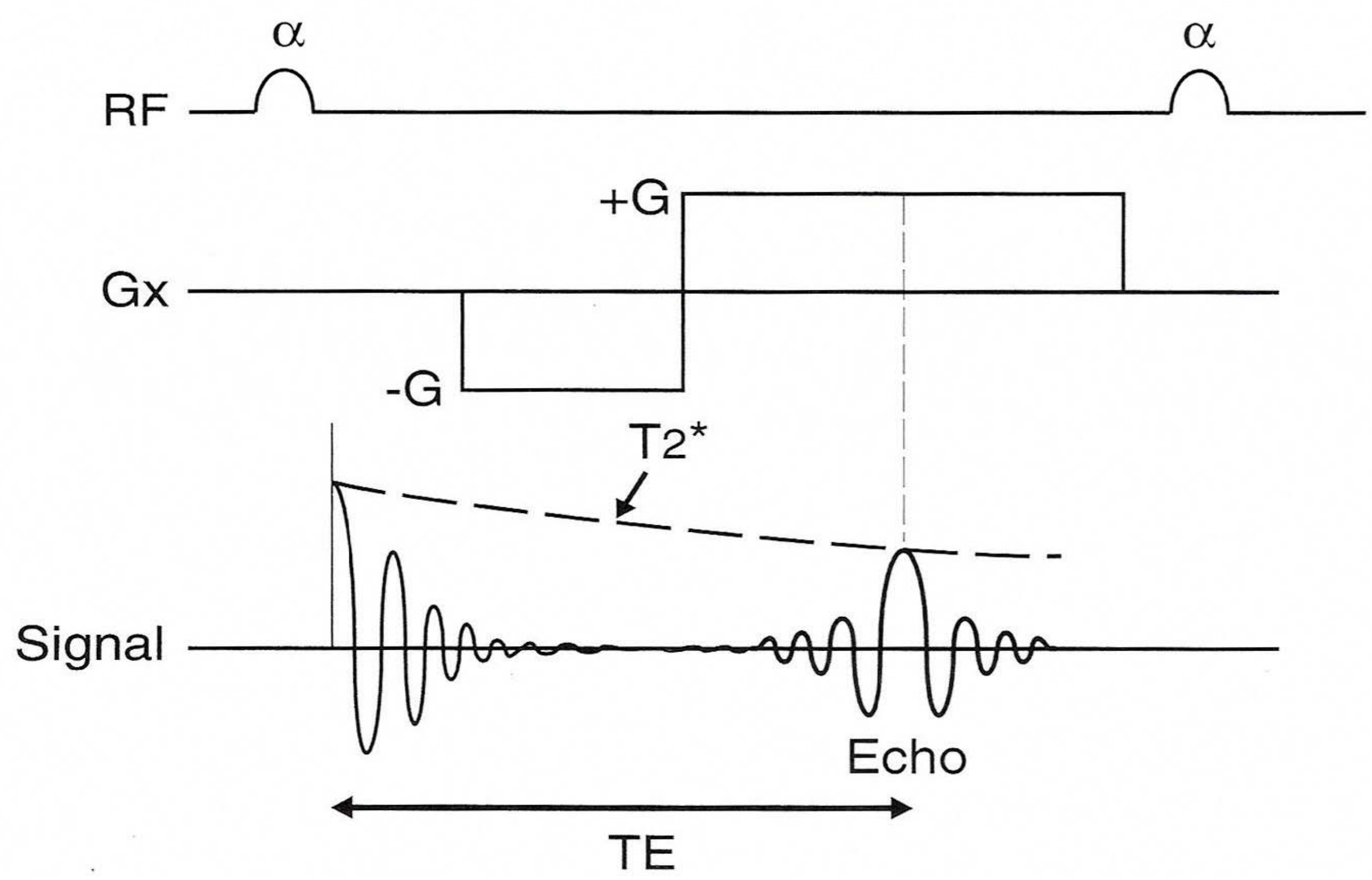
Gradient echo

- Small FA (less than 90 ^{0})
- Absent 180 ^{0} refocus
- Rapid scan technique (take time less than CSE)
- Less SNR compared with CSE



Echo time in GRE

Bi-lobed Gradient

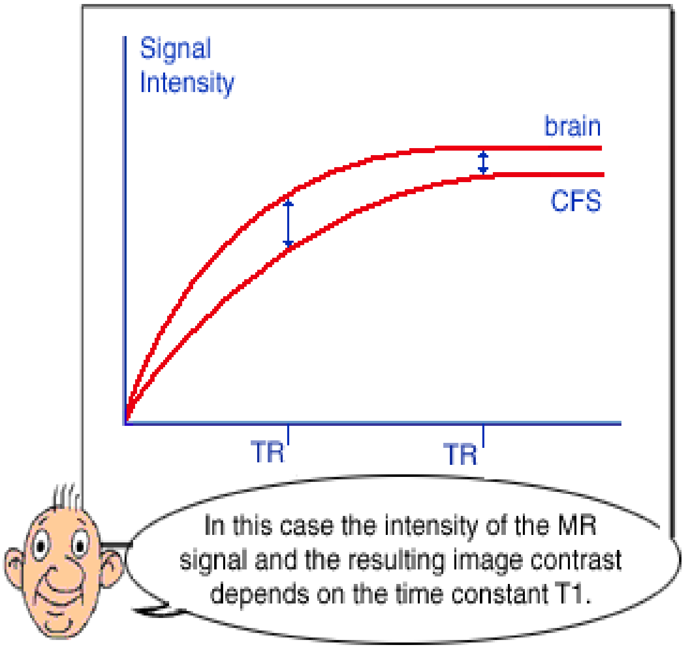


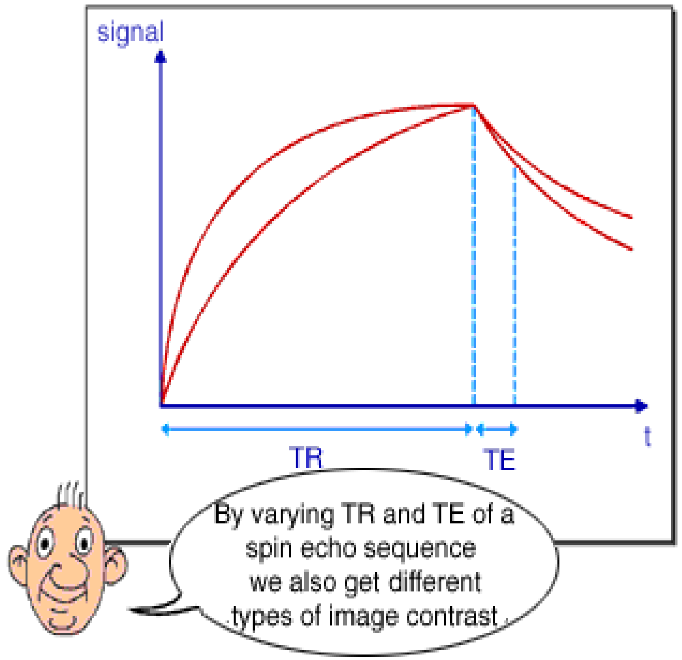
The contrast of gradient echo

	Small	Large
α	↑ PDW	↑ T1W
TR	↑ T1W	↑ PDW
TE	↑ PDW	↑ $T2^*$W

影響MRI訊號產生的公式

$$SI = N(H)\ (1-e^{-TR/T1})\ (e^{-TE/T2})$$





How about the scan time?

- TR
- NEX (Number of excitations)
- Number of phase encoding

$$\text{Scan time} = TR \times NEX \times PEs$$

How to reduce the scan time?

- Short TR

--- For T1 imaging: 400-800ms

--- For T2 imaging: 3000ms ↑

--- Gradient echo

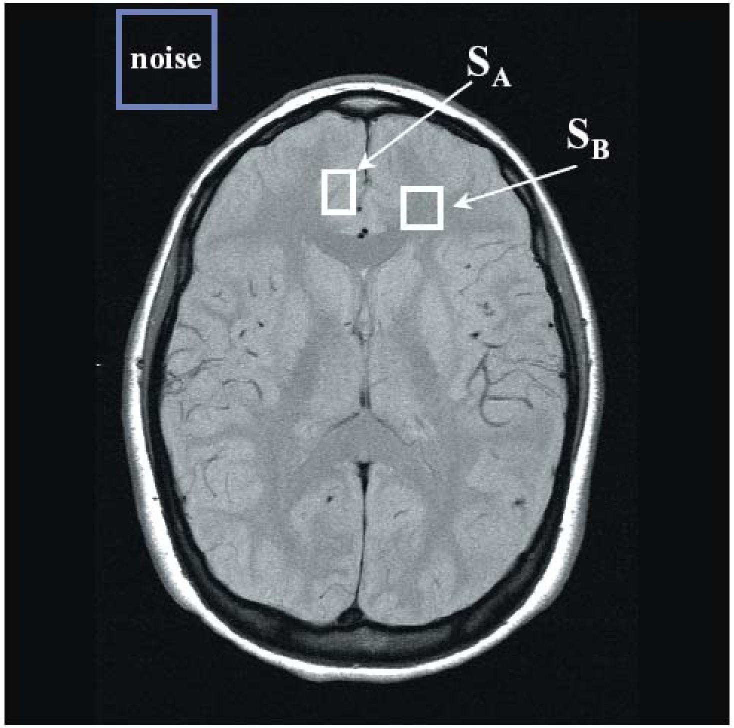
- Decrease NEX
- Decrease number of phase encoding

--- TSE or FSE

--- SENSE

Contrast

- Contrast was introduced in terms of the image appearance, or relative brightness of different tissues and pathology.
- Image contrast arises (or doesn't) when tissues generate MR signals which have different intensities because of their physical properties, i.e. T1 and T2 relaxation times and proton density.



Here's the maths bit

Mathematically we can define contrast as

$$C = \frac{S_A - S_B}{S_A + S_B}$$

where S_A and S_B are signal intensities for tissues A and B.

Signal-to-noise ratio (SNR) is defined as

$$\mathrm{SNR} = \frac{signal}{noise}$$

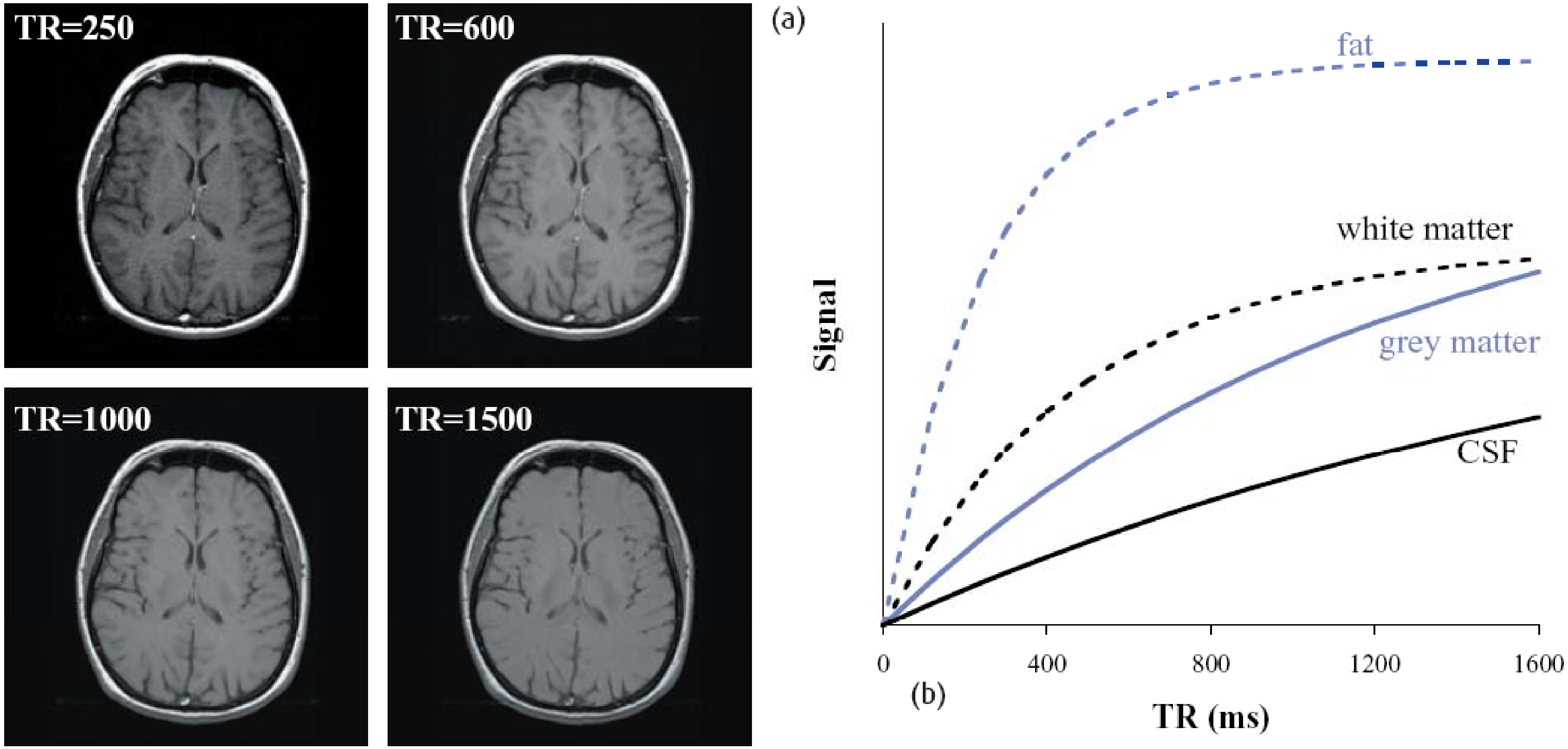
Contrast-to-noise ratio (CNR) is defined for tissues A and B as

$$CNR_{AB} = \frac{S_A - S_B}{noise}$$

In the simplest terms spatial resolution of the voxels is related to the field of view (FOV) and matrix thus

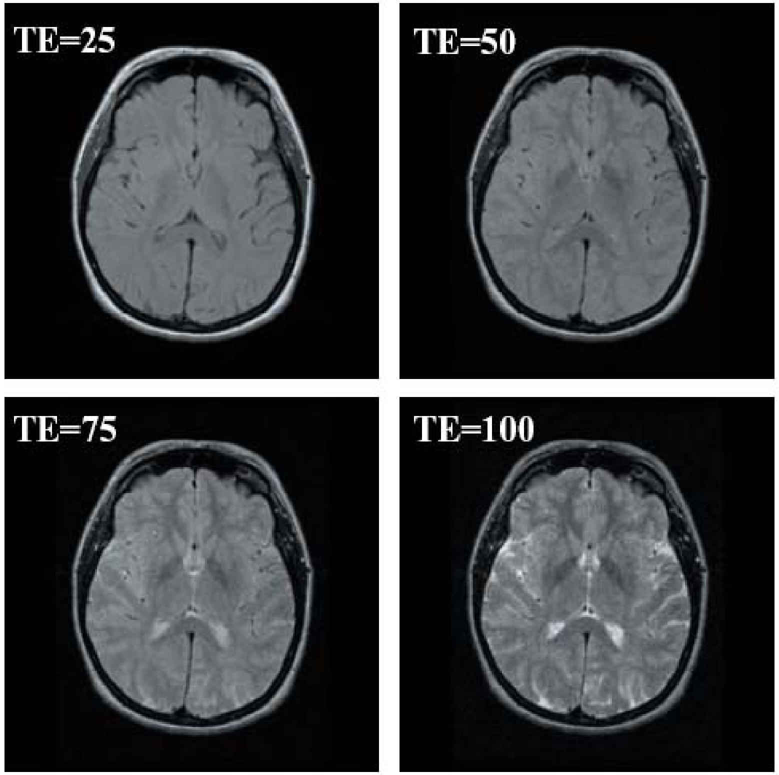
$$\Delta x = \frac{\mathrm{FOV}}{N_{FE}} \qquad \Delta y = \frac{\mathrm{FOV}}{N_{PE}} \qquad \Delta z = \text{slice width}$$

TR and tissue contrast

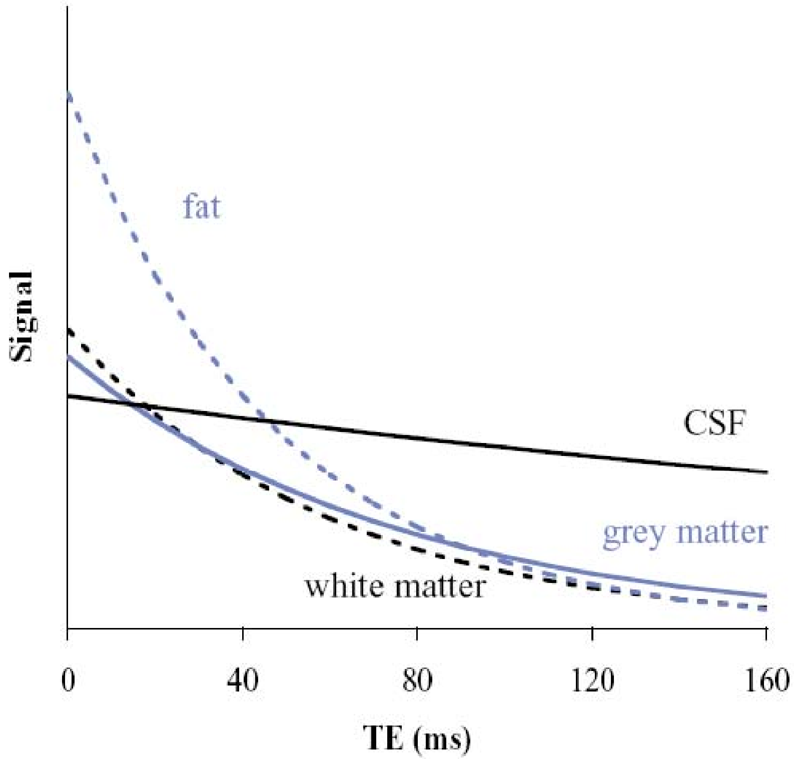


TE=10

TE and tissue contrast



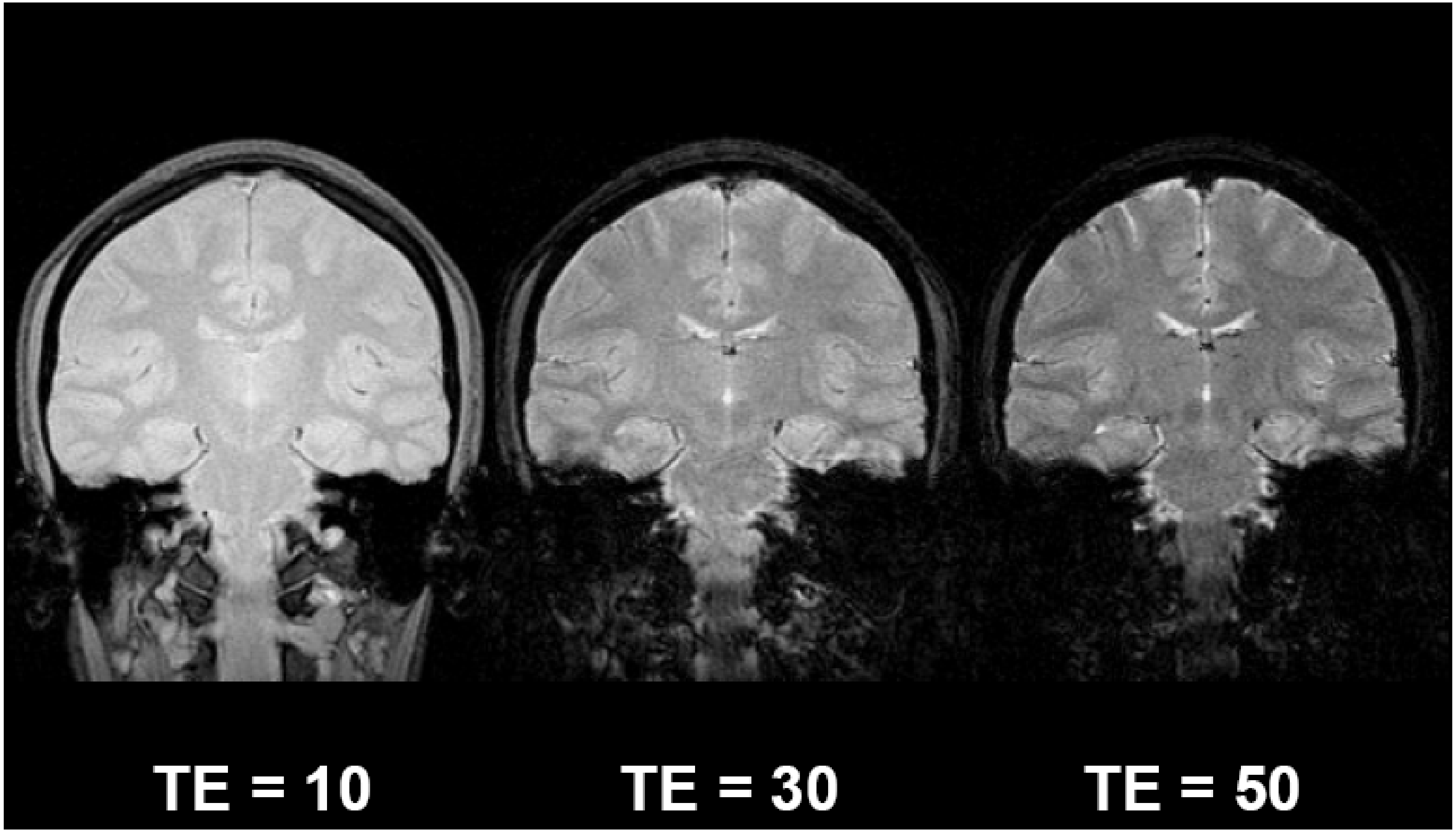
(a)



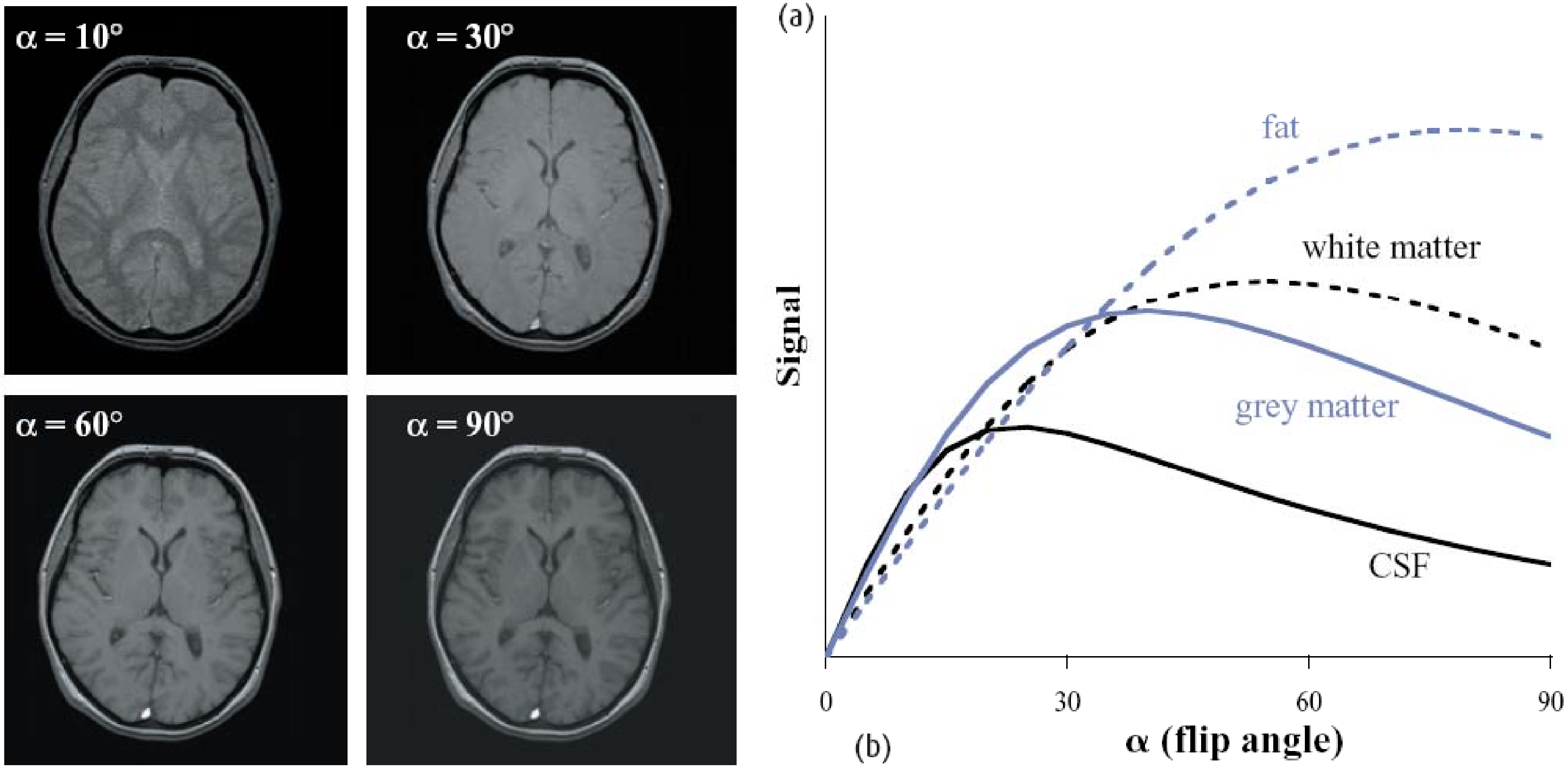
(b)

TR=1500

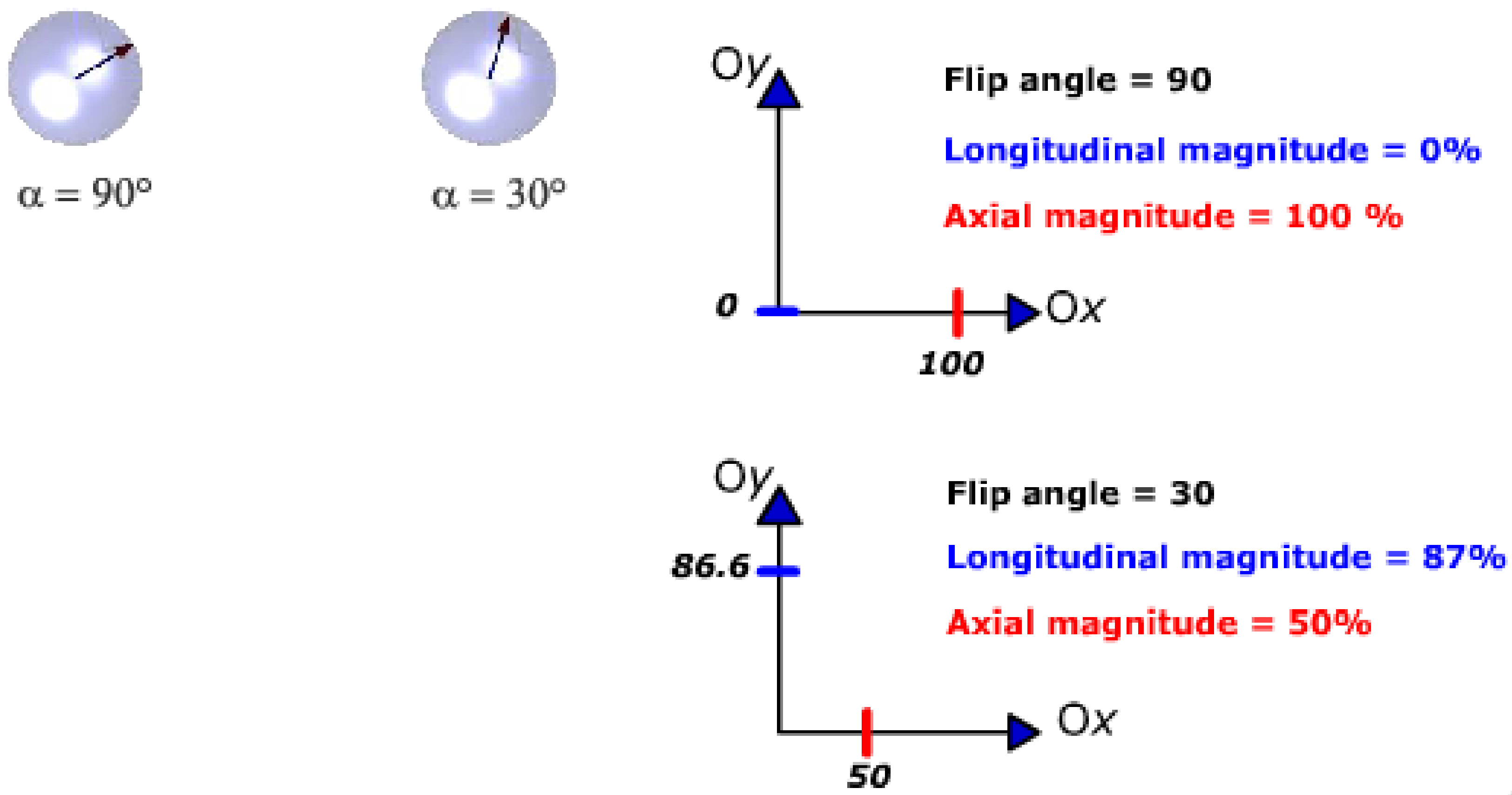
Tissue Contrast - TE

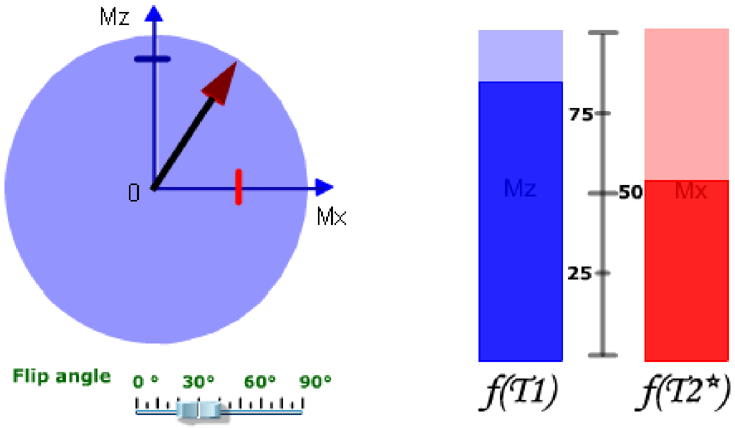


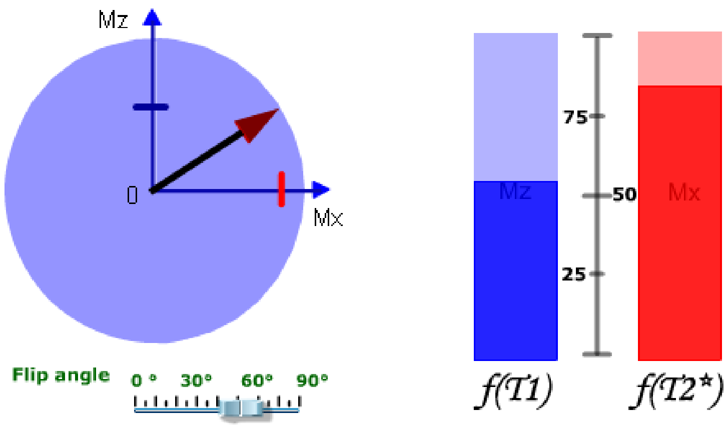
flip angles and contrast

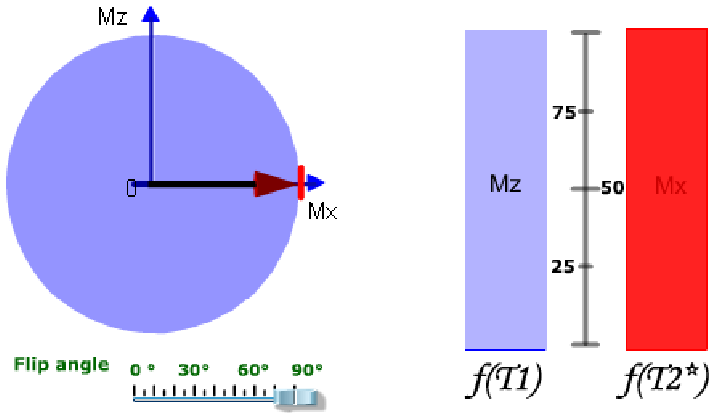


TR=150, TE=4.6

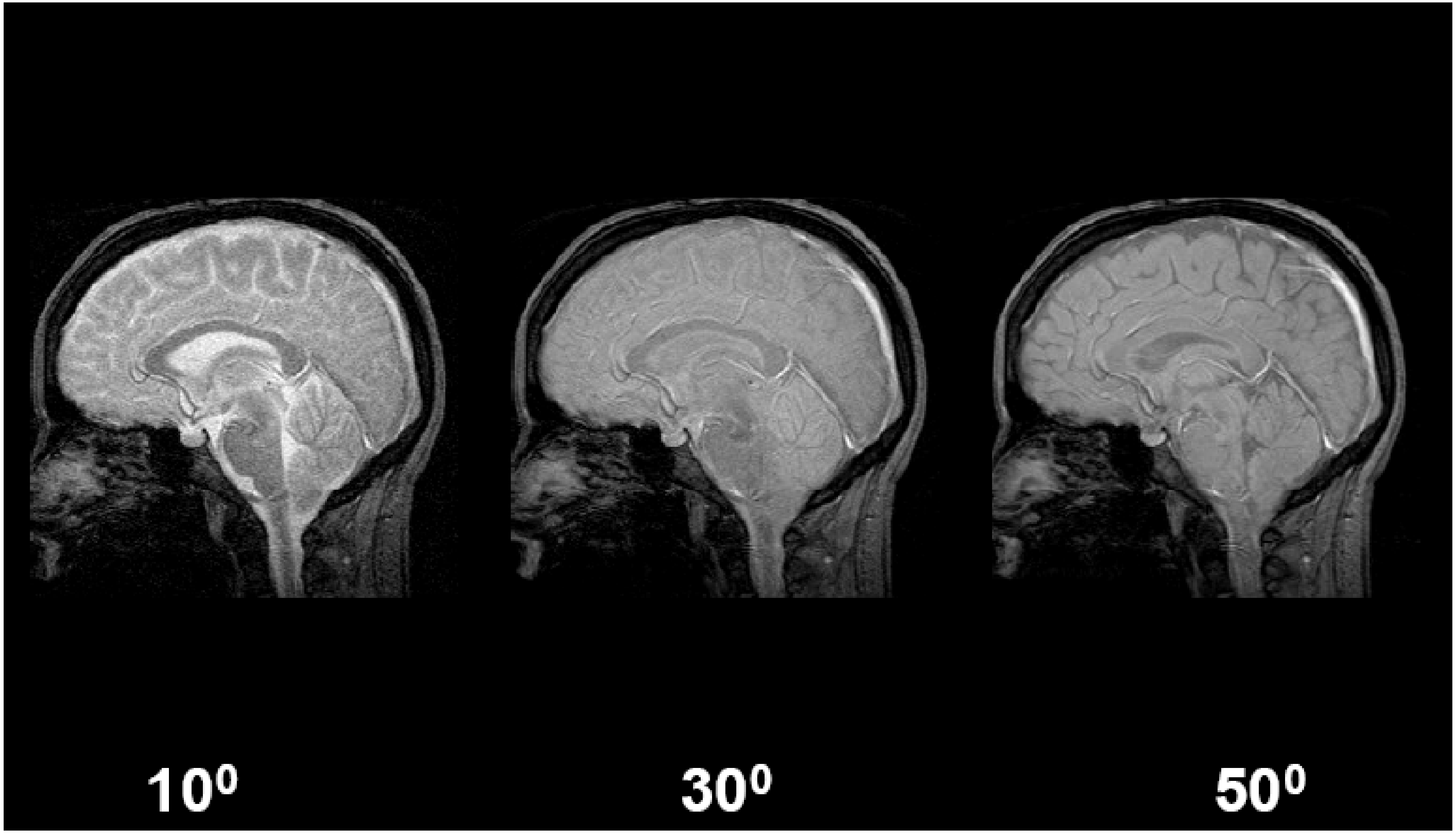

α = 90°
α = 30°
Oy
Flip angle = 90
Longitudinal magnitude = 0%
Axial magnitude = 100 %
0
Ox
100
Oy
Flip angle = 30
Longitudinal magnitude = 87%
Axial magnitude = 50%
86.6
Ox
50


Mz
0
Mx
Flip angle
0 °
30°
60°
90°
Mz
Mx
75
50
25
f(T1)
f(T2*)

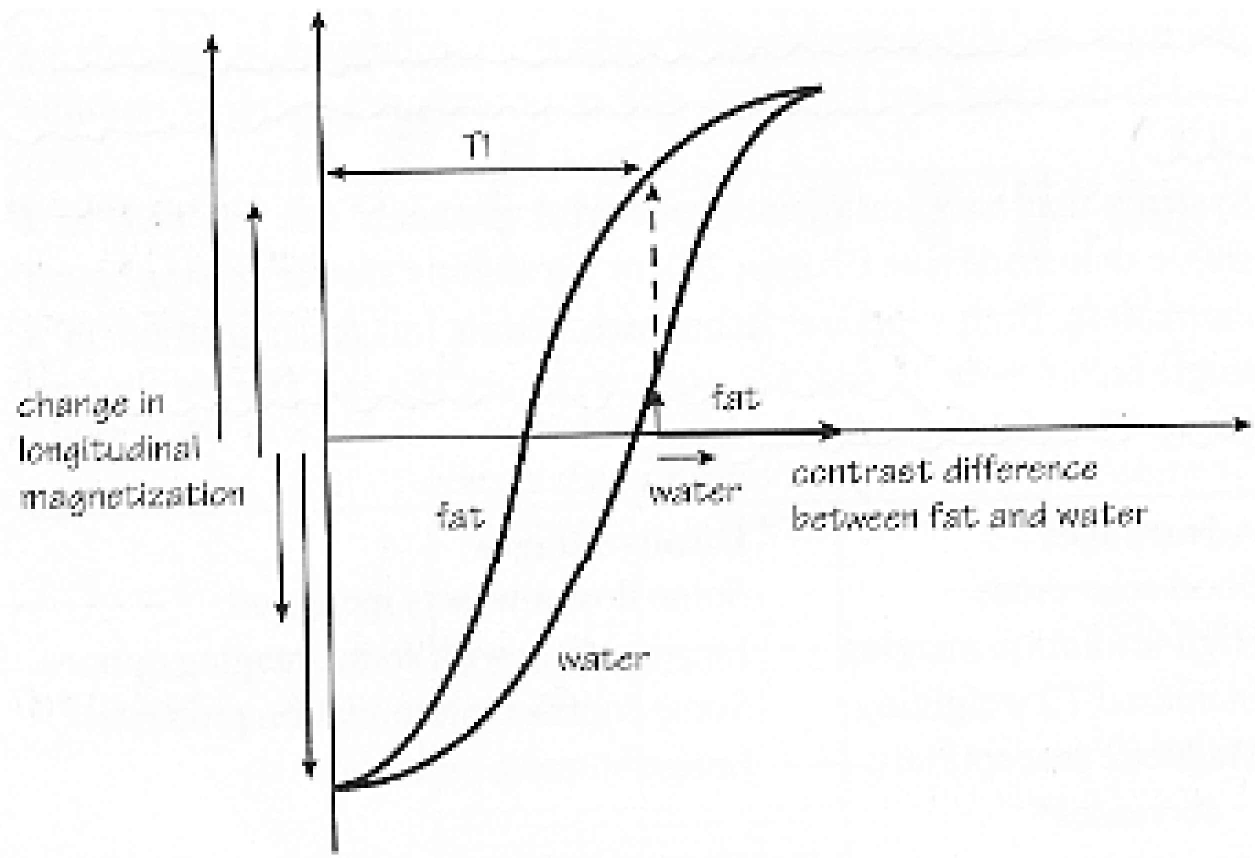

Mz
0
Mx
Flip angle
0 °
30°
60°
90°
Mz
Mx
75
50
25
f(T1)
f(T2*)


Mz
0
Mx
Flip angle
0 °
30°
60°
90°
Mz
Mx
75
50
25
f(T1)
f(T2*)

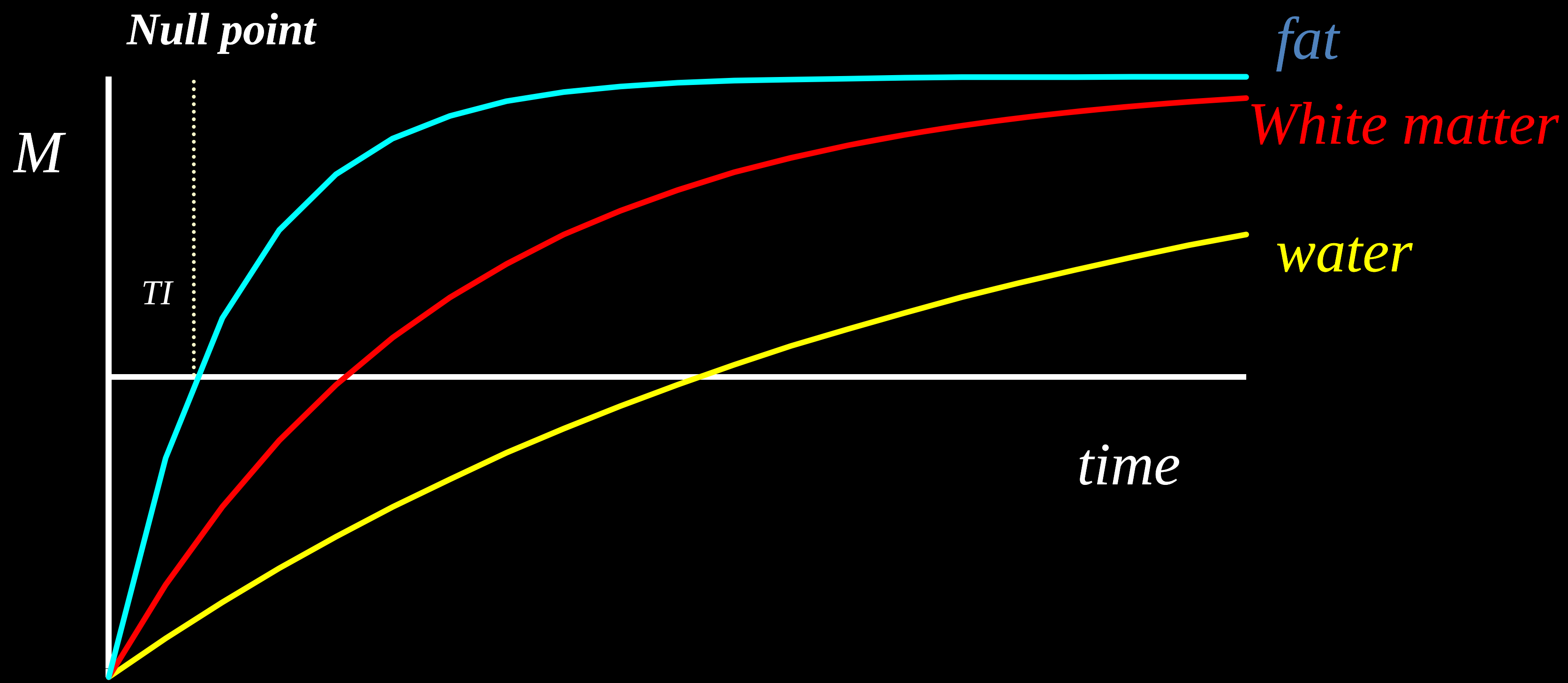
Tissue Contrast - FA



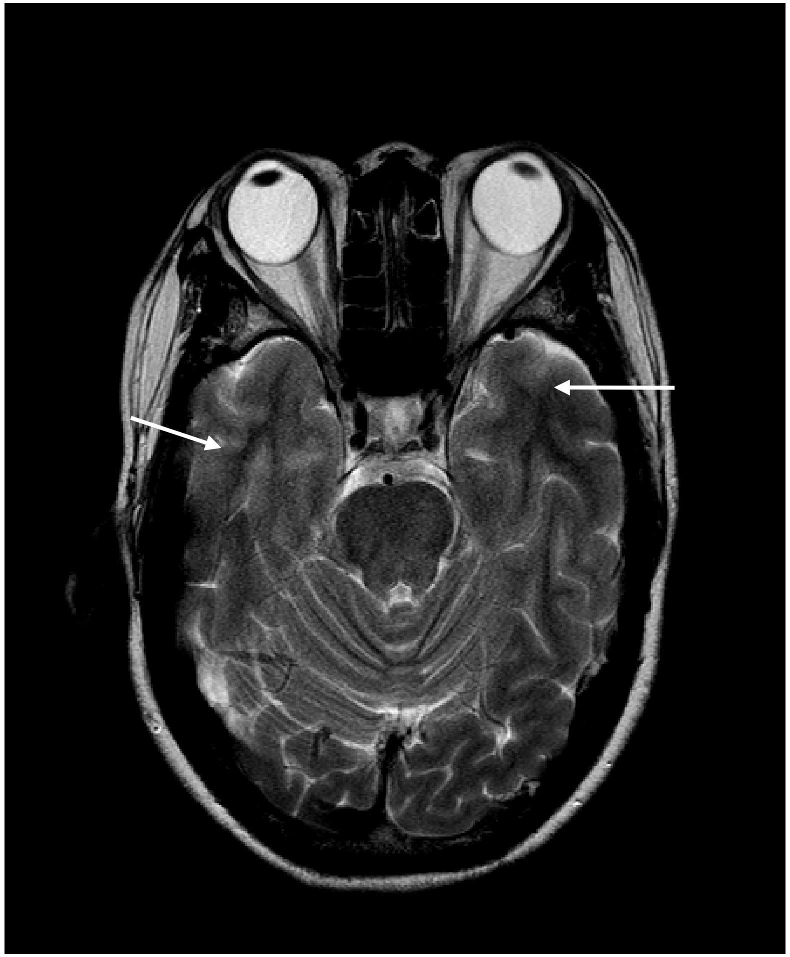
Invention recovery (IR)



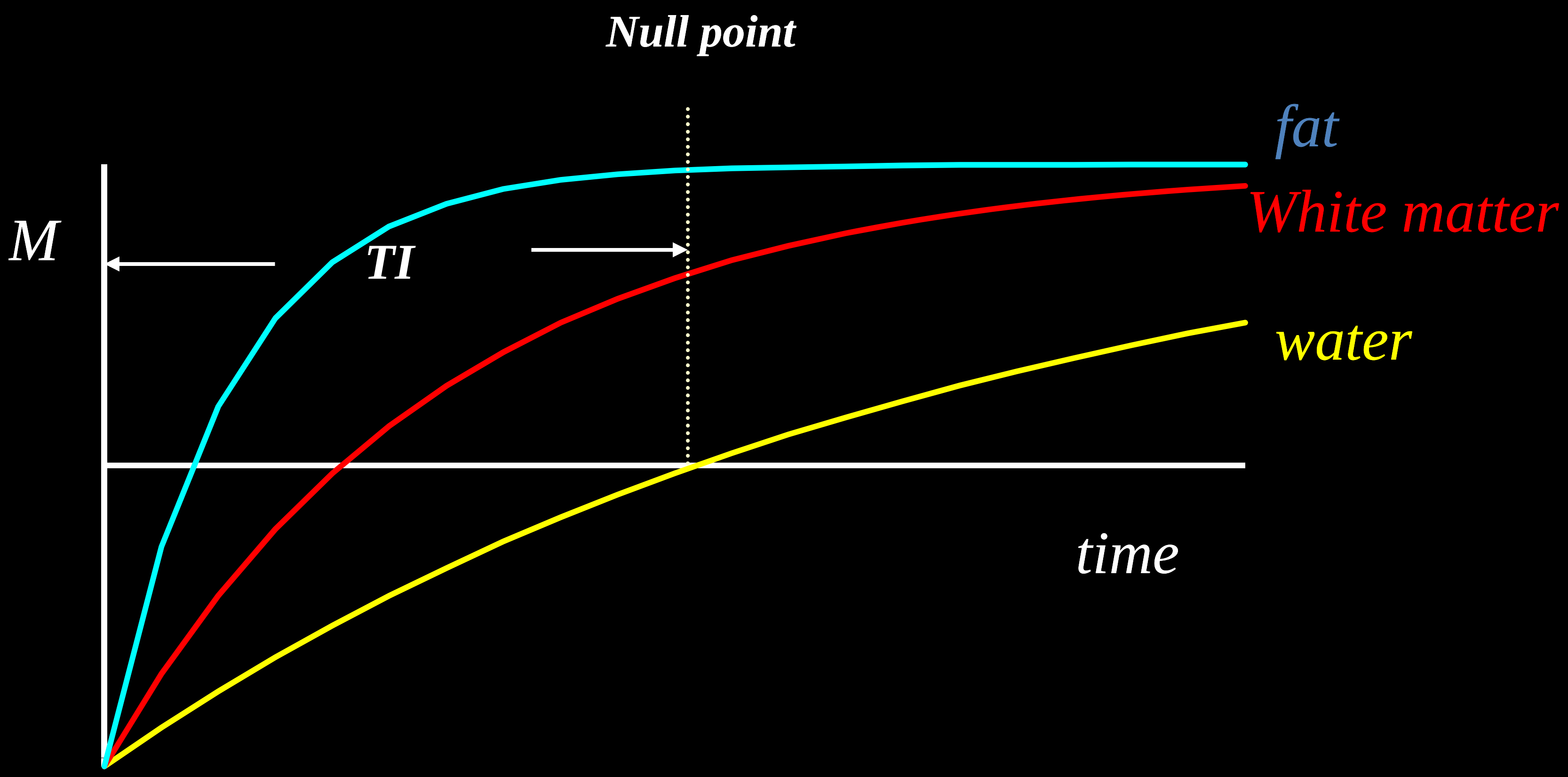
STIR

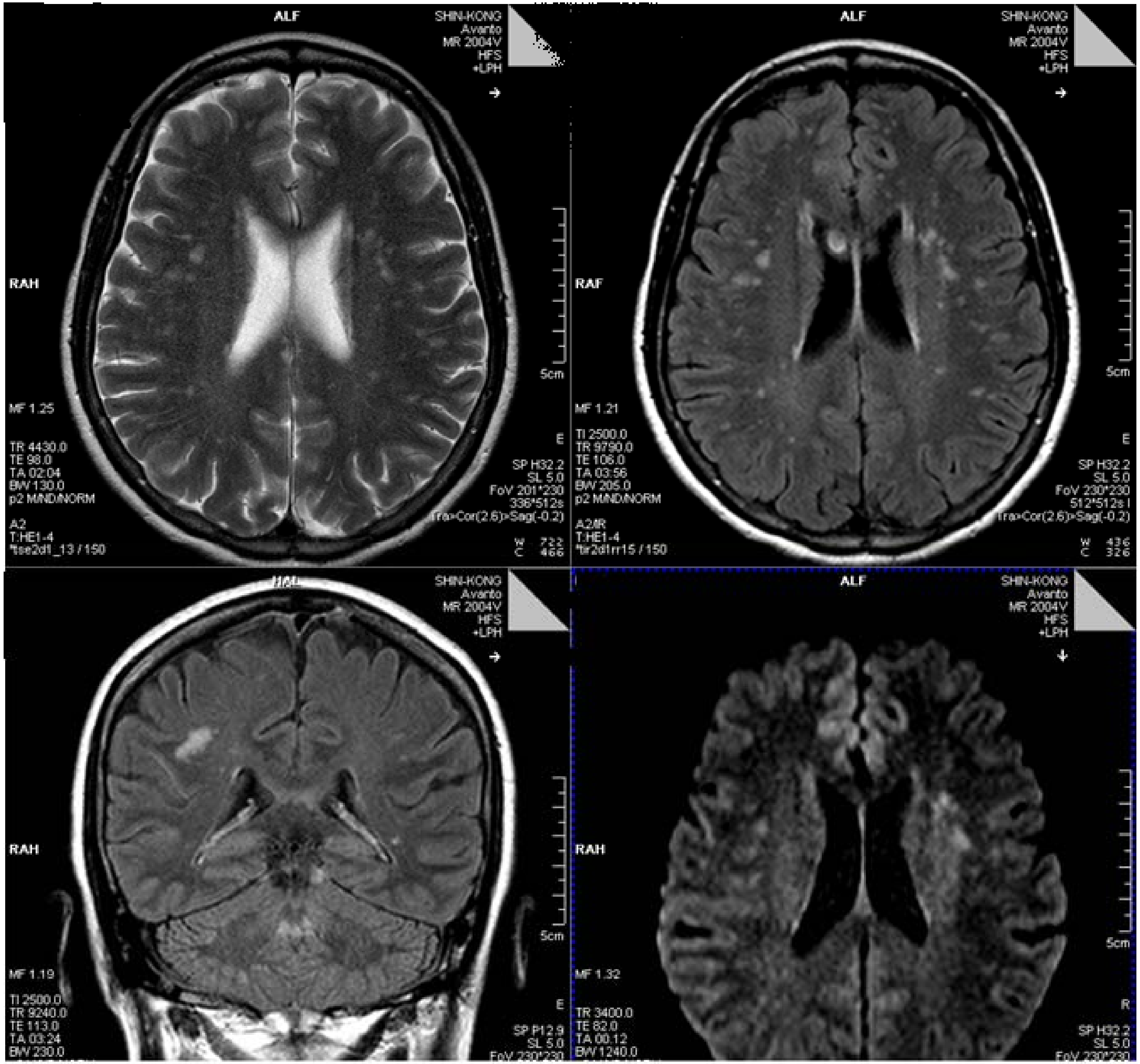


STIR image

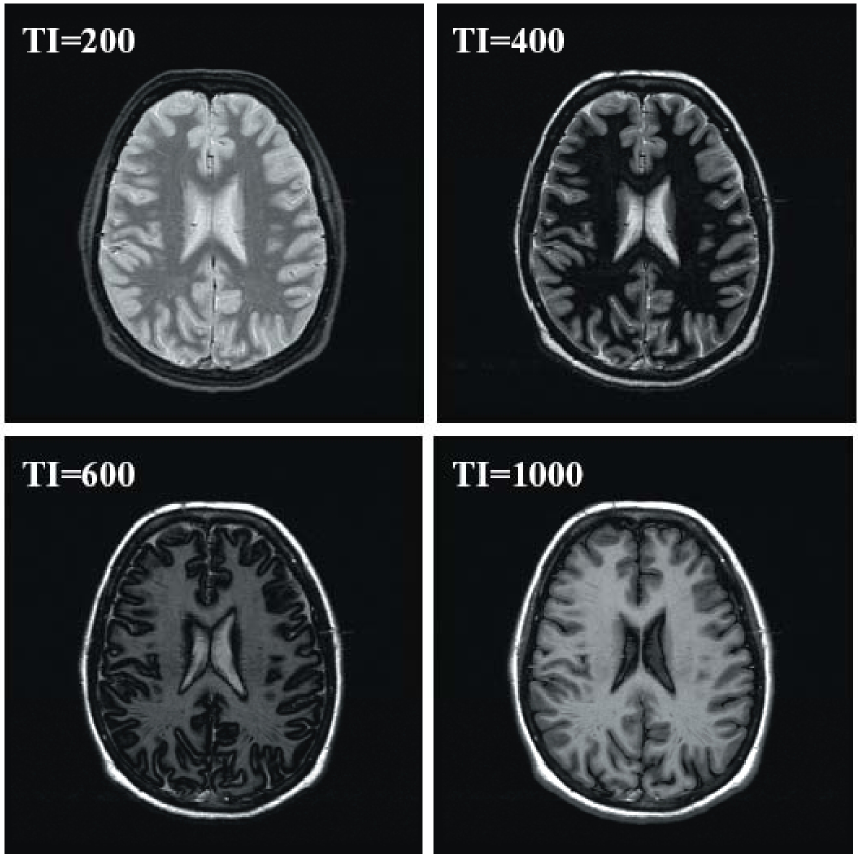


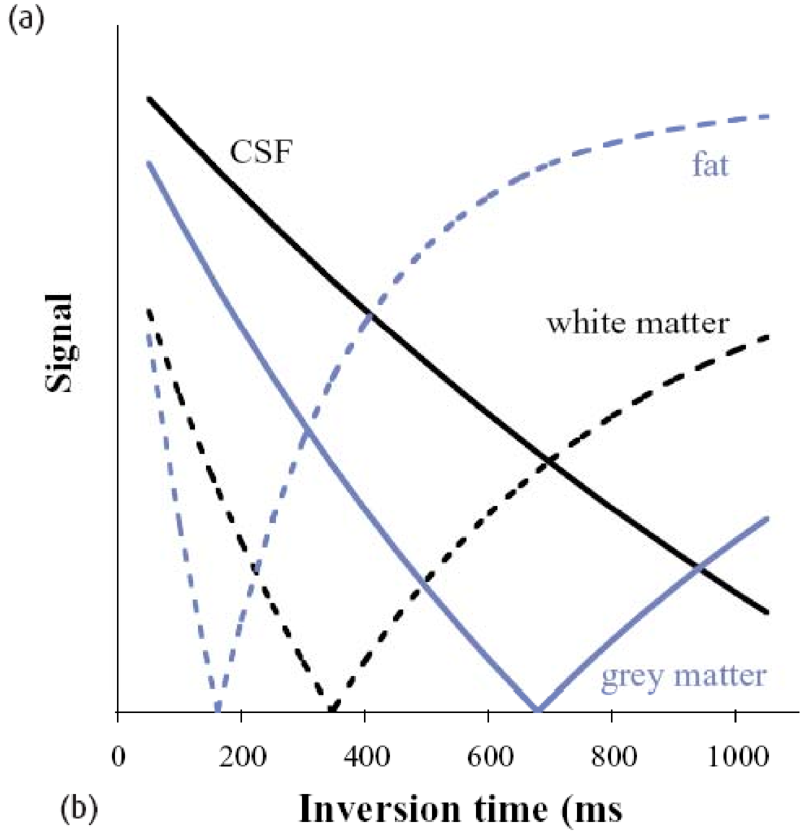
Flair




ALF
SHIN-KONG
Avanto
MR 2004V
HFS
+LPH
RAH
5cm
MF 1.25
TR 4430.0
TE 98.0
TA 02:04
BW 130.0
p2 M/ND/NORM
A2
T:HE1-4
*tse2d1_13 / 150
E
SP H32.2
SL 5.0
FoV 201*230
336*512s
Tra>Cor(2.6)>Sag(-0.2)
W 722
C 466
ALF
SHIN-KONG
Avanto
MR 2004V
HFS
+LPH
RAF
5cm
MF 1.21
TI 2500.0
TR 9790.0
TE 106.0
TA 03:56
BW 205.0
p2 M/ND/NORM
A2/IR
T:HE1-4
*tir2d1rr15 / 150
E
SP H32.2
SL 5.0
FoV 230*230
512*512s I
Tra>Cor(2.6)>Sag(-0.2)
W 436
C 326
SHIN-KONG
Avanto
MR 2004V
HFS
+LPH
RAH
5cm
MF 1.19
TI 2500.0
TR 9240.0
TE 113.0
TA 03:24
BW 230.0
E
SP P12.9
SL 5.0
ALF
SHIN-KONG
Avanto
MR 2004V
HFS
+LPH
RAH
5cm
MF 1.32
TR 3400.0
TE 82.0
TA 00:12
BW 1240.0
R
SP H32.2
SL 5.0

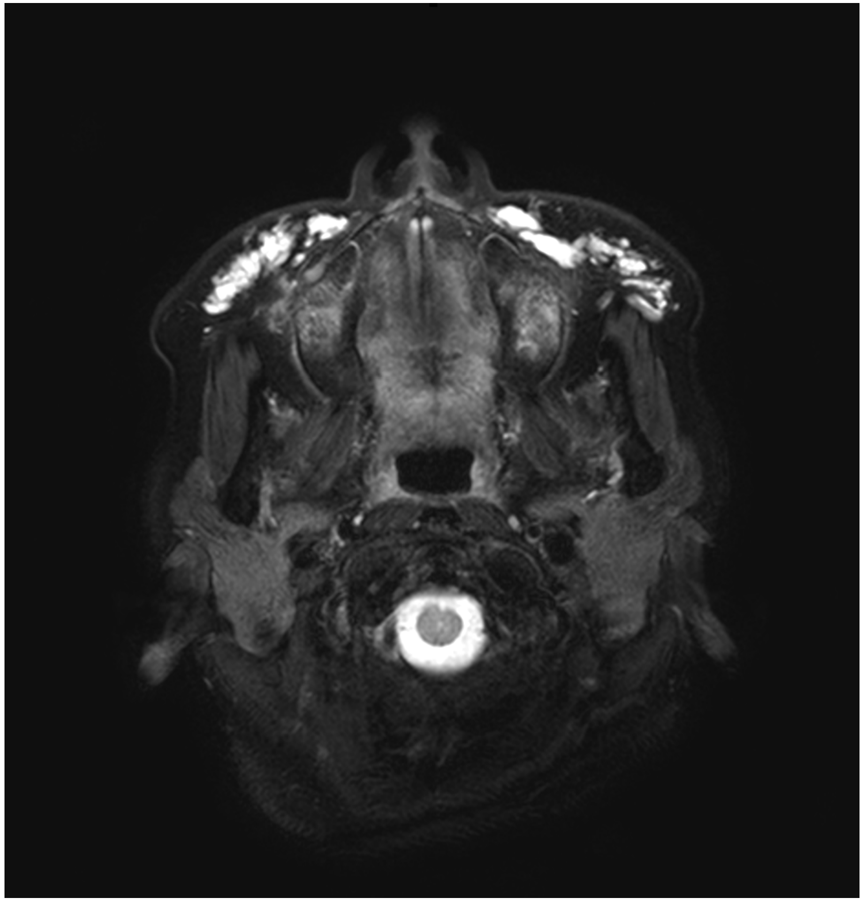
TI and contrast





TR=4000, TE=19

?



SNR (*signal-to-noise ratio)*

- Signal

--- the pixel or voxel brightness in the image.

--- related to the NMR signal .

- Noise

--- random differences in pixel values which give images a grainy, mottled look.

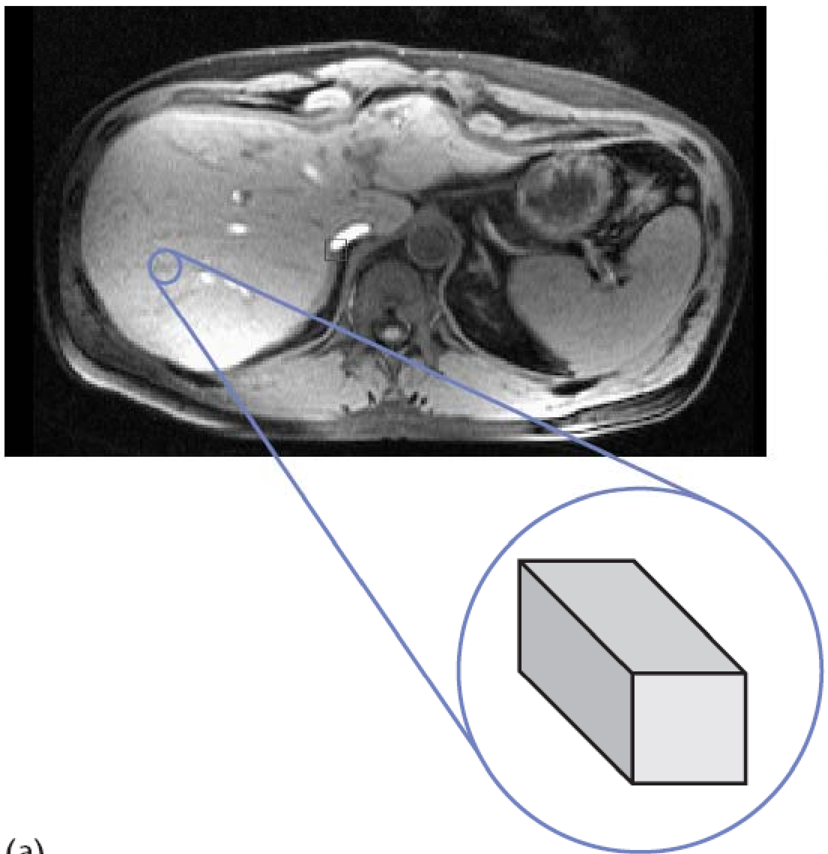
--- usually this noise originates mainly from the patient's tissues.

SNR???

$$SNR \propto \frac{\Delta x \cdot \Delta y \cdot \Delta z \cdot F_{\text{sequence}} \cdot \sqrt{NSA \cdot N_{\text{PE}} \cdot N_{\text{FE}}}}{\sqrt{BW}}$$

$$SNR \propto \frac{FOV_{\text{FE}} \cdot FOV_{\text{PE}} \cdot \Delta z \cdot F_{\text{sequence}} \sqrt{NSA}}{\sqrt{BW \cdot N_{\text{FE}} \cdot N_{\text{PE}}}}$$

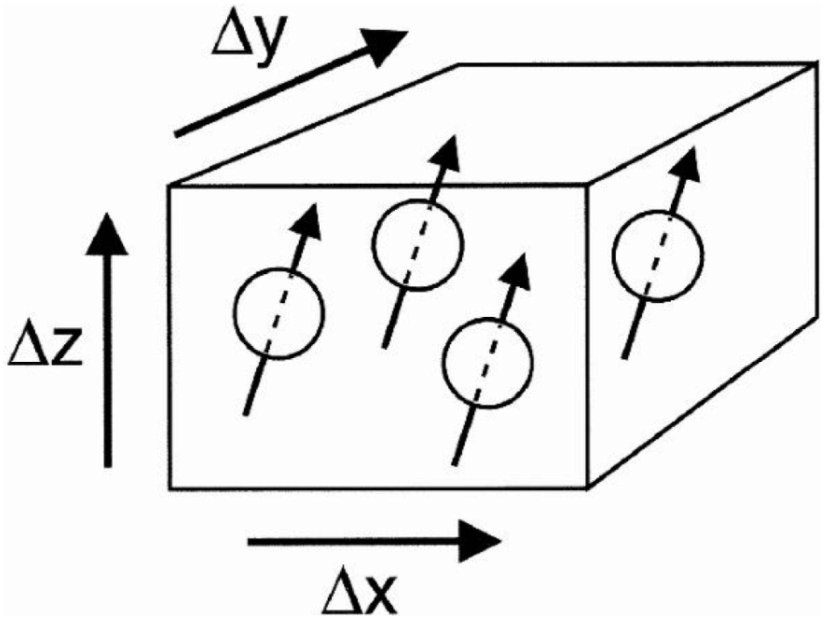
Image vs. voxel



(a)

(b)

Voxel size

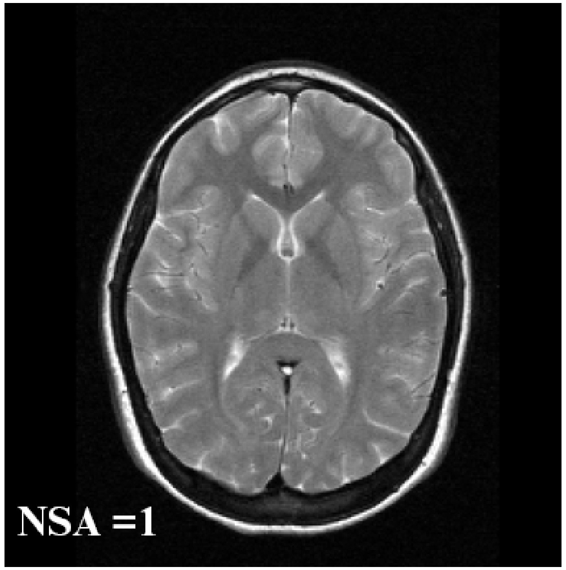


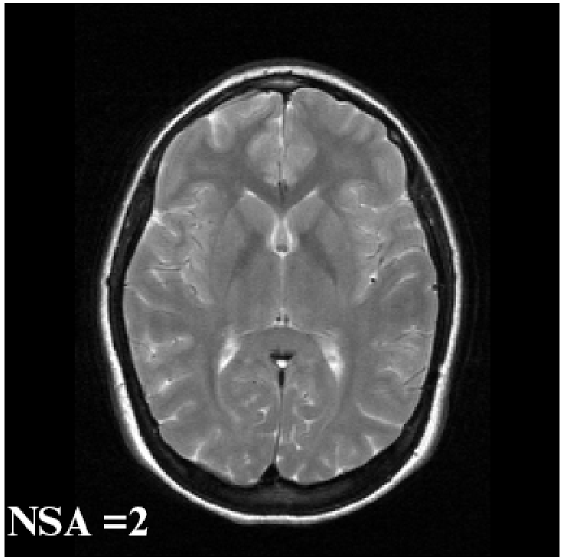
$$\text{FE pixel size} = \frac{\text{FE field-of-view}}{\text{FE matrix}}$$

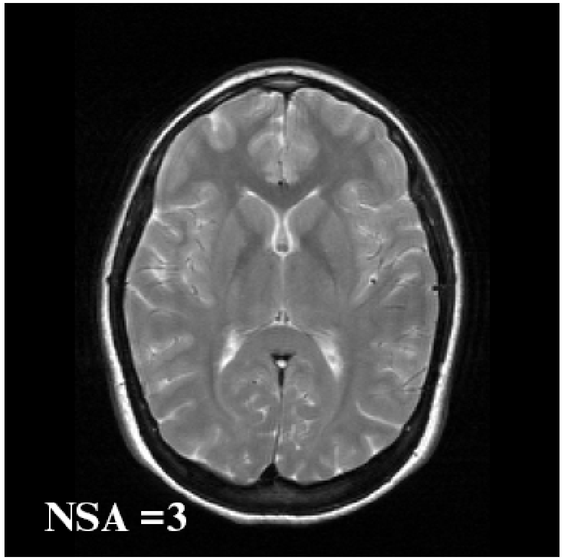
$$\text{PE pixel size} = \frac{\text{PE field-of-view}}{\text{PE matrix}}$$

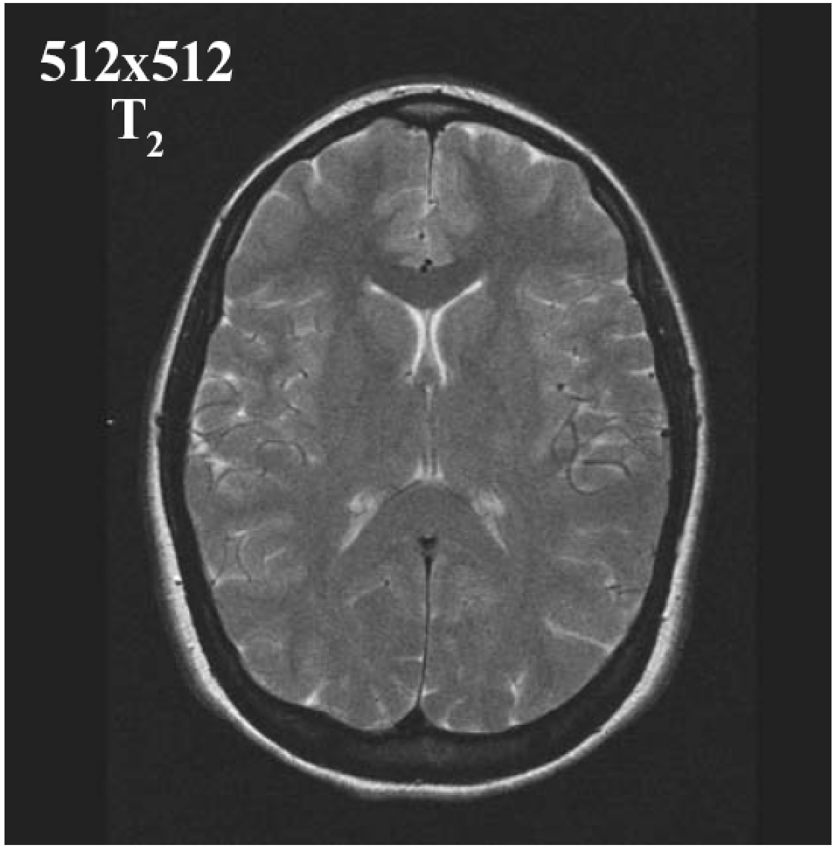
$$\text{Slice pixel size} = \text{slice thickness}$$

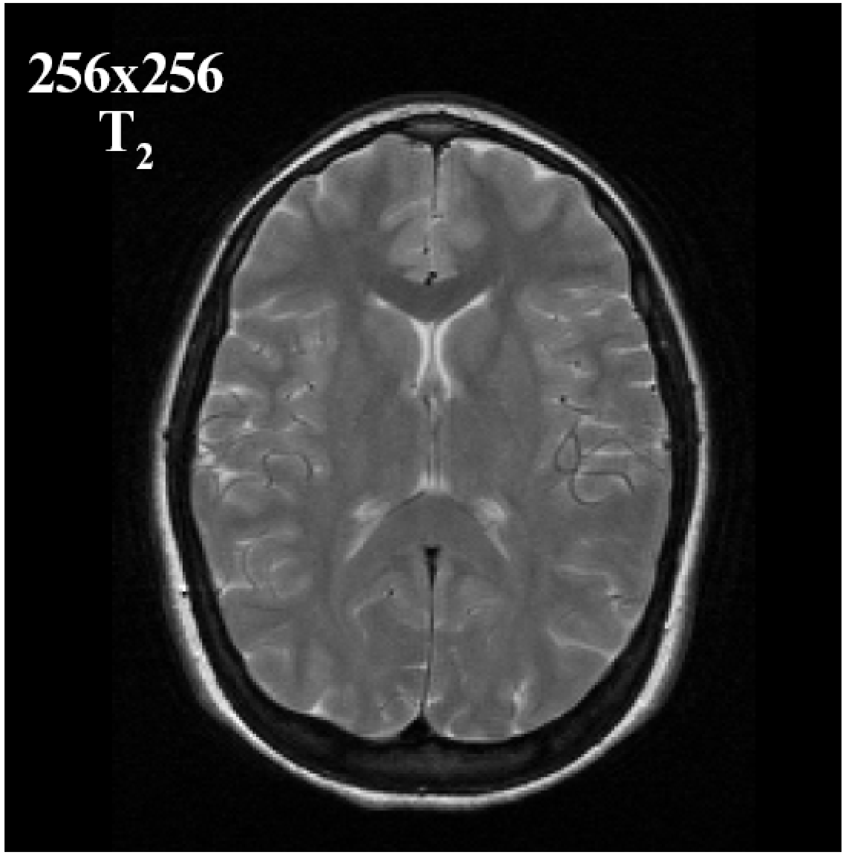
NSA

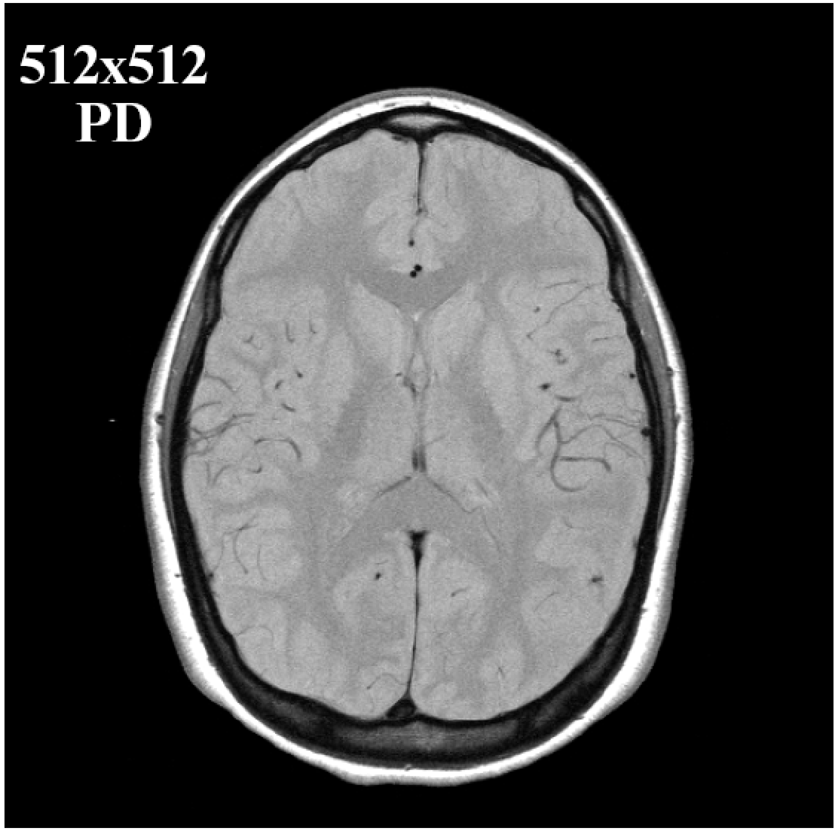


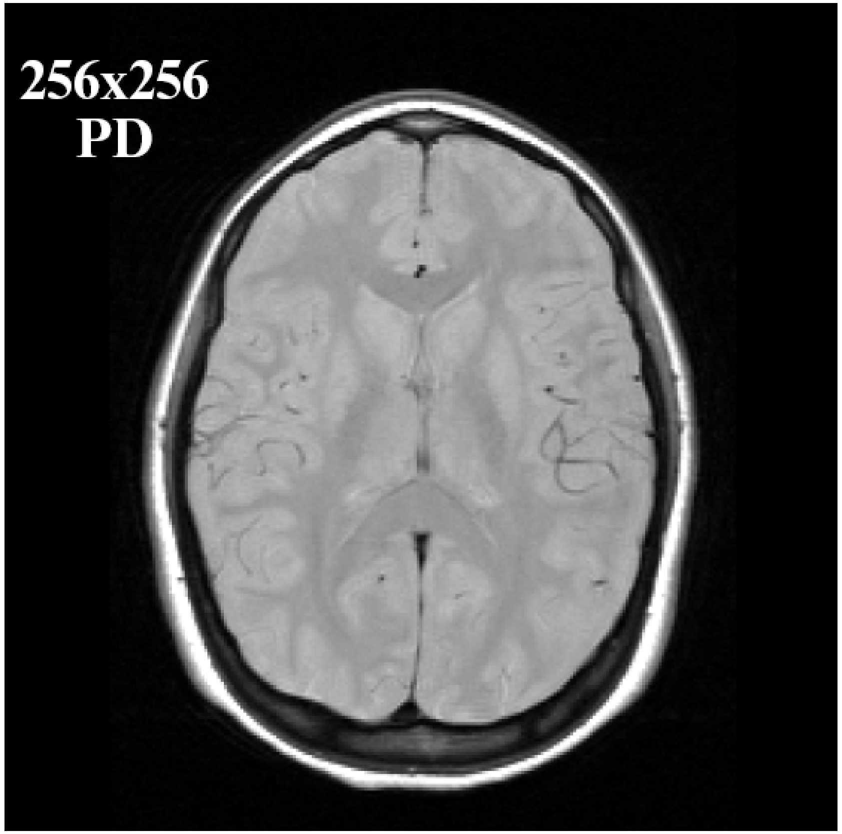





512x512
T2

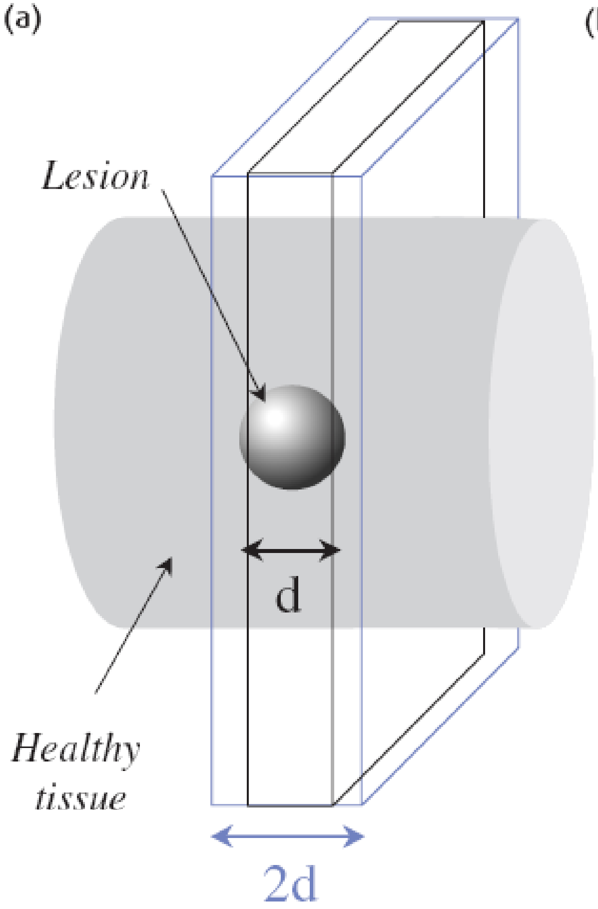

256x256
T2


512x512
PD


256x256
PD

Slice thickness vs. SNR

(a)



(b)

Slice = d

$$SNR = \frac{5}{1} = 5$$

$$Contrast = \frac{10-5}{10+5} = 0.33$$

$$CNR = \frac{10-5}{1} = 5$$

1	1	1	1	1
1	5	5	5	1
1	5	10	5	1
1	5	5	5	1
1	1	1	1	1

(c)

Slice =2 d

$$SNR = \frac{10}{1} = 10$$

$$Contrast = \frac{15-10}{15+10} = 0.2$$

$$CNR = \frac{15-10}{1} = 5$$

1	1	1	1	1
1	10	10	10	1
1	10	15	10	1
1	10	10	10	1
1	1	1	1	1

About BW

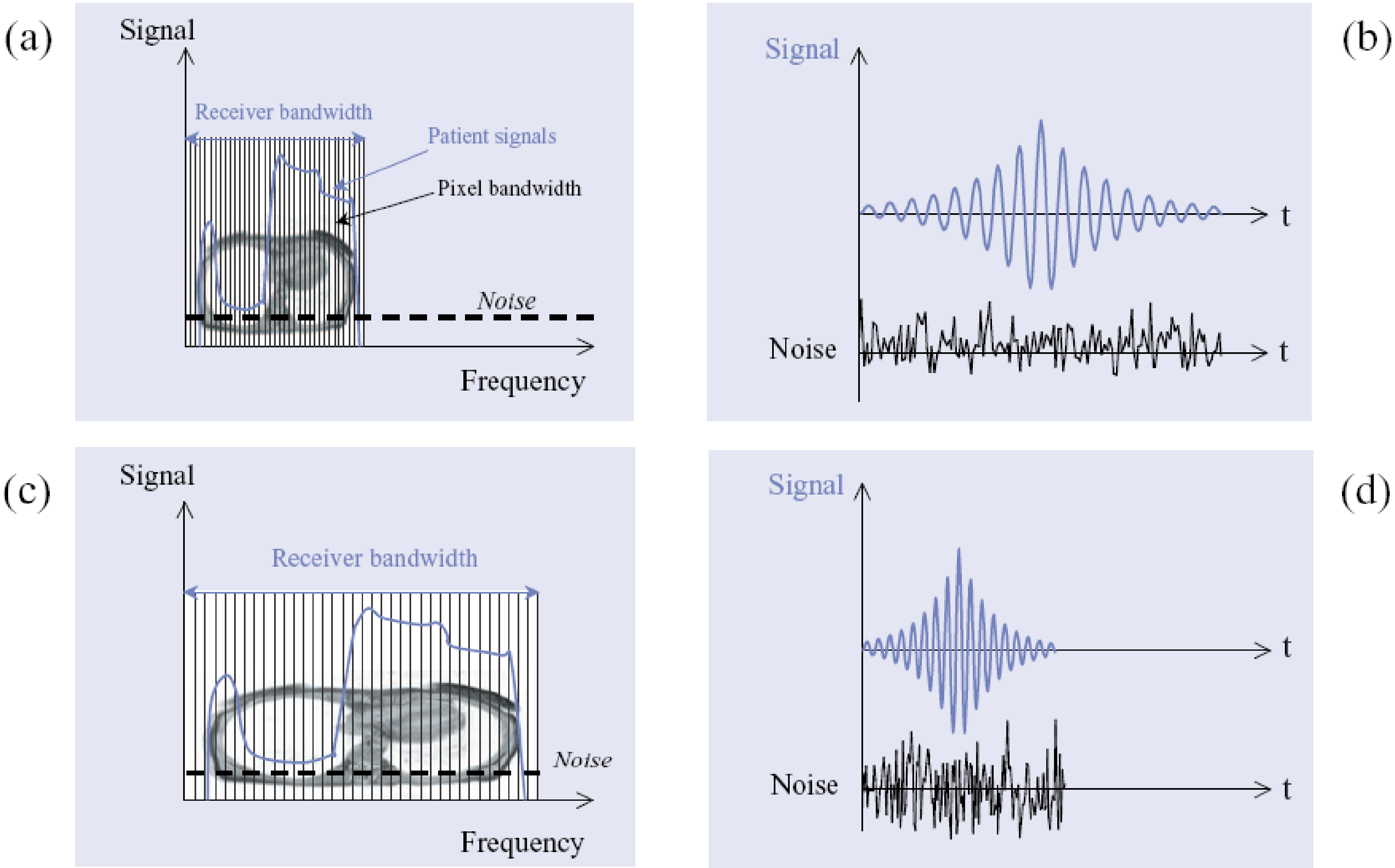
- An inverse relationship exists between BW and SNR
- Decreased bandwidth causes the following:

--- Increased SNR (decreasing the BW by a factor of 2 causes the SNR to improve by a factor of $\sqrt{2}$

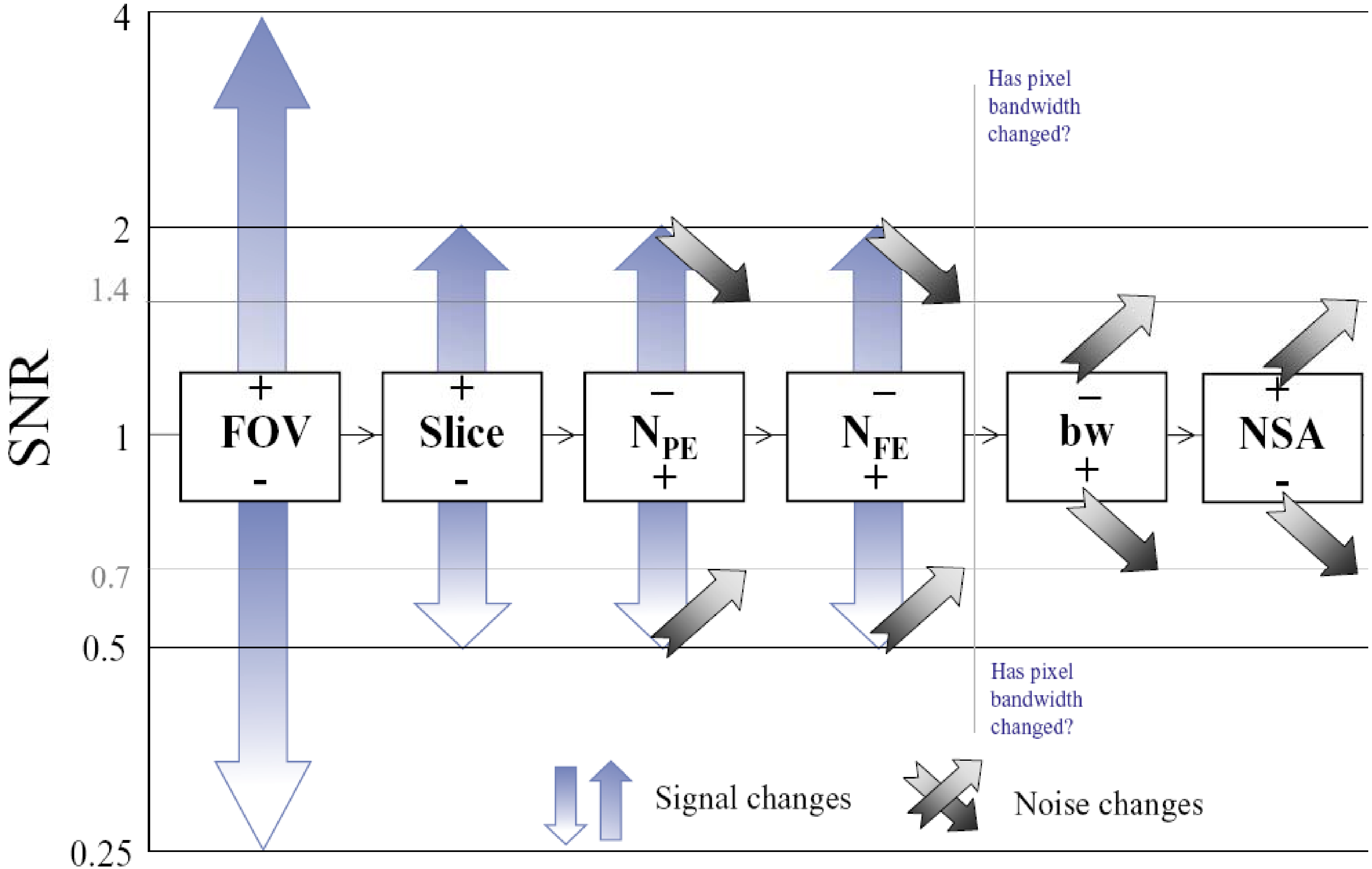
--- Increased chemical shift artifact (more on this later)

--- Longer TE (which means less signal due to more T2 decay). Remember that

Bandwidth = 1/ΔTs =Nx /Ts



(a)
Signal
Receiver bandwidth
Patient signals
Pixel bandwidth
Noise
Frequency
(b)
Signal
t
Noise
t
(c)
Signal
Receiver bandwidth
Noise
Frequency
(d)
Signal
t
Noise
t


SNR
4
2
1.4
1
0.7
0.5
0.25
FOV
Slice
N PE
N FE
bw
NSA
Has pixel bandwidth changed?
Has pixel bandwidth changed?
Signal changes
Noise changes

In summary

SNR can be increased by doing the following:

- Increasing TR
- Decreasing TE
- Using a lower BW
- Using volume (i.e., 3D) imaging
- Increasing NEX
- Increasing Ny
- Increasing the voxel size

Resolution

- Spatial resolution

--- by voxel size

- Temporal resolution

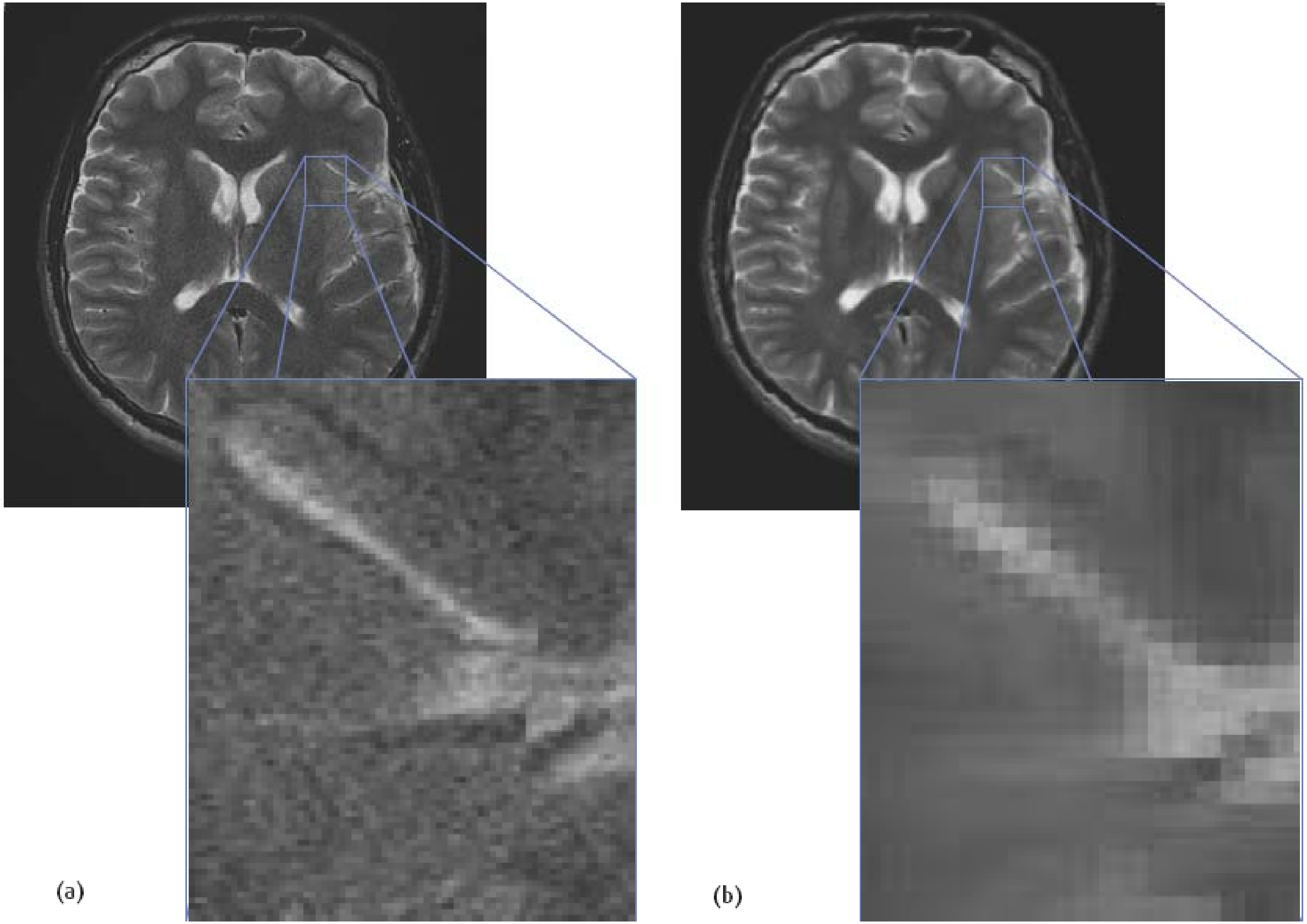
--- by scan time

--- for dynamic scan

Spatial resolution (or pixel size)

- The minimum distance that we can distinguish between two points on an image.
- Determined by Pixel size = FOV /# of pixels

Pixel size vs. resolution



(a) (b)

About TR

Increasing TR :

- increases SNR (according to the T1 recovery curve)
- increases coverage (more slices)
- decreases T1 weighting
- increases proton density and T2 weighting
- increases scan time

Decreasing TR :

- decreases SNR
- decreases coverage
- increases T1 weighting
- Decreases proton density and T2 weighting
- Decreases scan time

Coverage

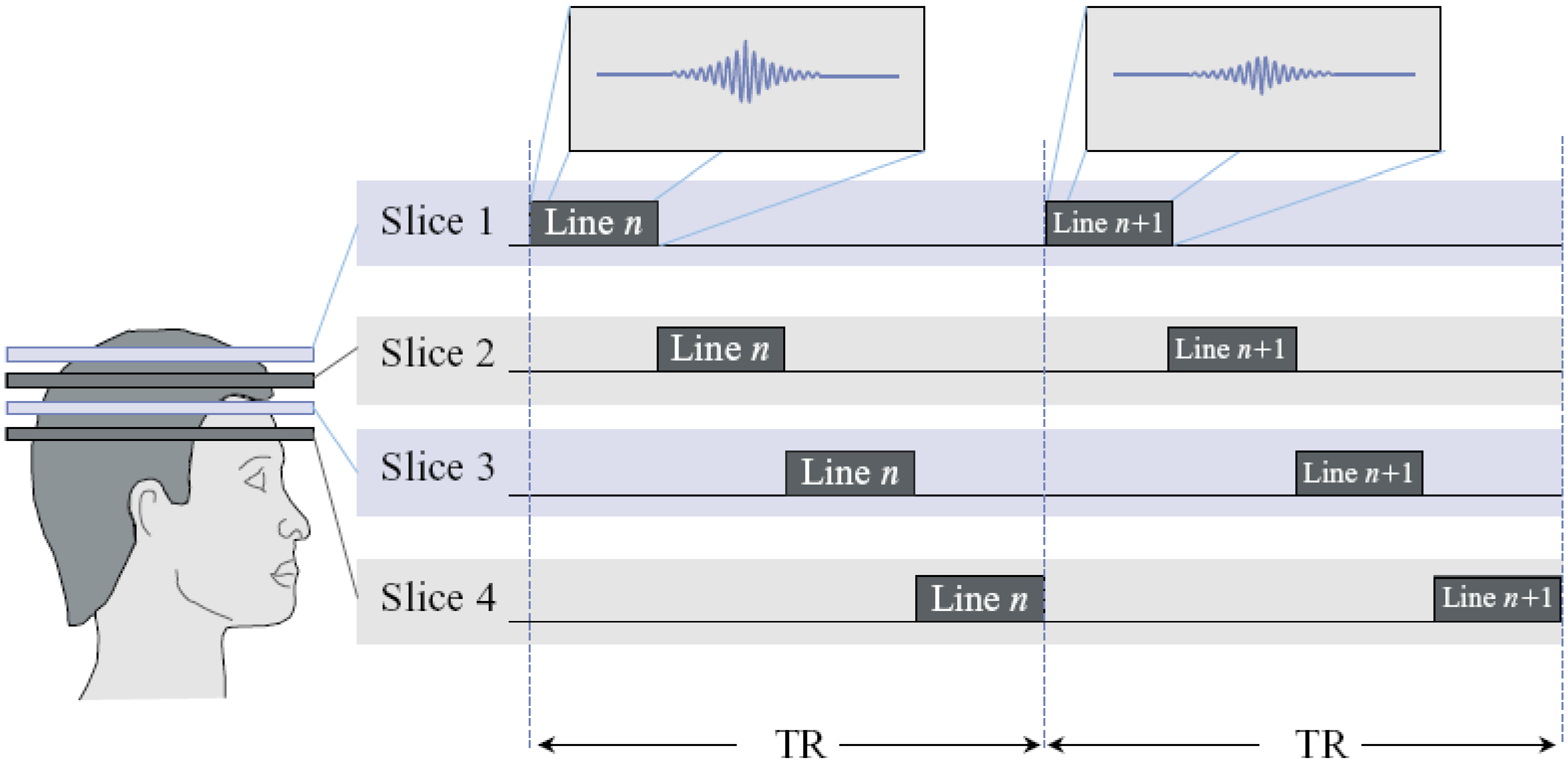
The distance covered by a multislice acquisition.

- Number of slices

  $$\# \text{ slices} = TR/(TE + T_s/2 + T_o)$$

- Slice thickness
- Gaps

TR vs. slices



Slice 1
Line n
Line n+1
Slice 2
Line n
Line n+1
Slice 3
Line n
Line n+1
Slice 4
Line n
Line n+1
TR
TR

About coverage

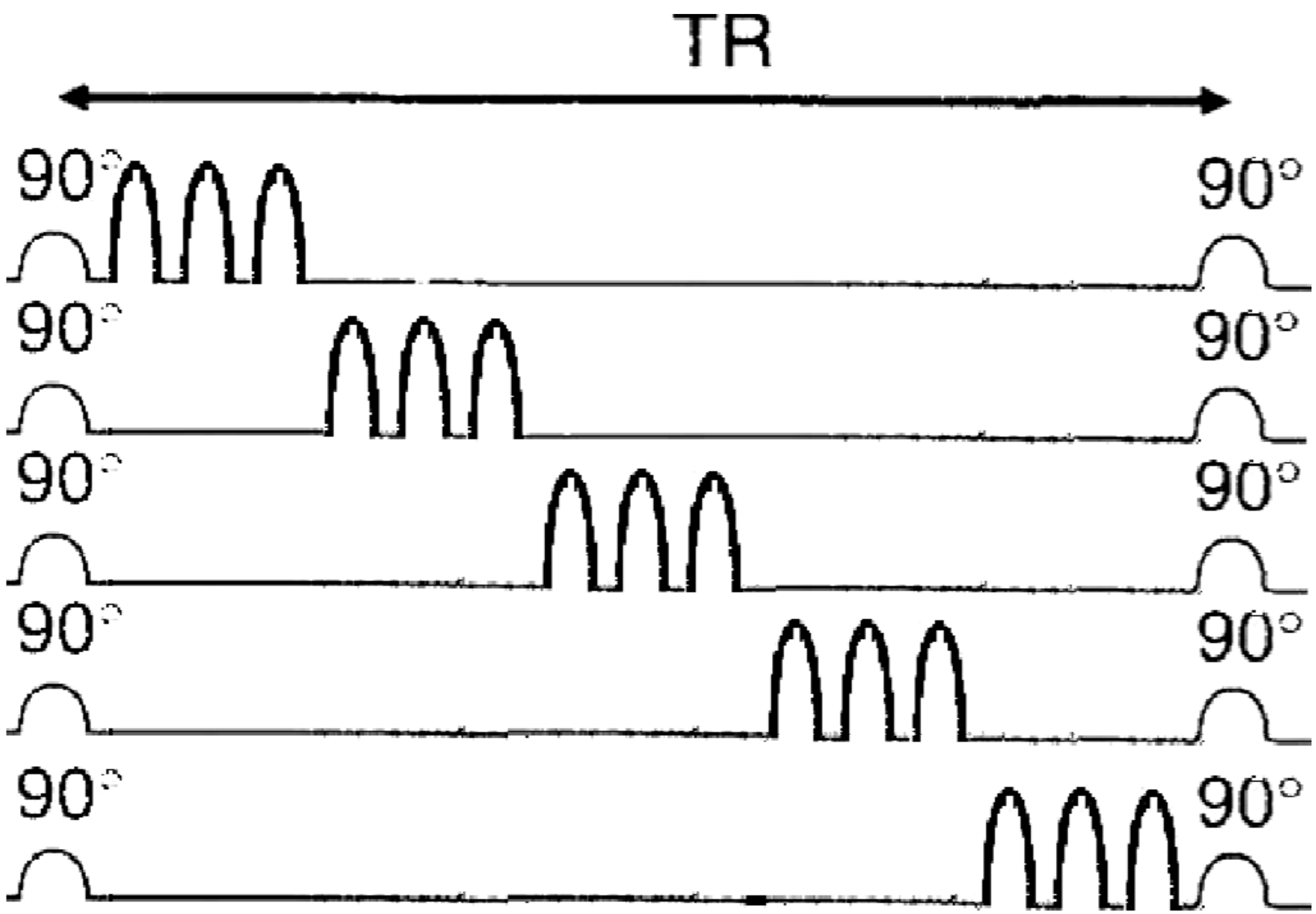
Coverage is increased if we:

- increase slice thickness
- increase interslice gap
- increase TR or decrease the last TE (i.e., increase TR /TE ratio)
- decrease sampling time Ts (resulting in a lower TE), i.e., increase the bandwidth

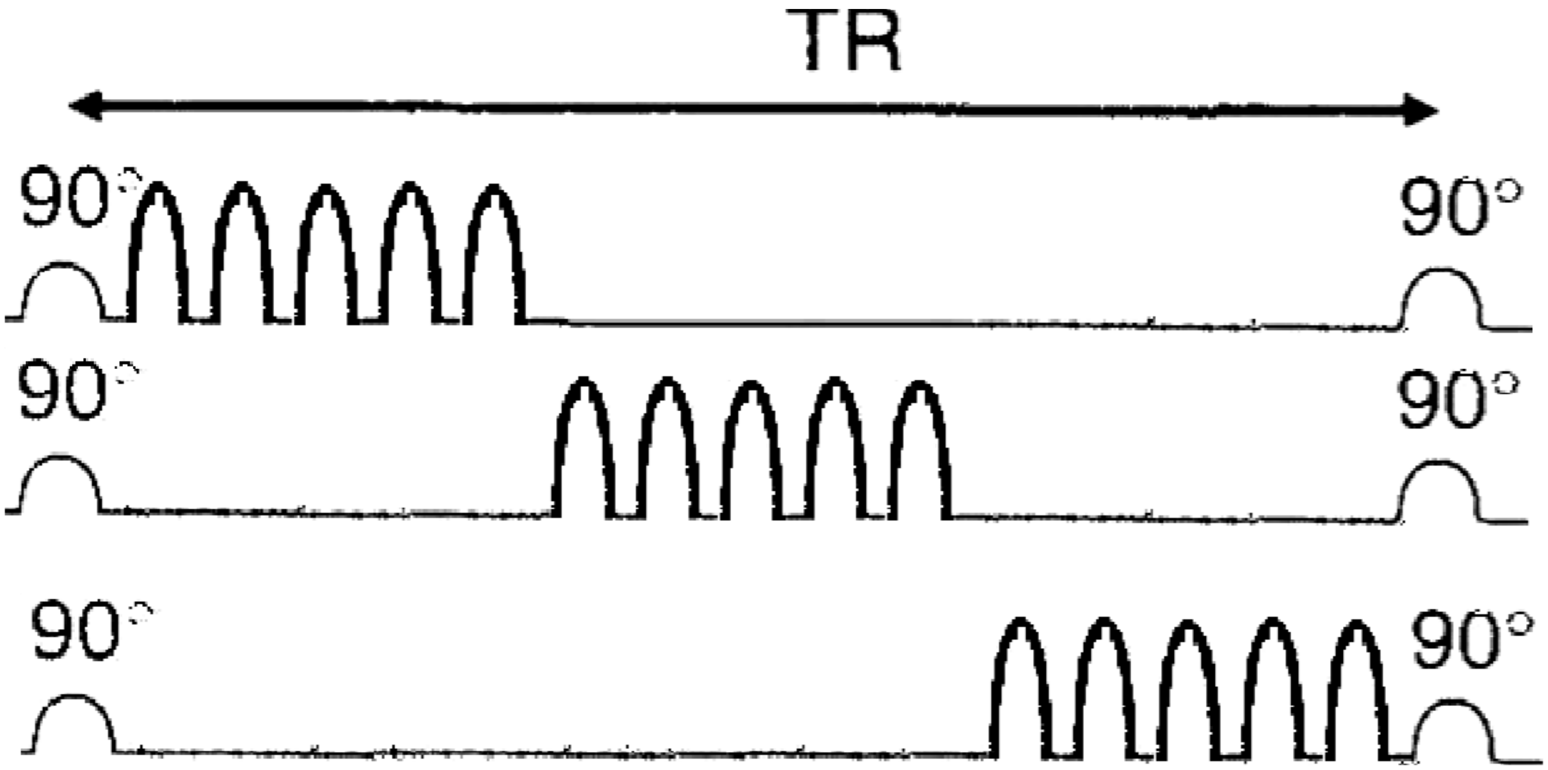
Coverage is decreased if we:

- increase TE
- increase Ts
- increase ETL in FSE imaging (due to longer final TE)

ETL vs. coverage

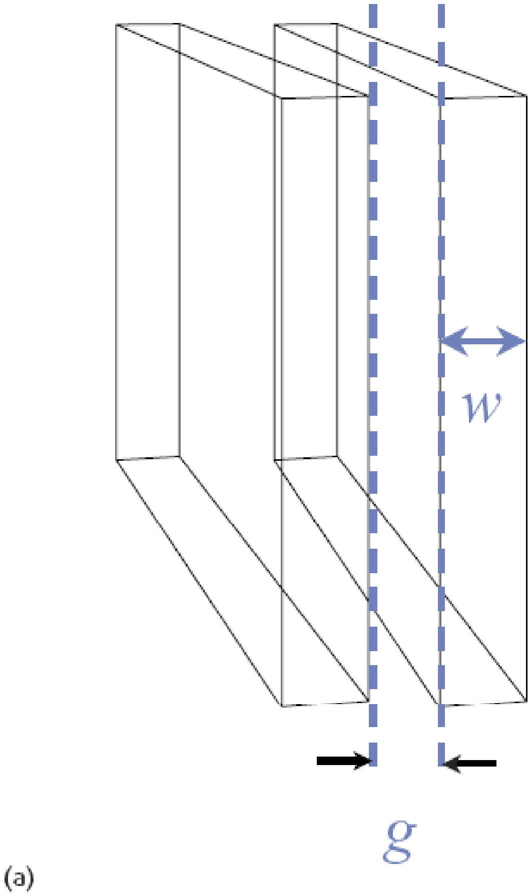


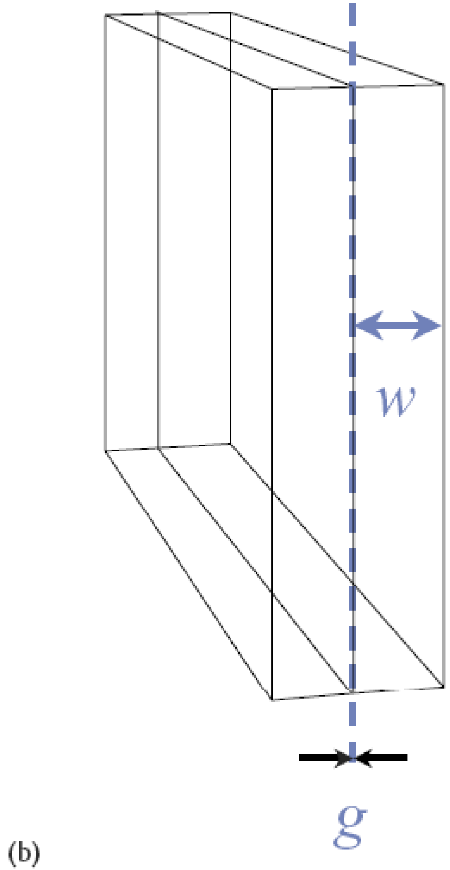
ETL=3



ETL=5

Gap

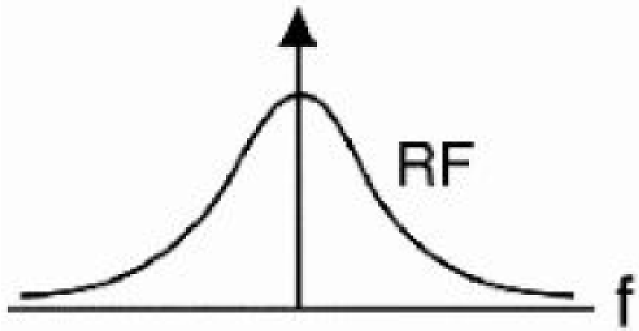


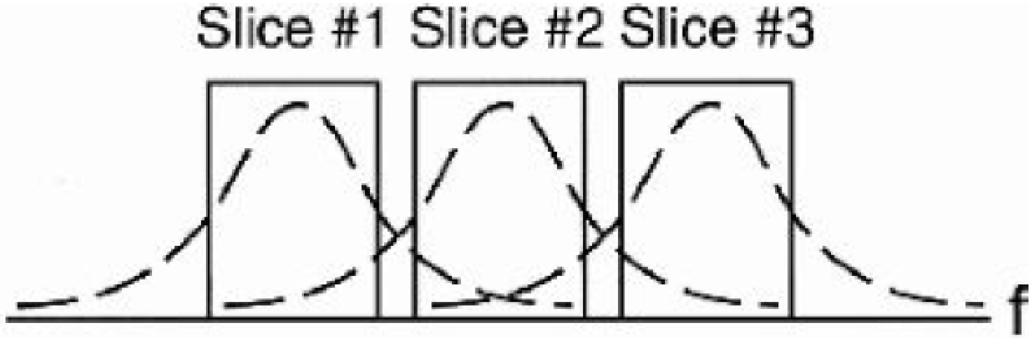


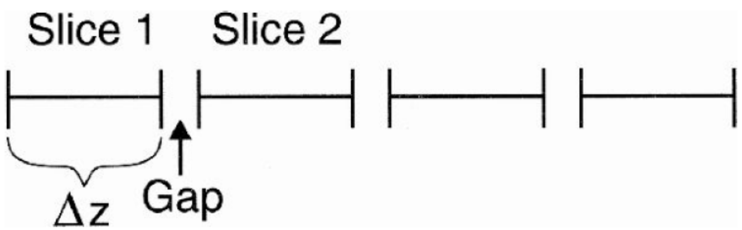
Increasing interslice gap causes:

- increased coverage
- decreased “cross-talk” artifact
- increased SNR (due to increasing effective TR by reducing cross-talk)

Gap vs. cross talk







About TE

By increasing TE :

- increase T2 weighting
- increase dephasing and thus decrease SNR (according to the T2 decay curve)
- decrease number of possible slices (decrease coverage)
- no change in scan time (unless, of course, the coverage is not adequate and either longer TR or extra acquisitions are required)

By decreasing TE :

- decrease T2 weighting and increase T1 or proton density weighting
- increase SNR (less dephasing). However, if TE is reduced by reducing Ts (i.e., increasing BW), SNR may be reduced!
- increase coverage
- no change in scan time