ARTIFACTS IN MRI

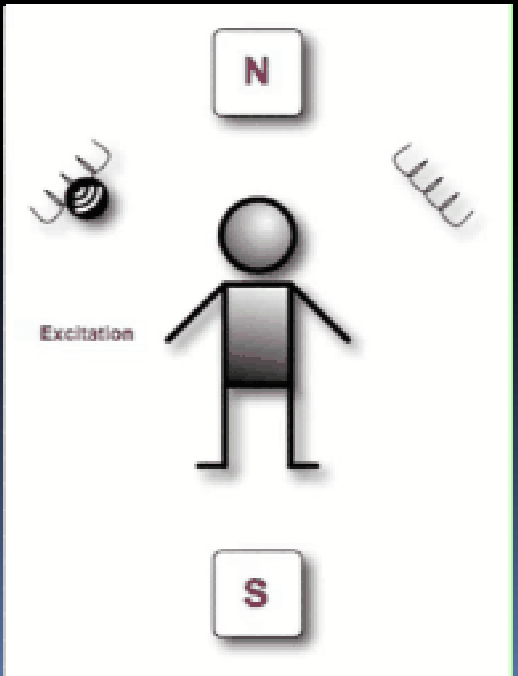
Basic concepts

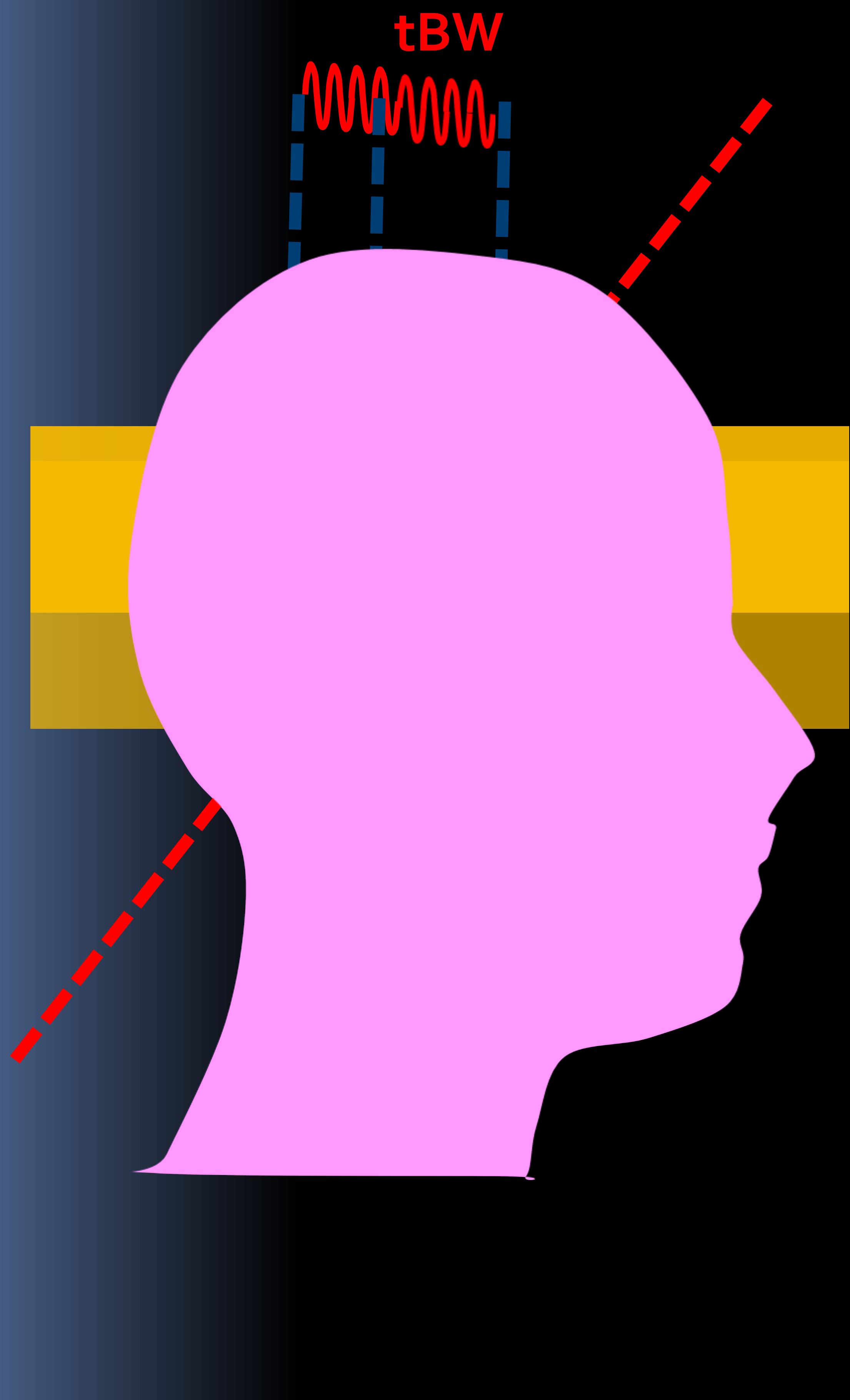
- BW
- Spatial encoding
- K-space
- Artifacts

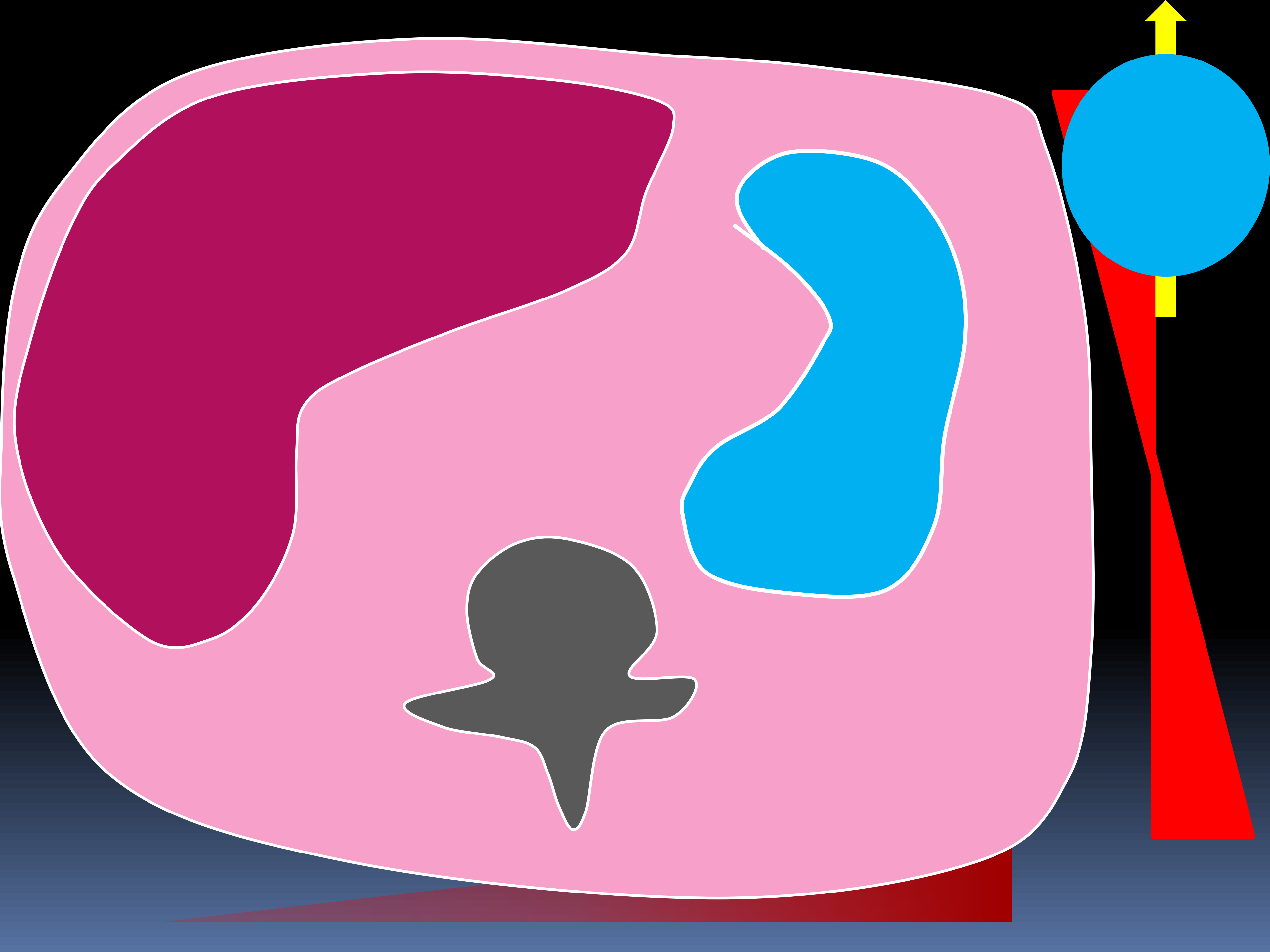
BW

- *Bandwidth (BW)* is the range of frequencies (measured in Hz) involved in the transmission or reception of an electronic signal.

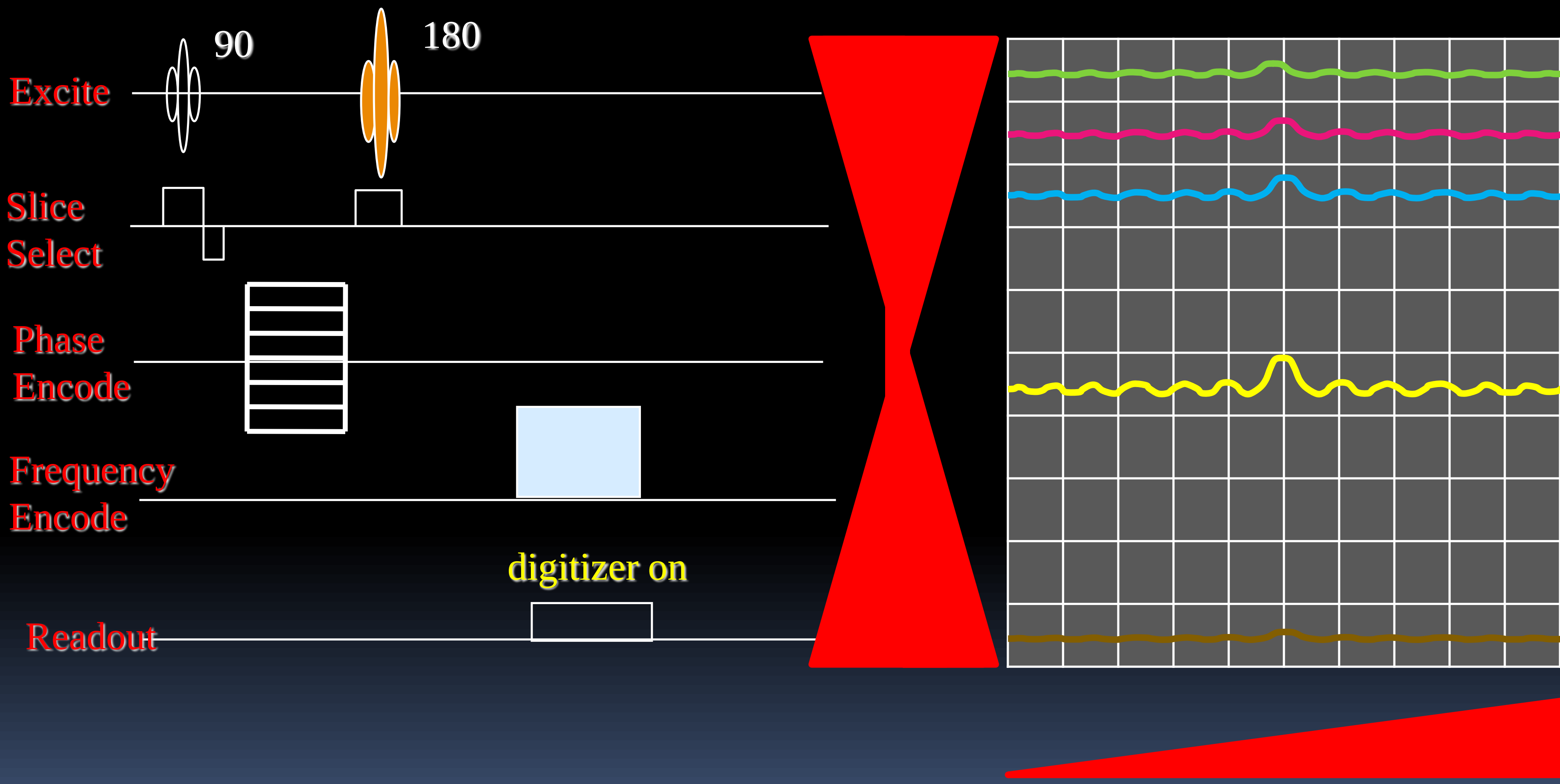
- RF-excitation (*transmitter bandwidth, tBW)*
- signal reception (*receiver bandwidth, rBW)*



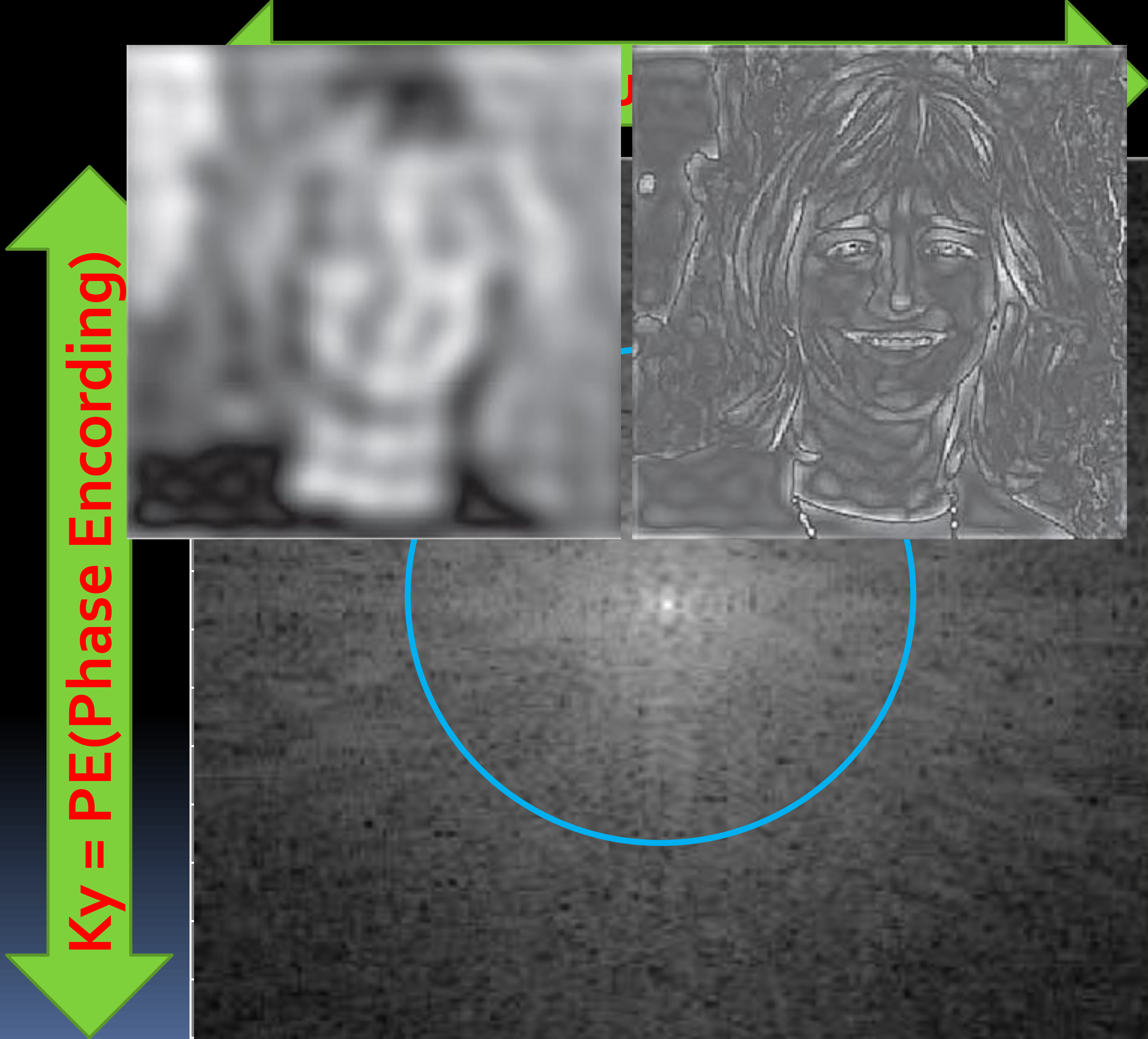

tBW



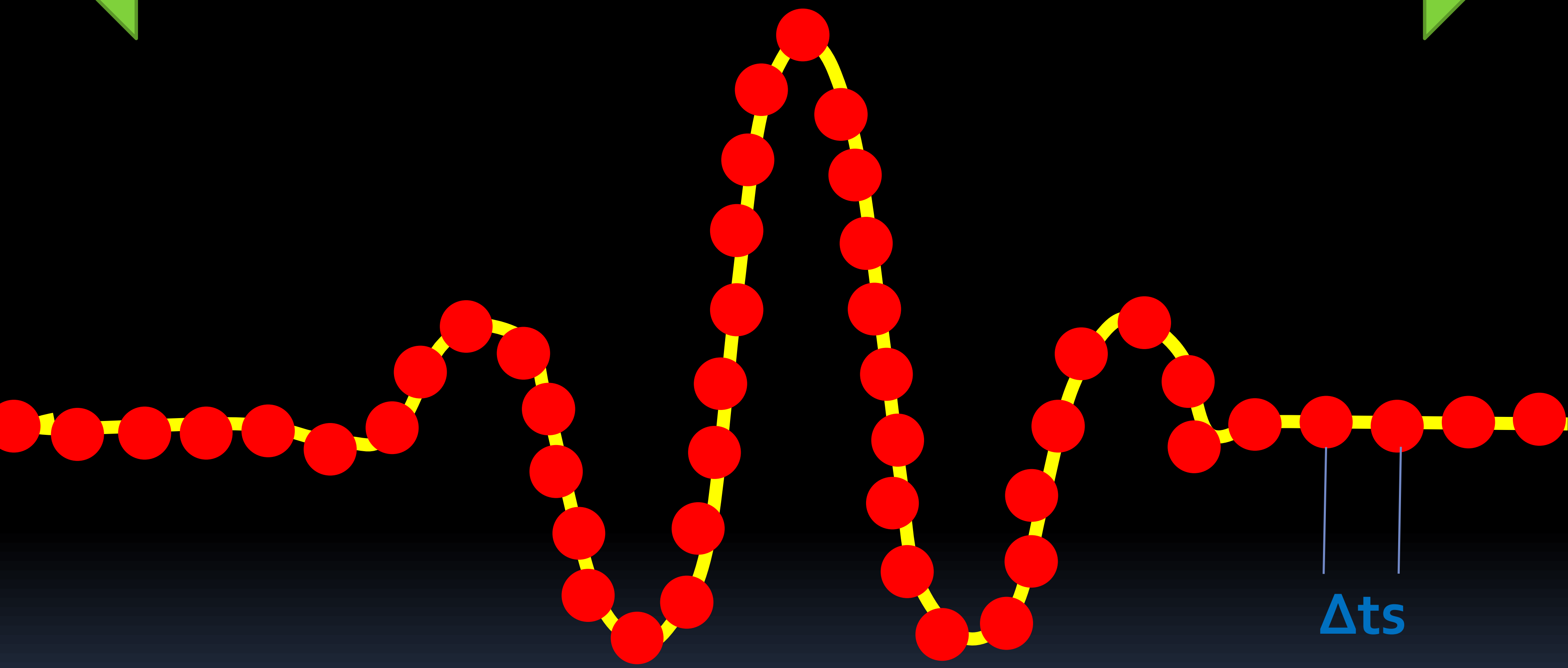

NO.
收銀員
1111
SHOWTIME
CINEMAS
票號:
0007468V
嘉義秀泰影城
收銀機:
1
4樓 巨幕廳
片名: 數位版 英語版 級別:輔15
13 Hours: The Secret Soldiers of Bengh
13小時:班加西的秘密士
時間: 2016/01/30 15:30(六)
座位: 8 排 16 號
票別: 開幕優惠
票價: 99 (現99)
售出:2016/01/30 12:21:08
NO.100000039
放[redacted]01/30 15:30(六)
售[redacted]01/30 12:21:08



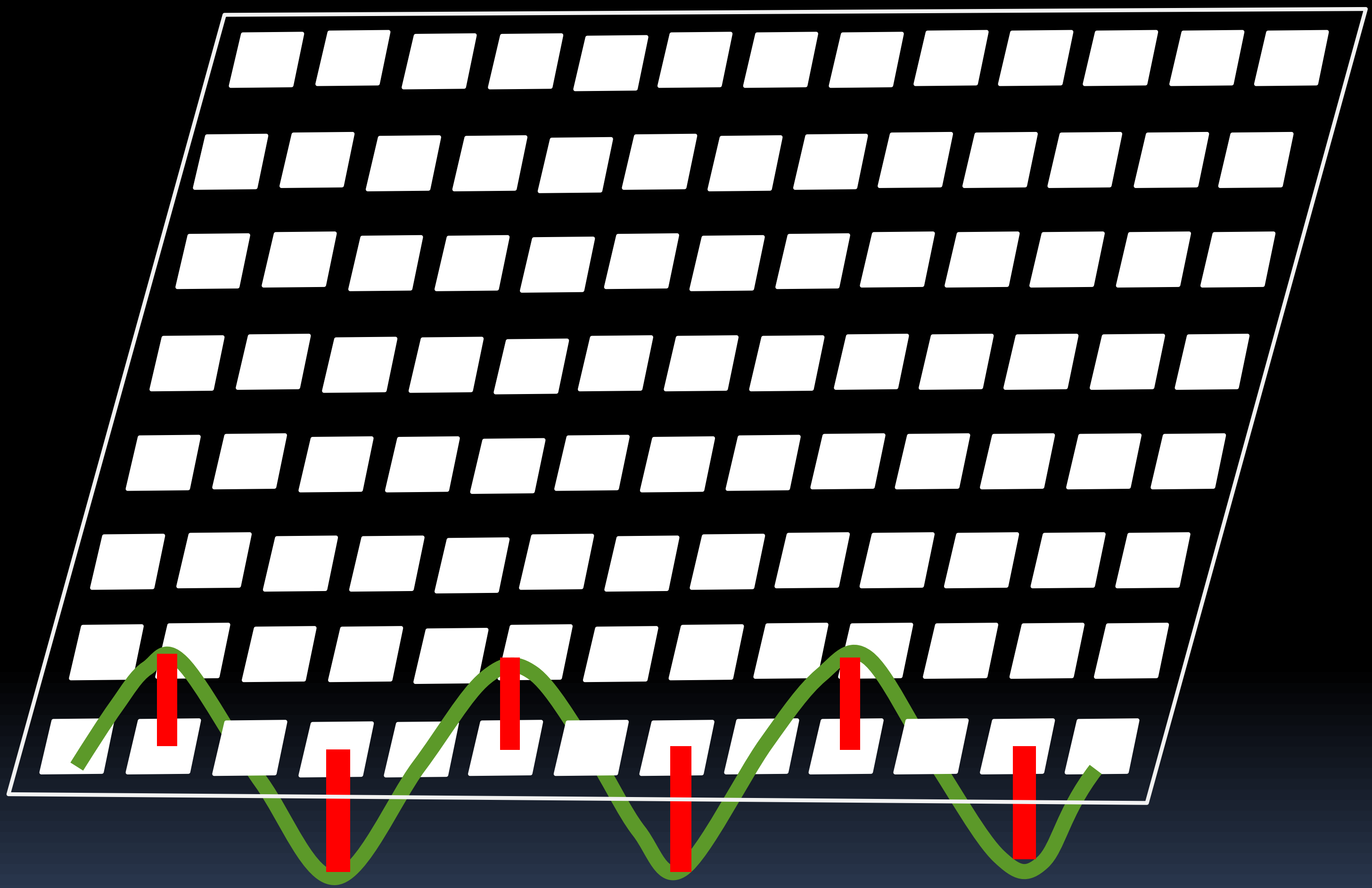
90
180
Excite
Slice
Select
Phase
Encode
Frequency
Encode
digitizer on
Readout


Ky = PE(Phase Encording)

$$Ts = \Delta ts * Ns \ (\Delta ts = Ts/Ns)$$



$$BW = 1/\Delta ts = Ns/Ts$$

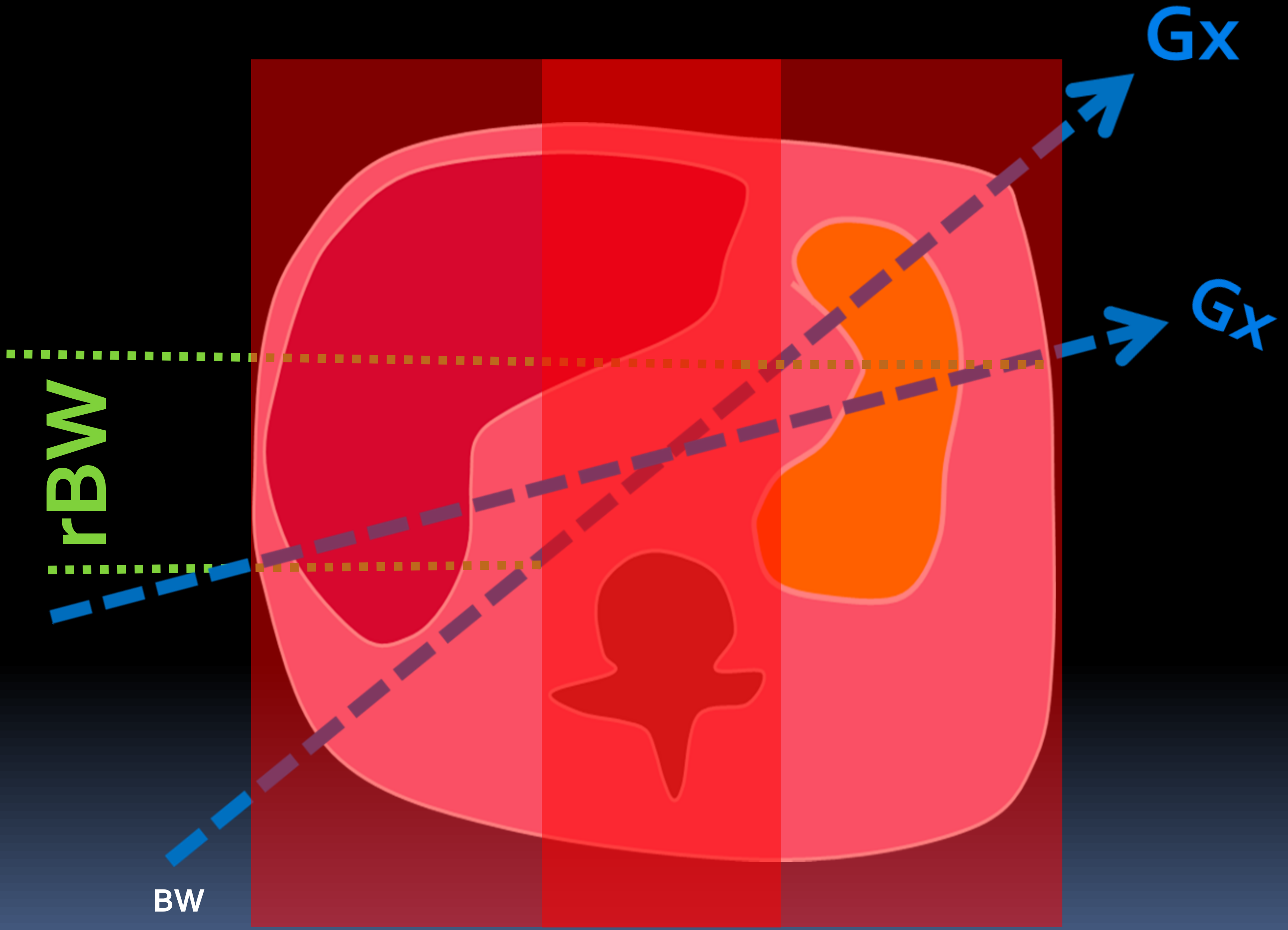


- **At 1.5 Tesla, it typically takes 8 msec to perform one readout: *T*s 8 msec.**

  We have a matrix of 256*256 pixels.
- BW =1/△*T*s = 1/(Ts/NS) = Ns/TS =256/8 msec
  256/0.008 sec = 32,000 Hz =32 kHz = ±16 kHz/pixel

- **if we go to a 512*512 matrix**

  BW=512/.008 sec = 64 kHz = ±32 kHz/pixel



$$FOV = \frac{BW}{\gamma \, Gx}$$

RF coil+Spatial encoding

Coil collated signal

A/D converter

Digital data filled K-space matrix

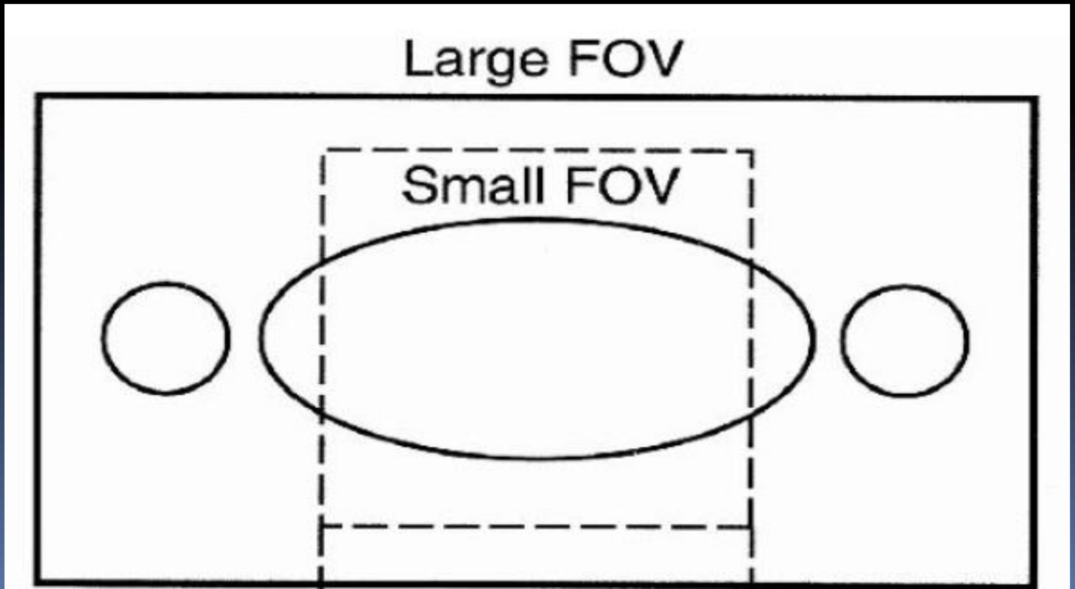
F.T transfer

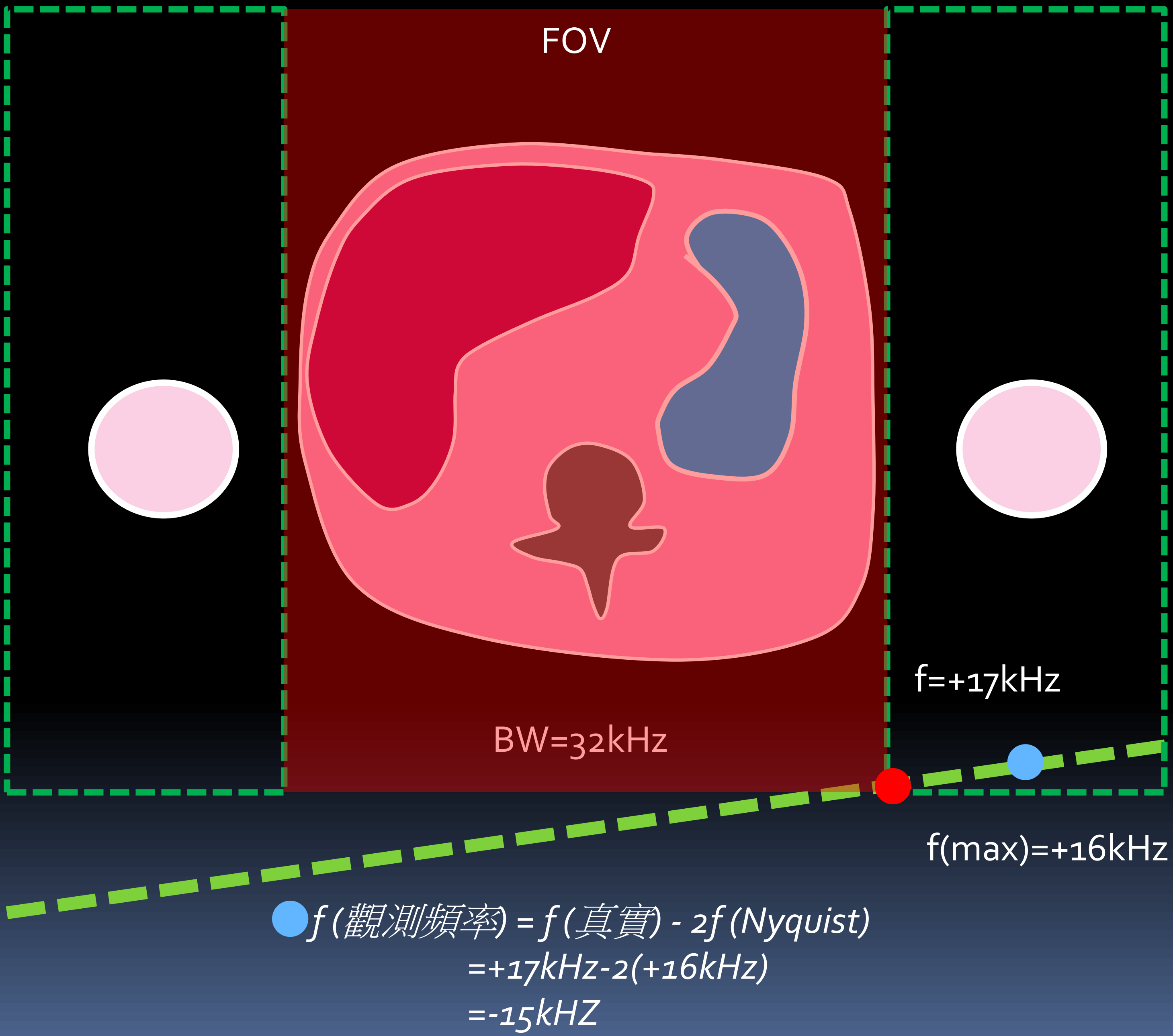
MR image

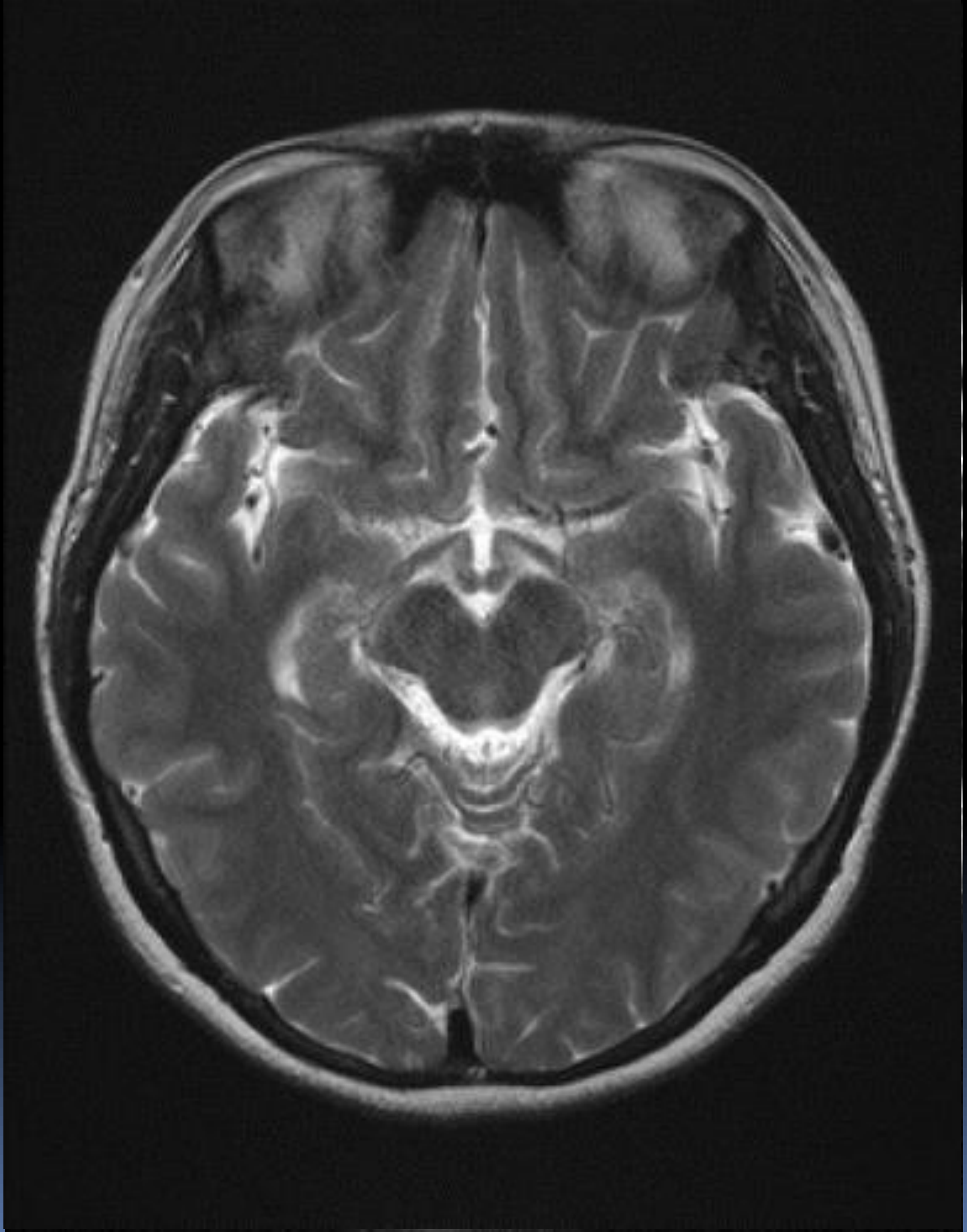
- Image processing artifact
  - Aliasing
  - Chemical shift
  - Truncation
  - Partial volume
- Patient-related artifact
  - Motion artifacts
  - Magic angle
- Radio frequency (RF)-related artifact
  - Cross-talk
  - Zipper artifacts
  - RF feedthrough
  - RF noise
- External magnetic field artifacts
  - Magnetic inhomogeneity
- Magnetic susceptibility artifacts
  - Diamagnetic,
  - Paramagnetic,
  - Ferromagnetic
  - Metal
- Gradient-related artifacts
  - Eddy currents
  - Nonlinearity
  - Geometric distortion

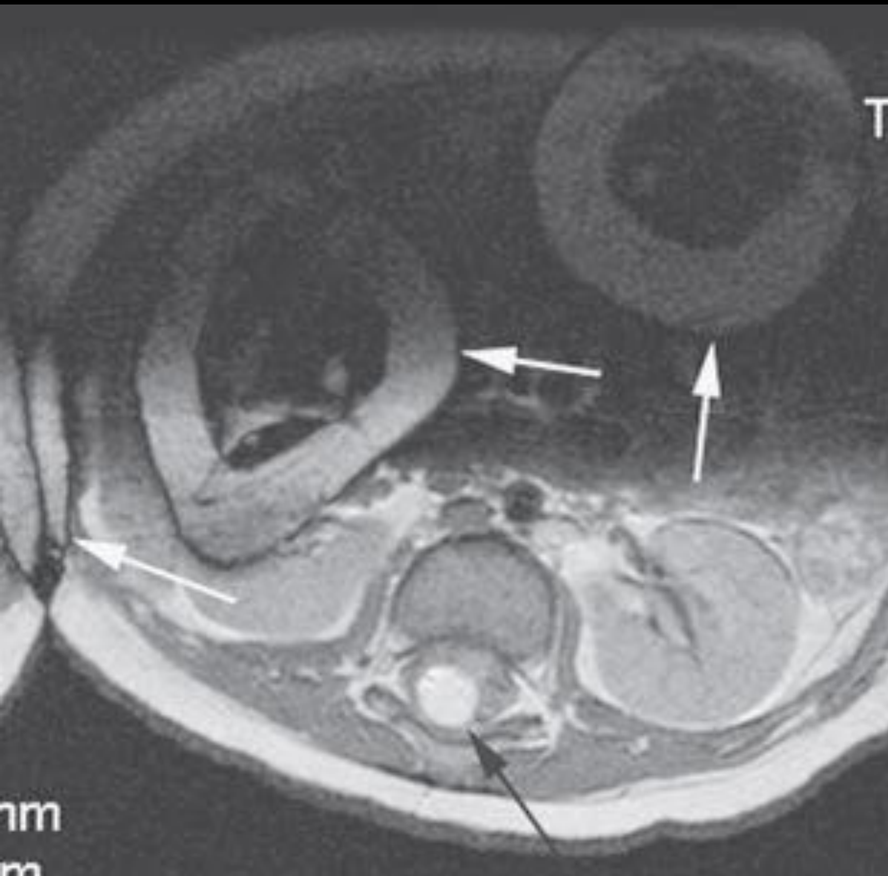
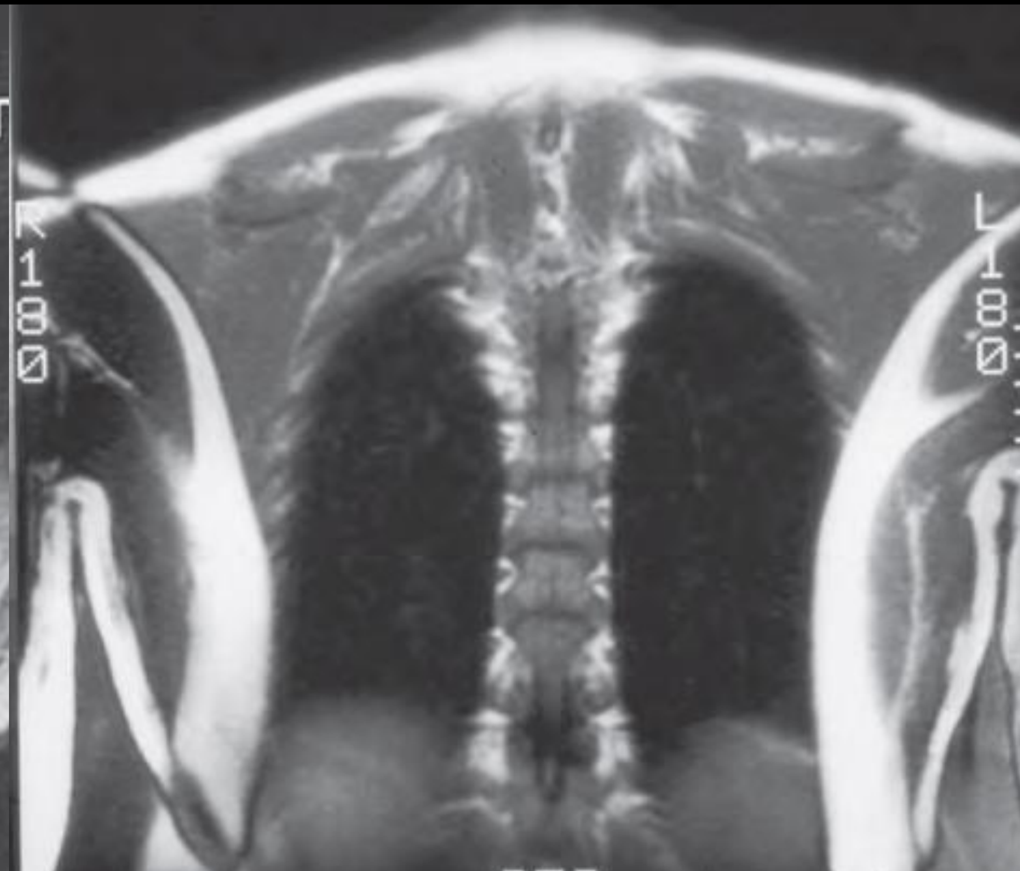
Aliasing (Wrap-around)

- when the field of view (FOV) is smaller than the body-part being imaged. The part of the body that lies beyond the edge of the FOV is projected on to the other side of the image.




FOV
BW=32kHz
f=+17kHz
f(max)=+16kHz
f (觀測頻率) = f (真實) - 2f (Nyquist)
=+17kHz-2(+16kHz)
=-15kHZ



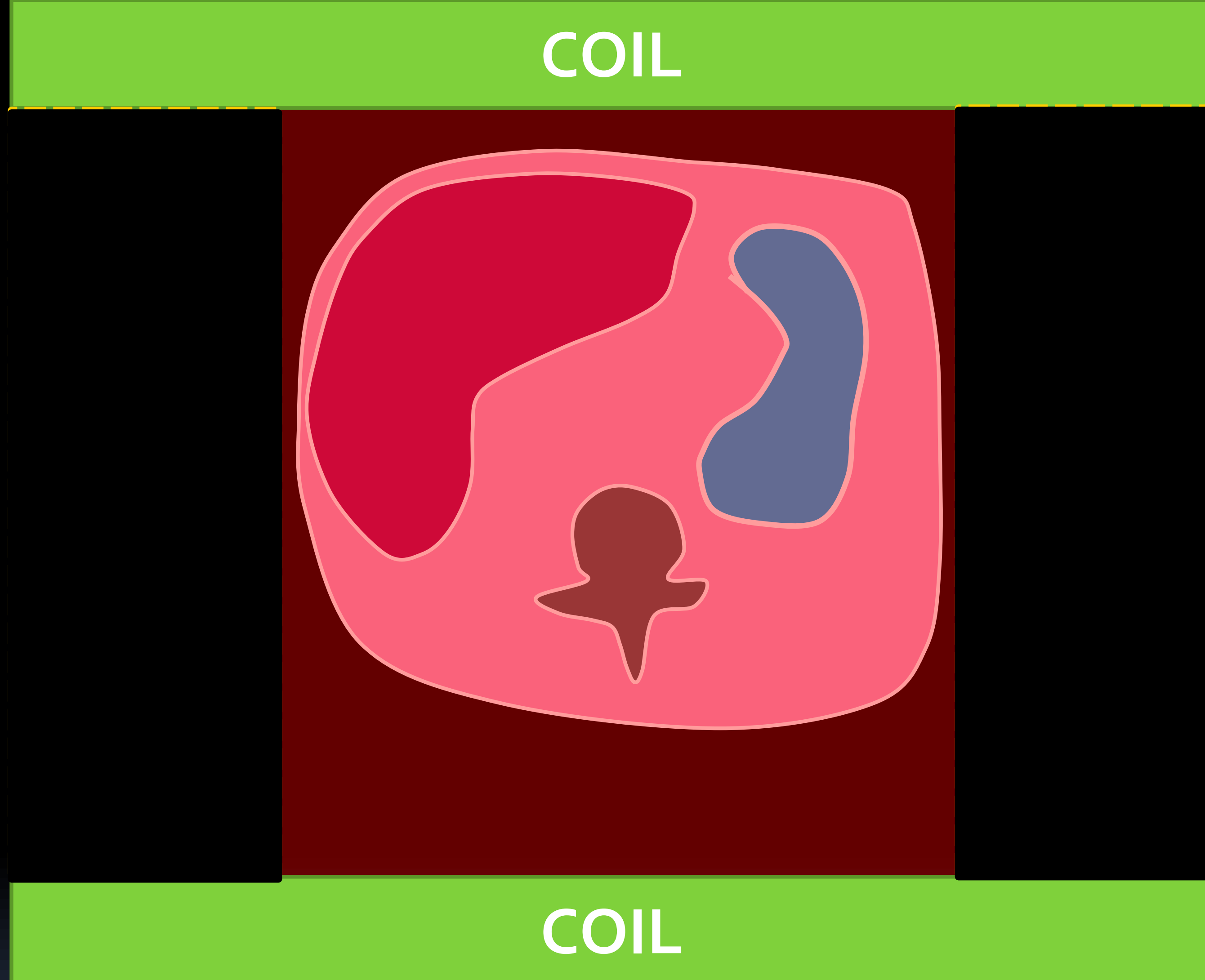


L
180

Remedies

- Surface coil
- Increase FOV
- Saturation pulses
- Oversampling

  Frequency oversampling (no frequency wrap [NFW])

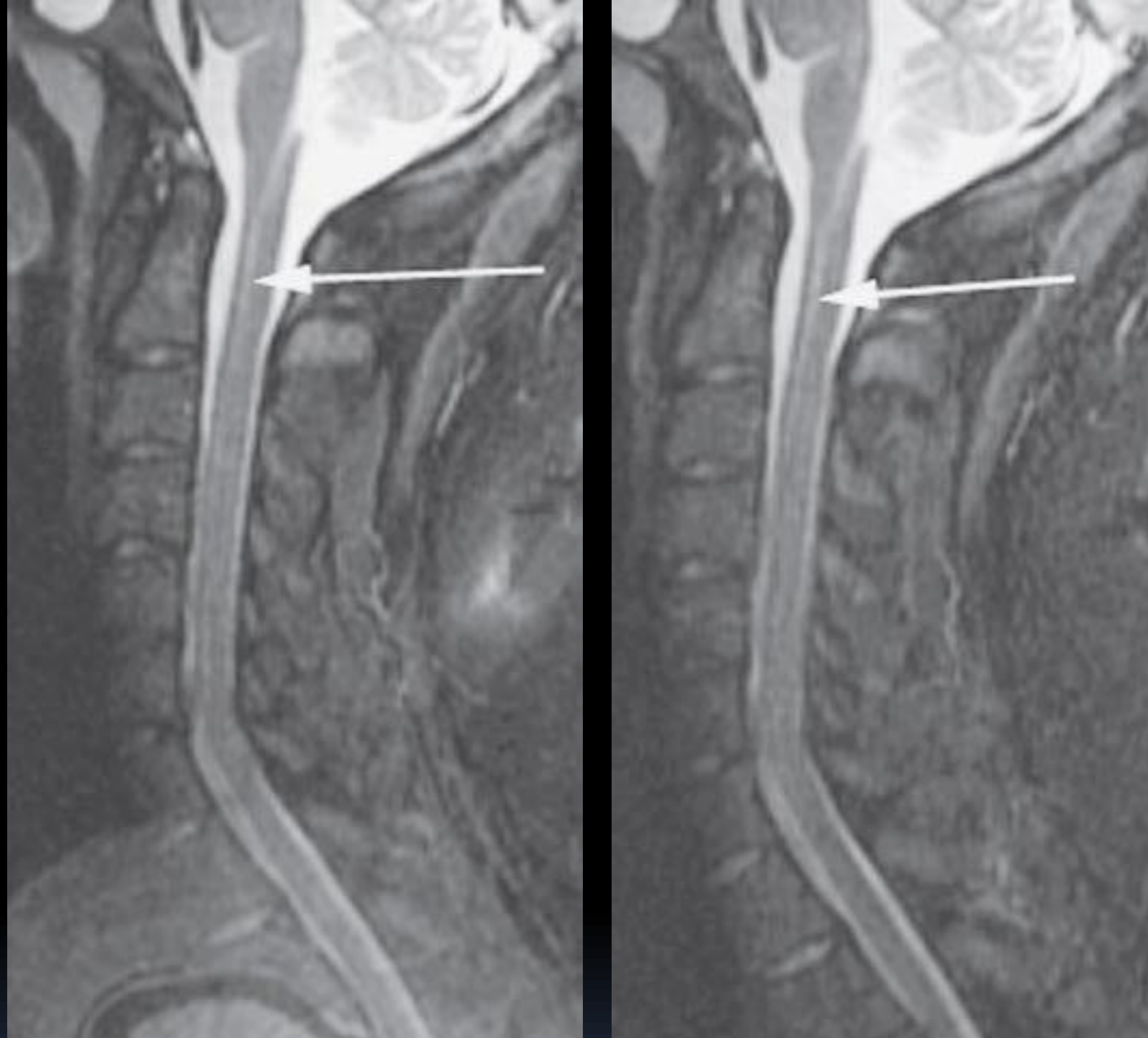
  Phase oversampling (no phase wrap [NPW])



Saturation pulses

Post-processing

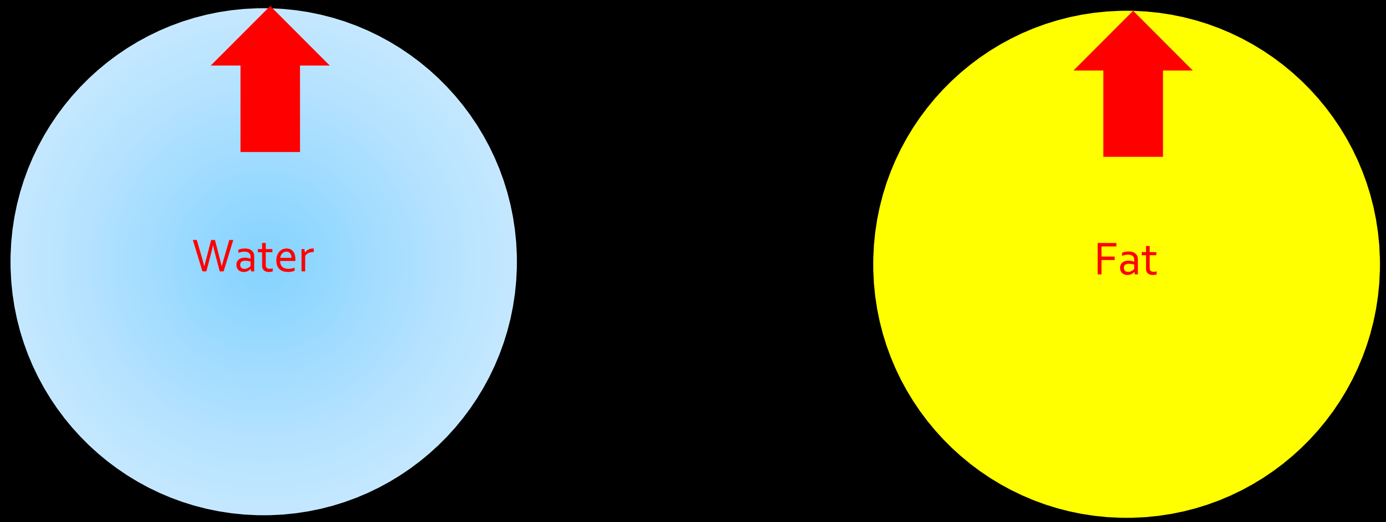
- "***Phase oversampling***" (Siemens),
- "***No phase-wrap***" (GE),
- "***Fold-over suppression***" (Philips),
- "***Anti-wrap***" (Hitachi), and "***Phase-wrap suppression***" (Toshiba).



Sagittal STIR image (A) of the cervical spine with craniocaudal phase-encode direction demonstrates aliasing of the brain onto the upper thoracic spine. (B) The same image after no phase wrap was applied. Truncation artifact is also seen (arrows).

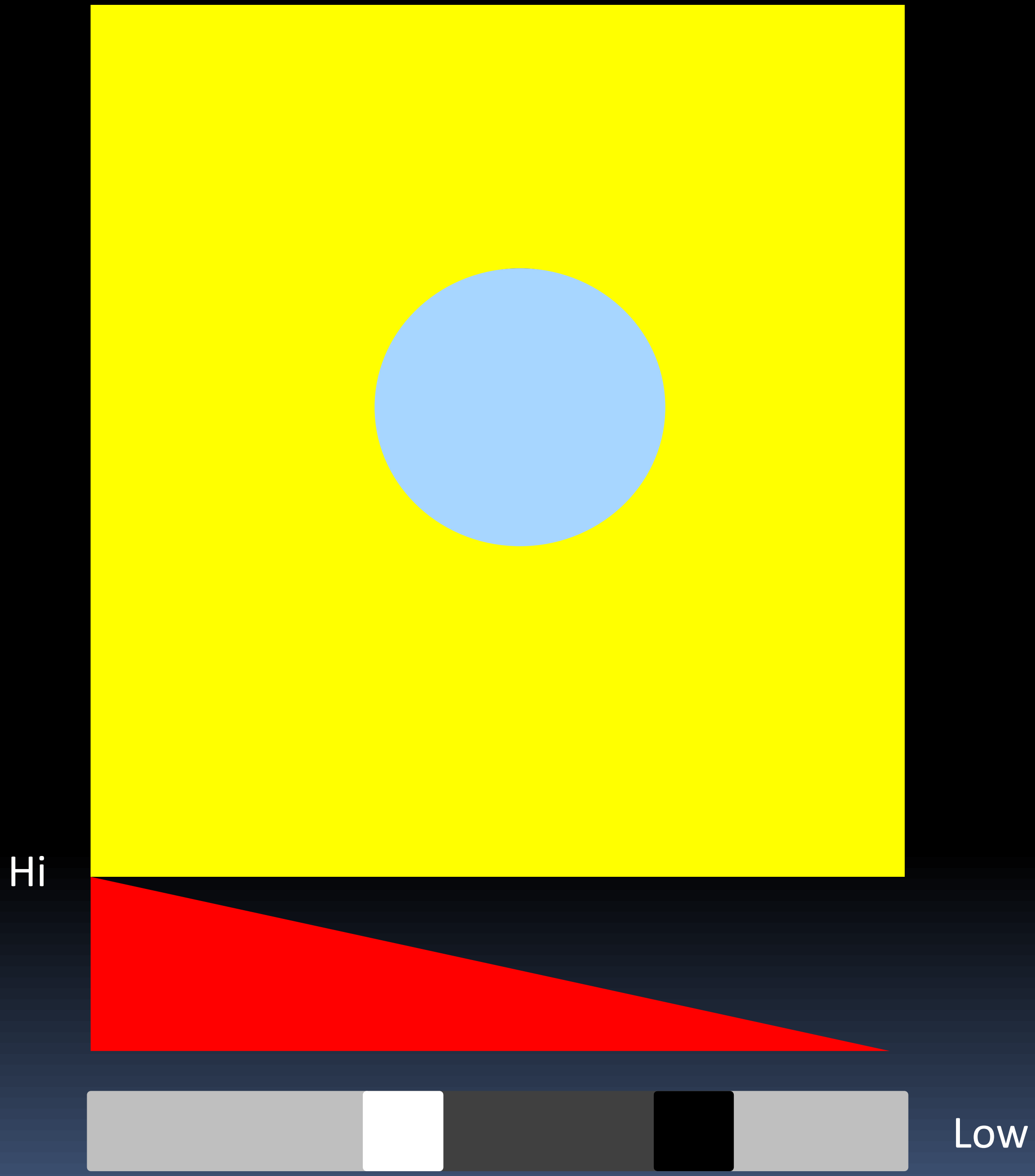
Chemical Shift Artifact

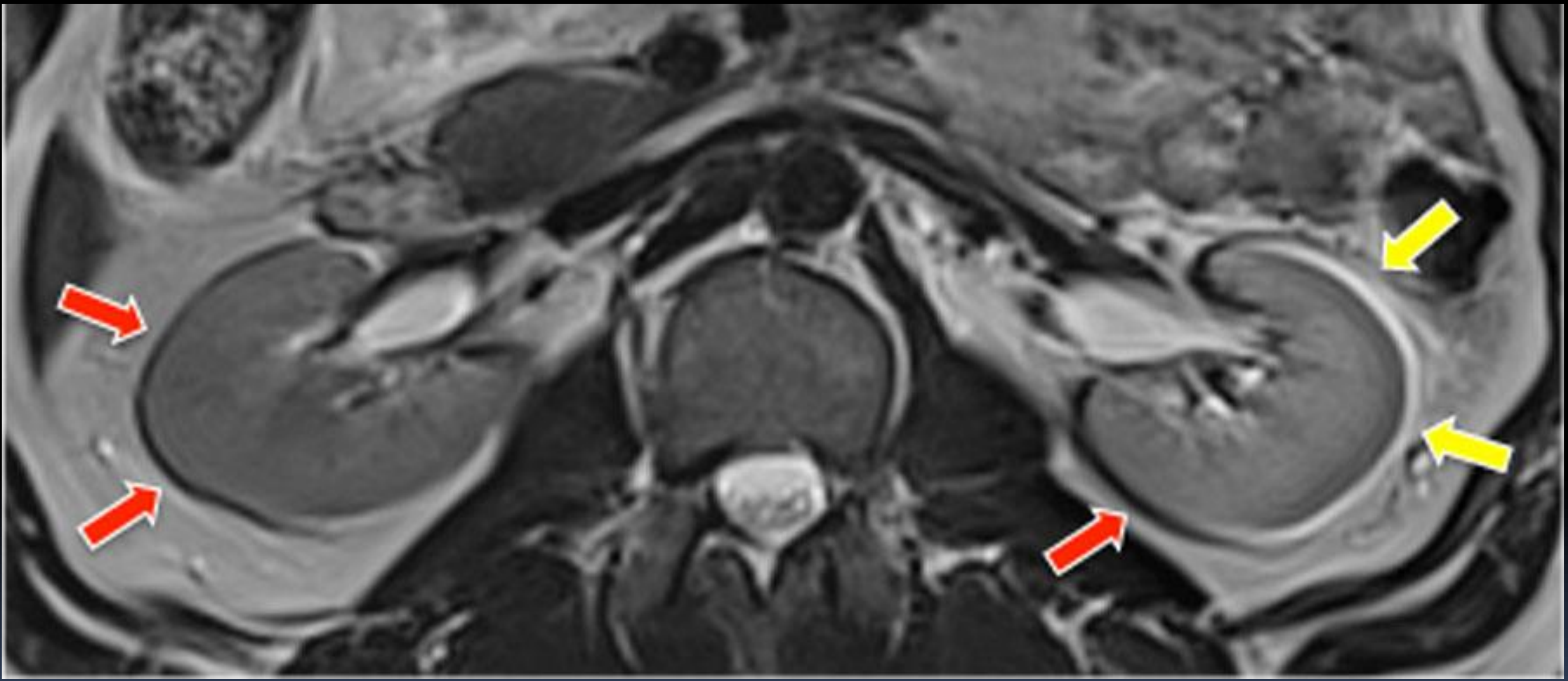
- Chemical shift is due to the differences between resonance frequencies between fat and water.

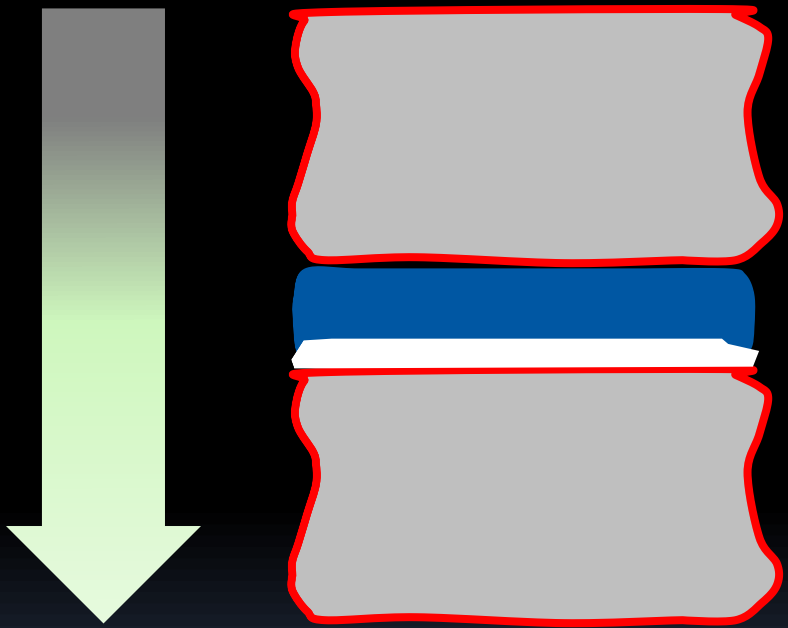


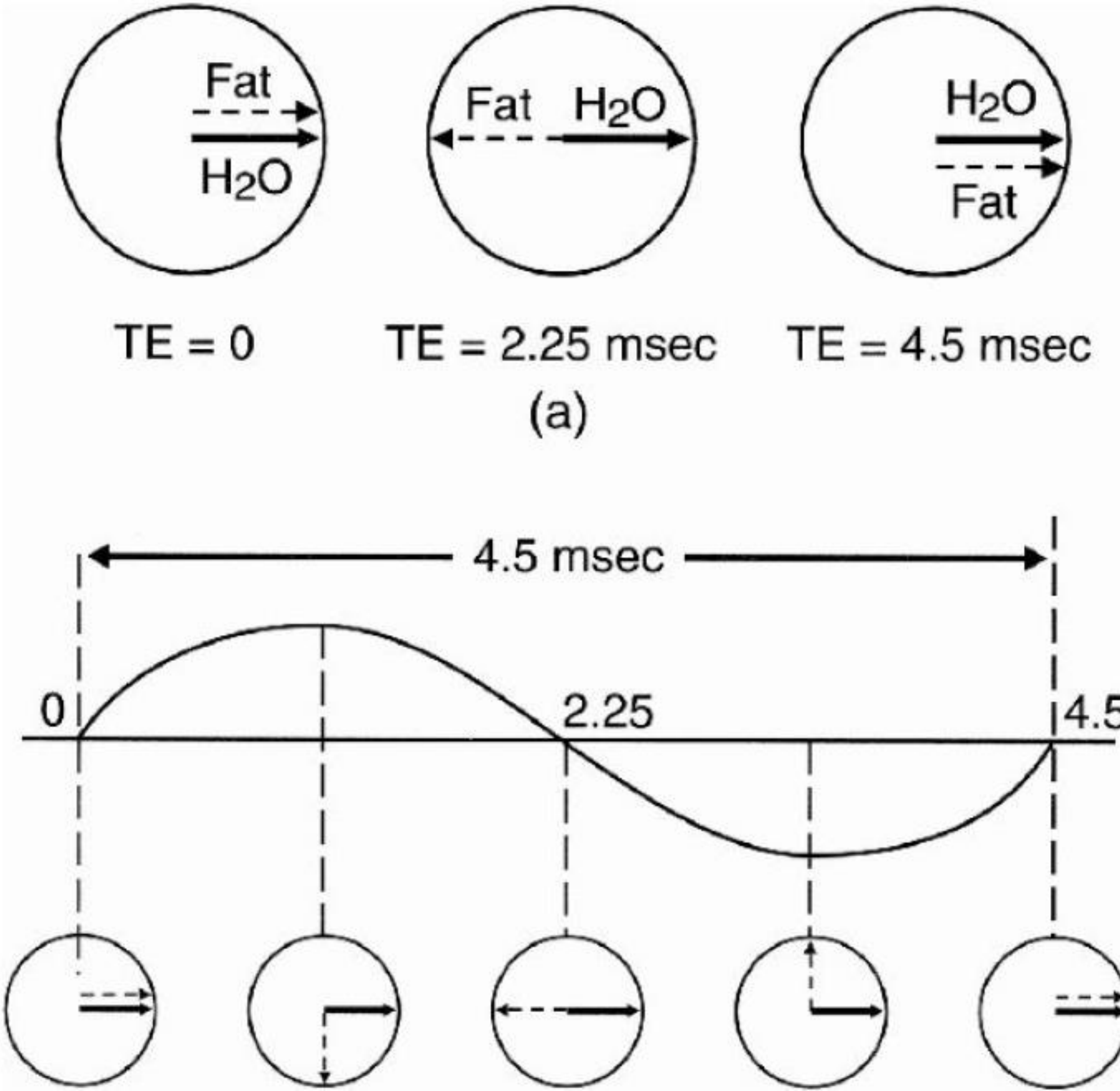
- Frequency = $\omega_0 = \gamma B_0$ = (42.6 MHz/T) (1.5 T) ≒ 64 MHz

  = 64×10^6 Hz
- 3.5 ppm = 3.5×10^{-6}
- (3.5 × 10-6)(64 × 106 Hz) =220 Hz
- In other words, at 1.5 T, the difference in precessional frequency of the hydrogen protons in fat and in H_2O is 220 Hz.

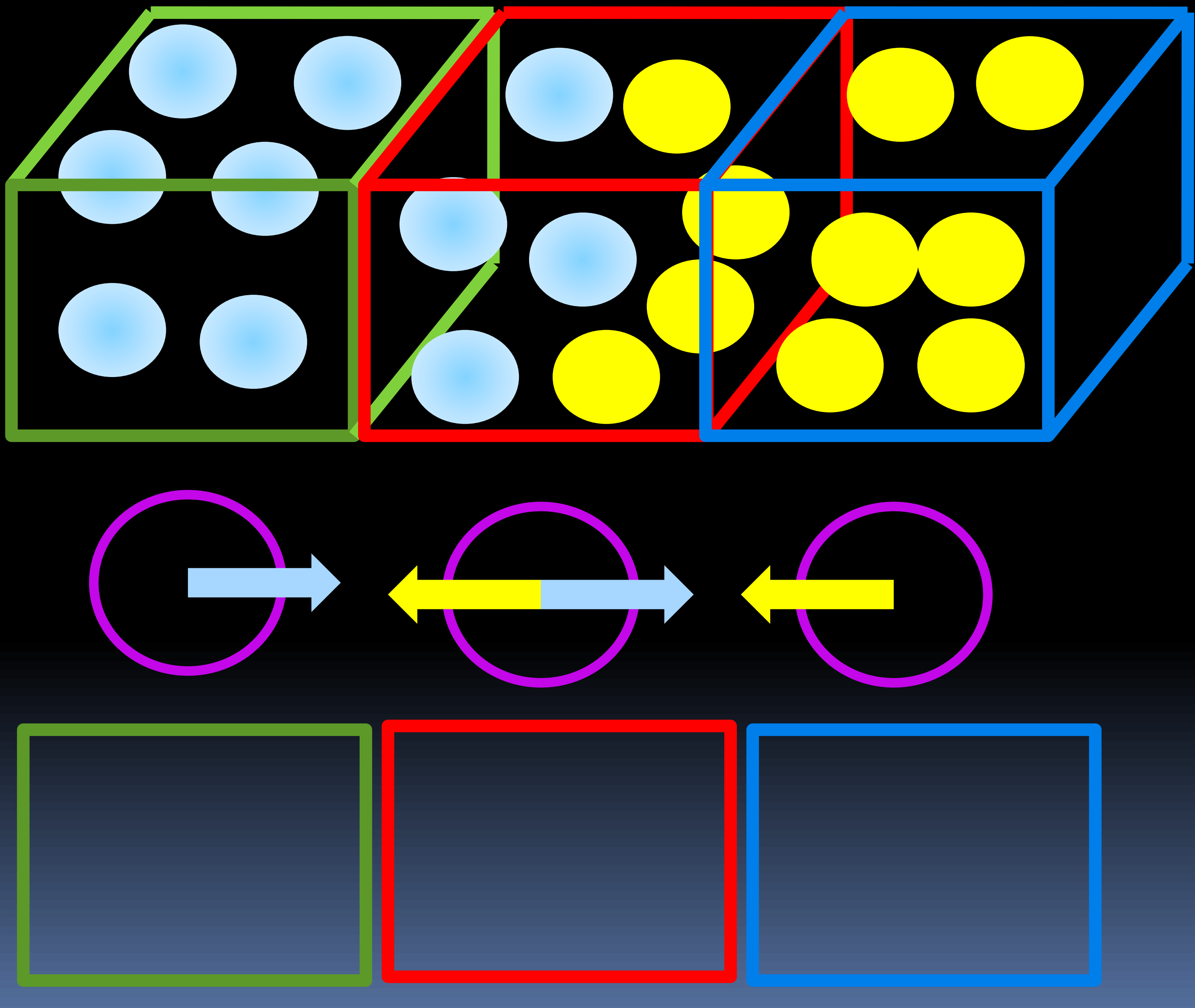

Hi
Low

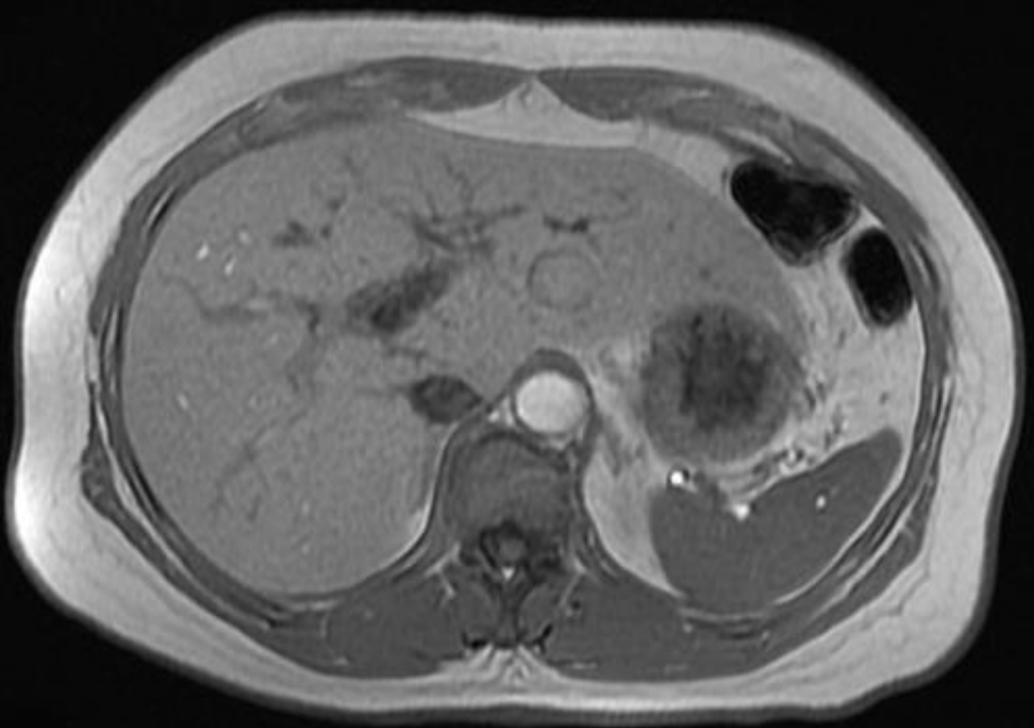





Fat
H2O
TE = 0
Fat H2O
TE = 2.25 msec
H2O
Fat
TE = 4.5 msec
(a)
4.5 msec
0
2.25
4.5

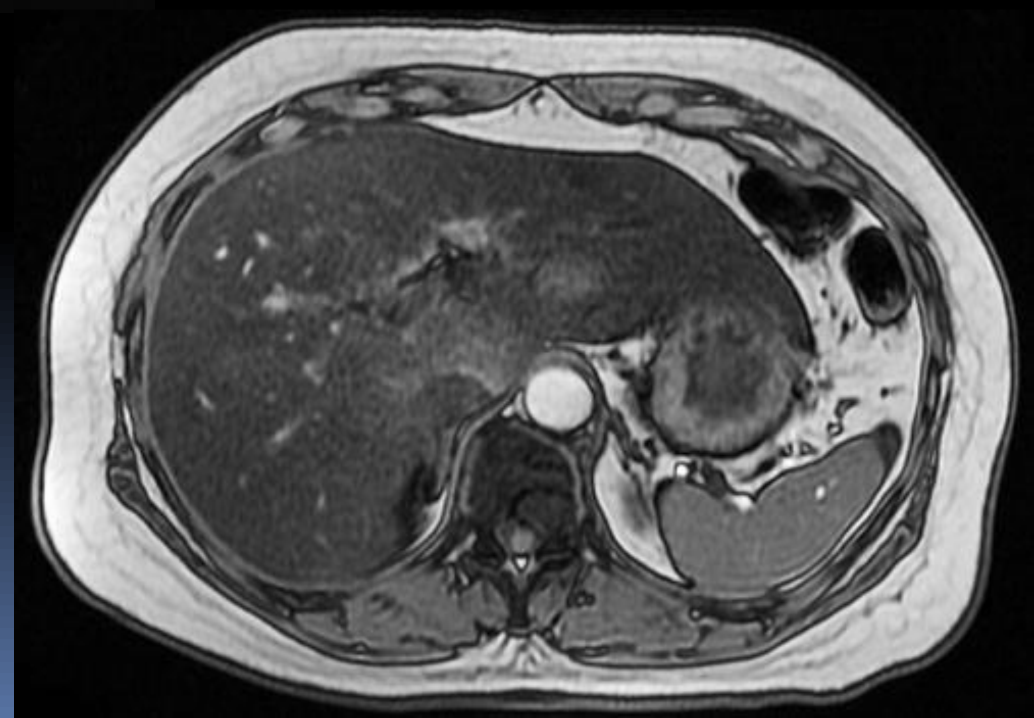
TE = 2.25 m sec (T1)

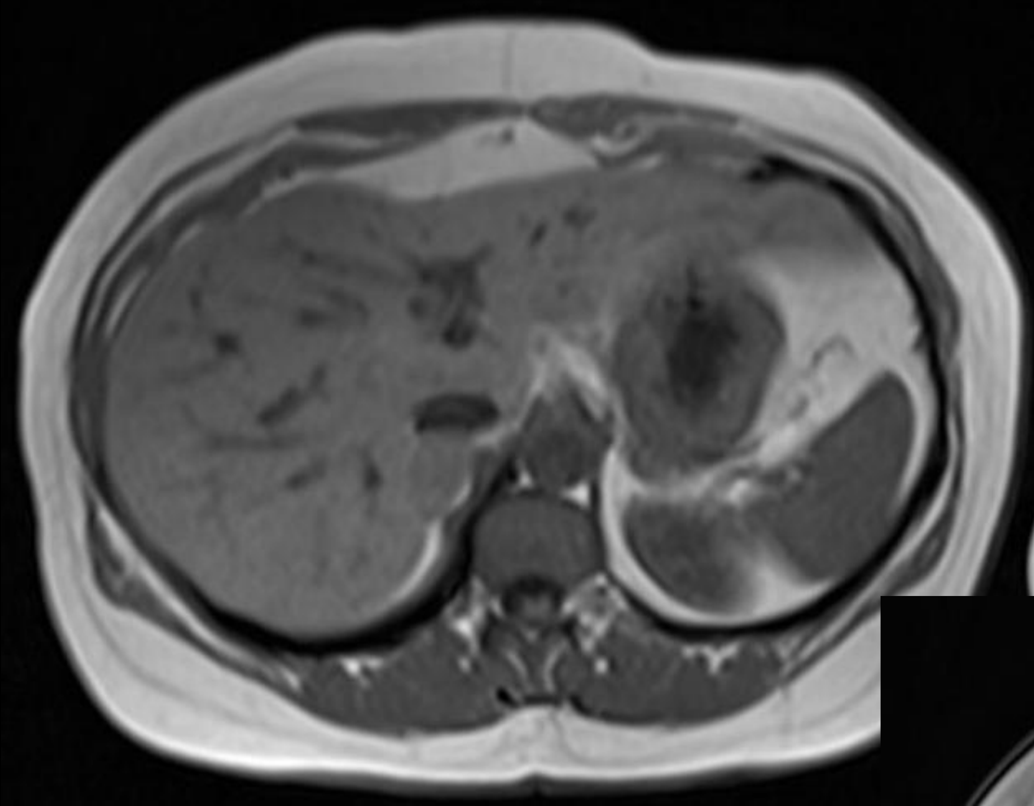




out-of-phase GRE image with TE=2.2 msec.

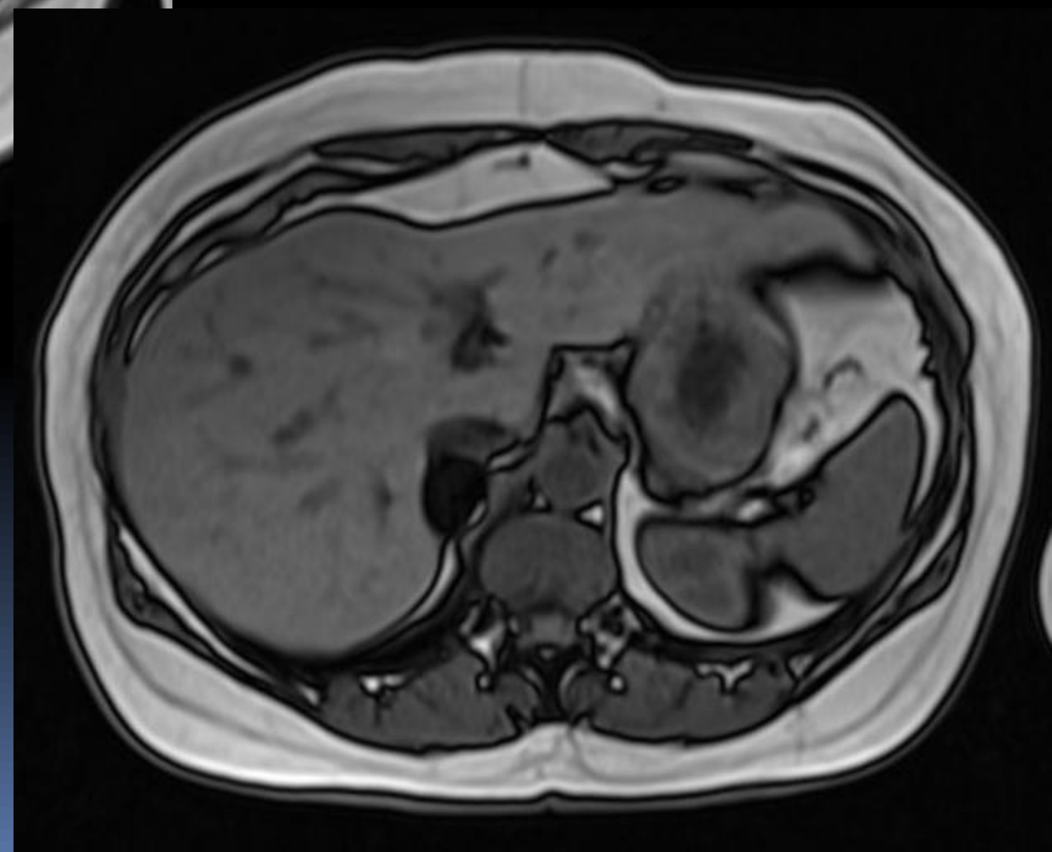
In-phase GRE with TE=4.4 msec.

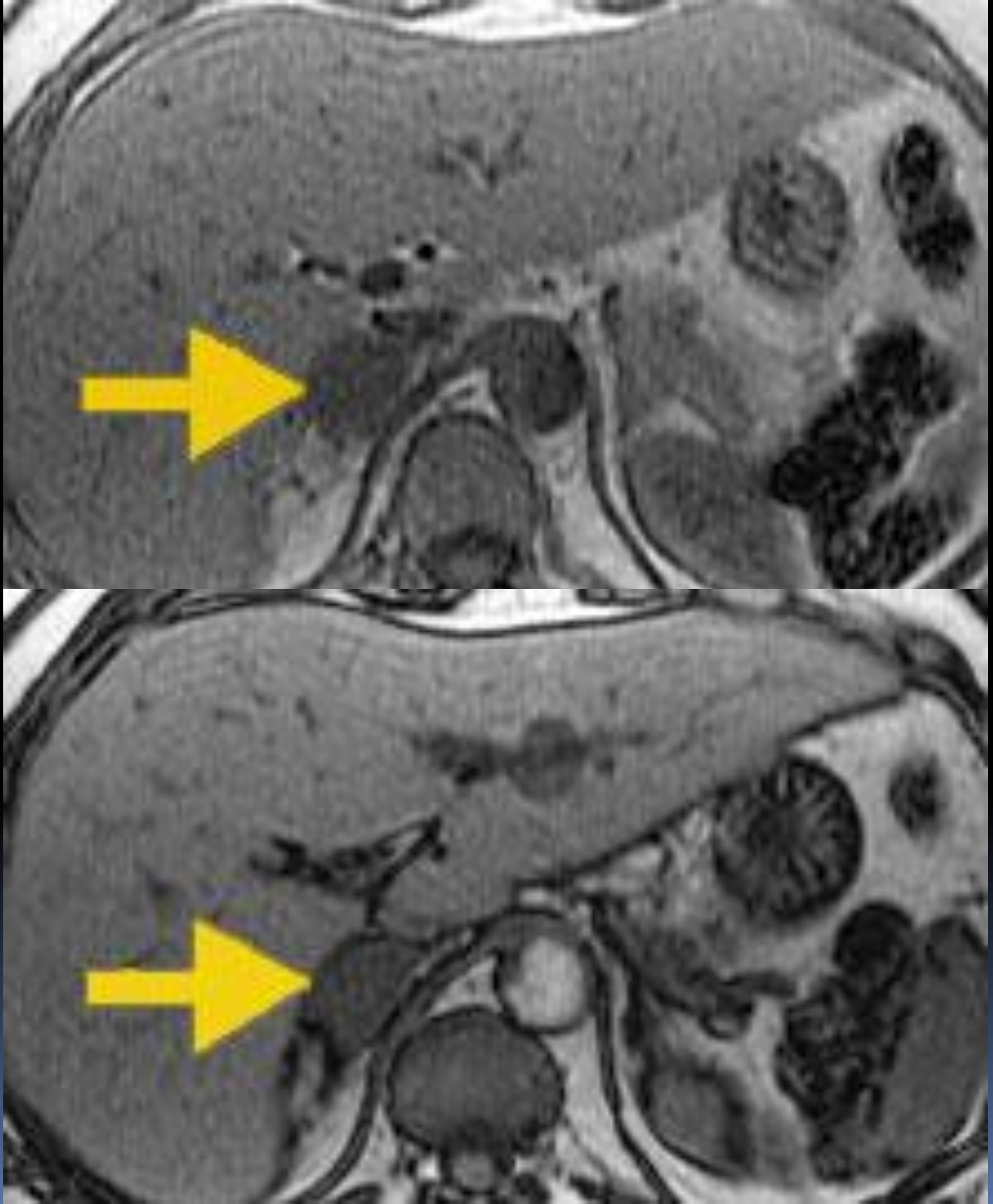




In-phase T1 with TE=4.4 msec.

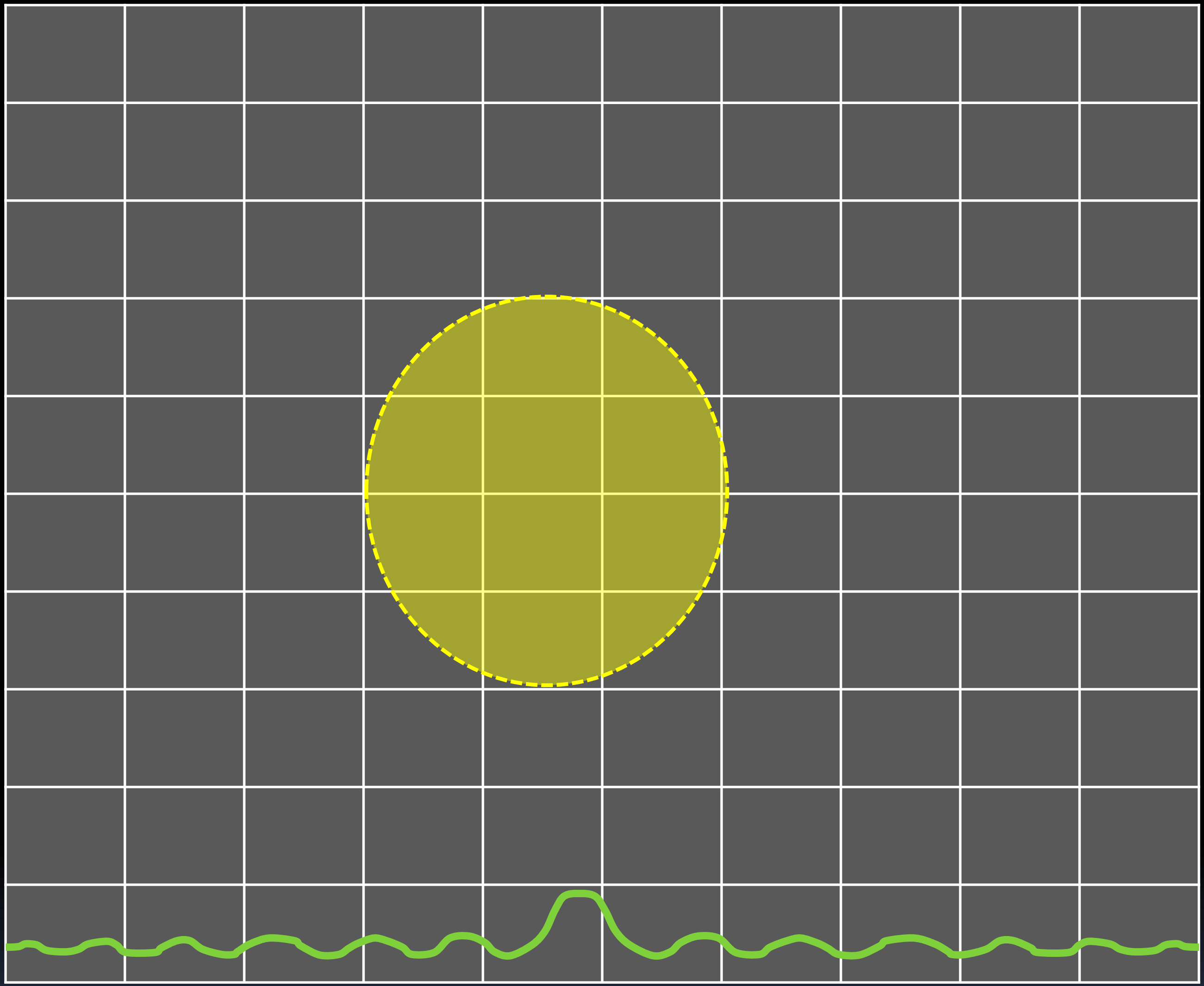
out-of-phase T1 image with TE=2.2 msec.





Remedies

- Get rid of fat using fat suppression
- Increase pixel size by keeping FOV the same and decreasing Nx (trade-off: deteriorates resolution).
- Lower the magnet's field strength
- Increase bandwidth (trade-off: lowers SNR)
- Switch phase and frequency directions
- Use a long TE



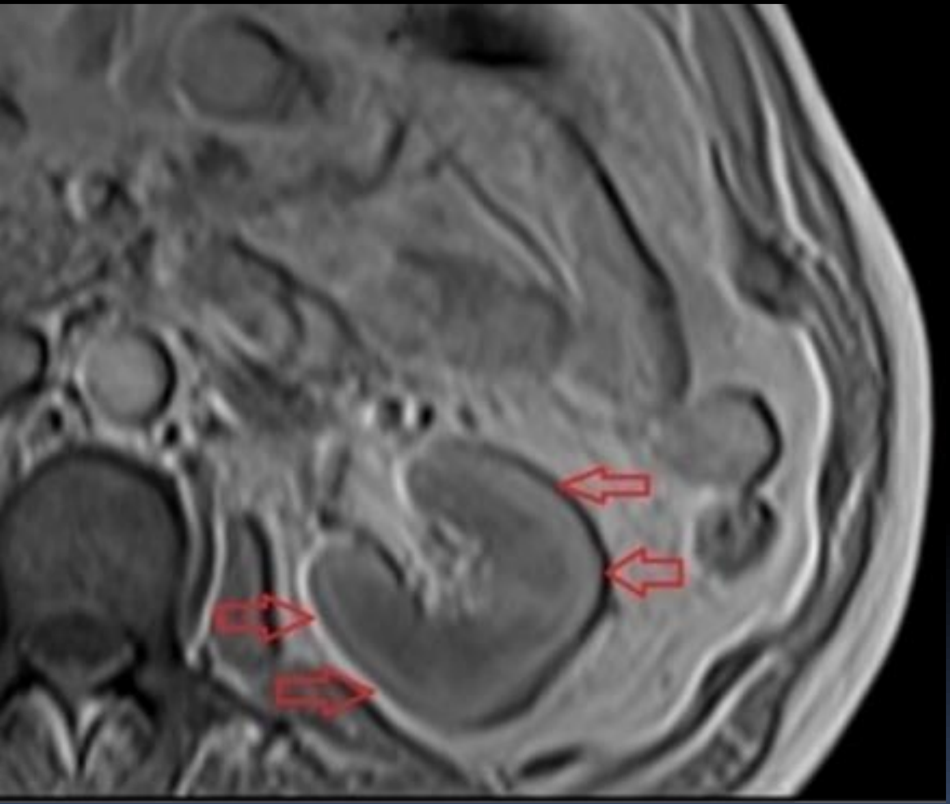
BW=32kHz(256pixels) Pixel=125Hz

1.5T 220Hz

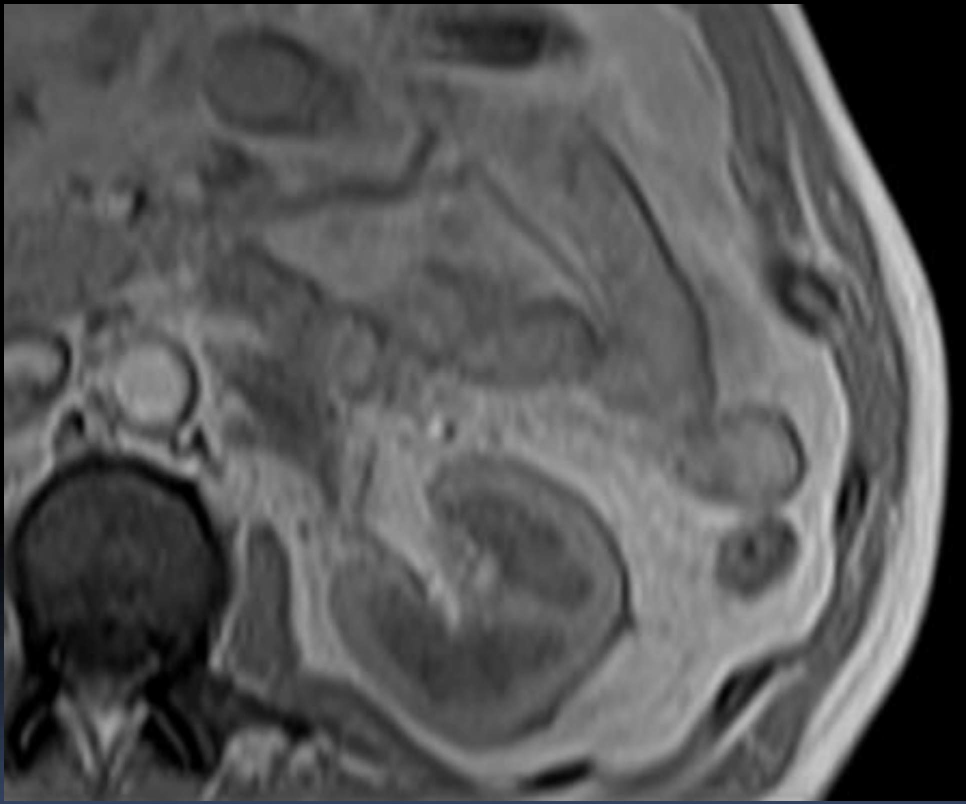
BW=64kHz Pixel=250Hz

1.5T 220Hz=1pixel

BW:130

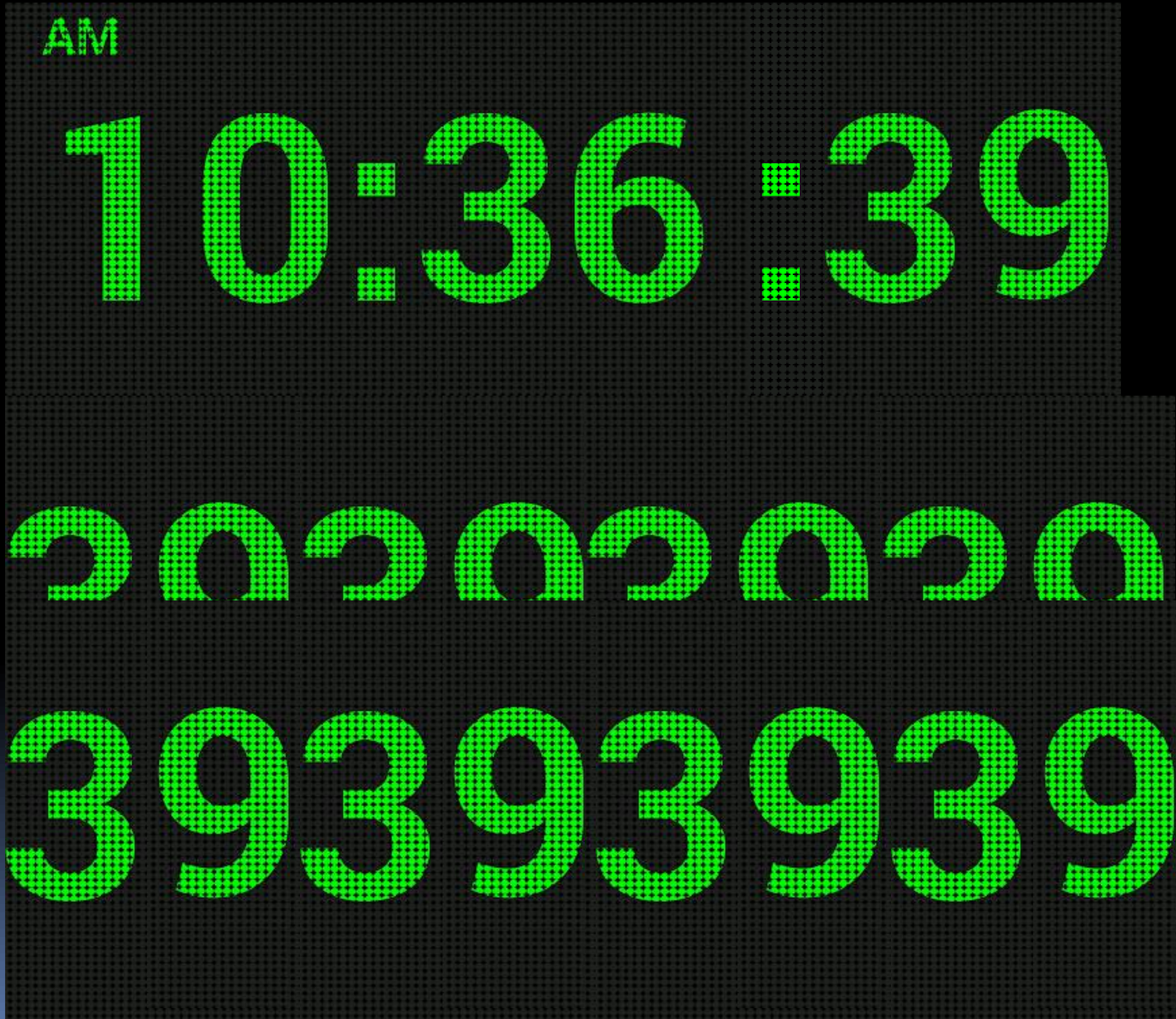


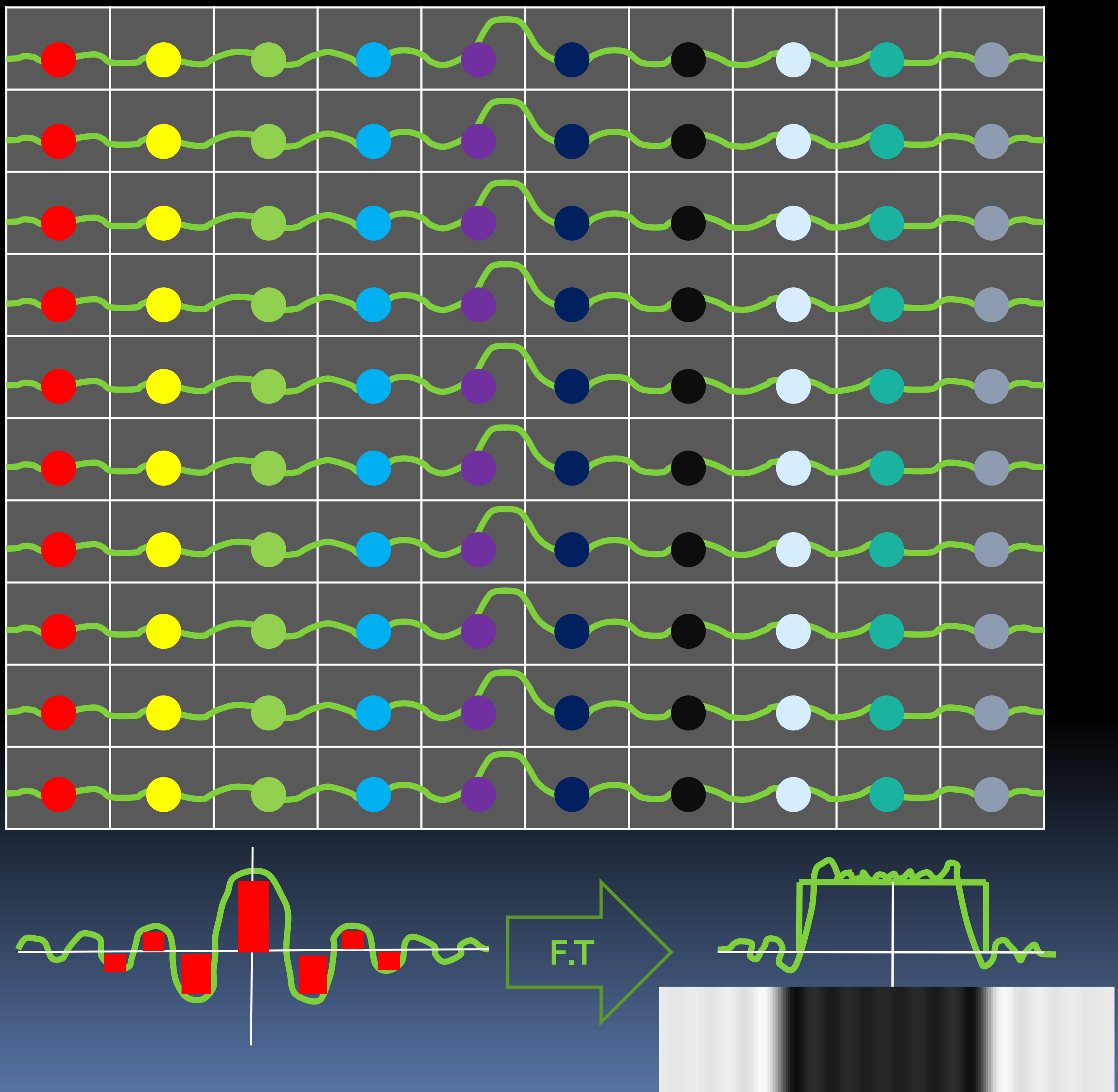
BW:450

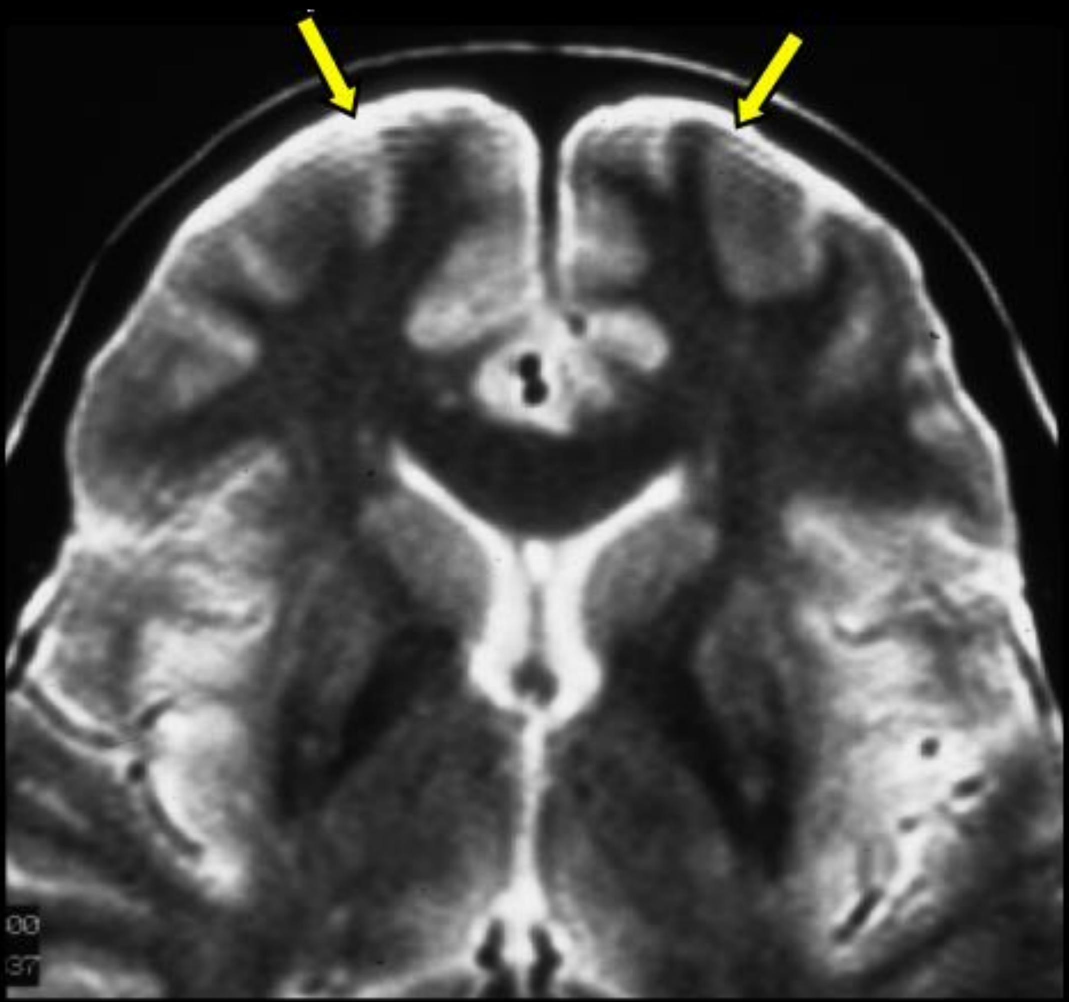


Truncation Artifact (Gibbs Phenomenon)

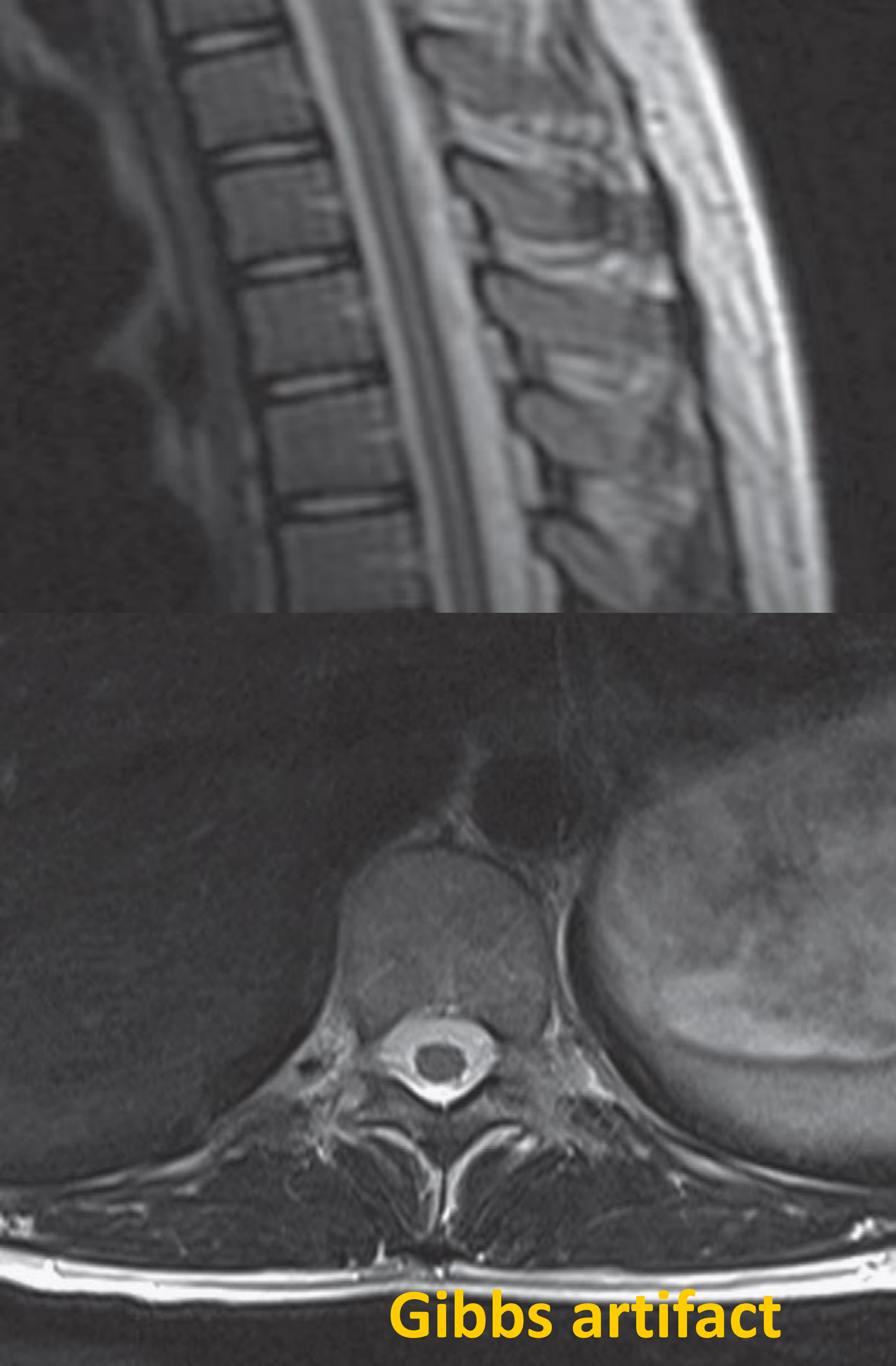
- This artifact occurs at high contrast interfaces.skull/brain,cord/cerebrospinal fluid (CSF),meniscus/fluid in the knee) and causes alternating bright and dark bands that may be mistaken for lesions

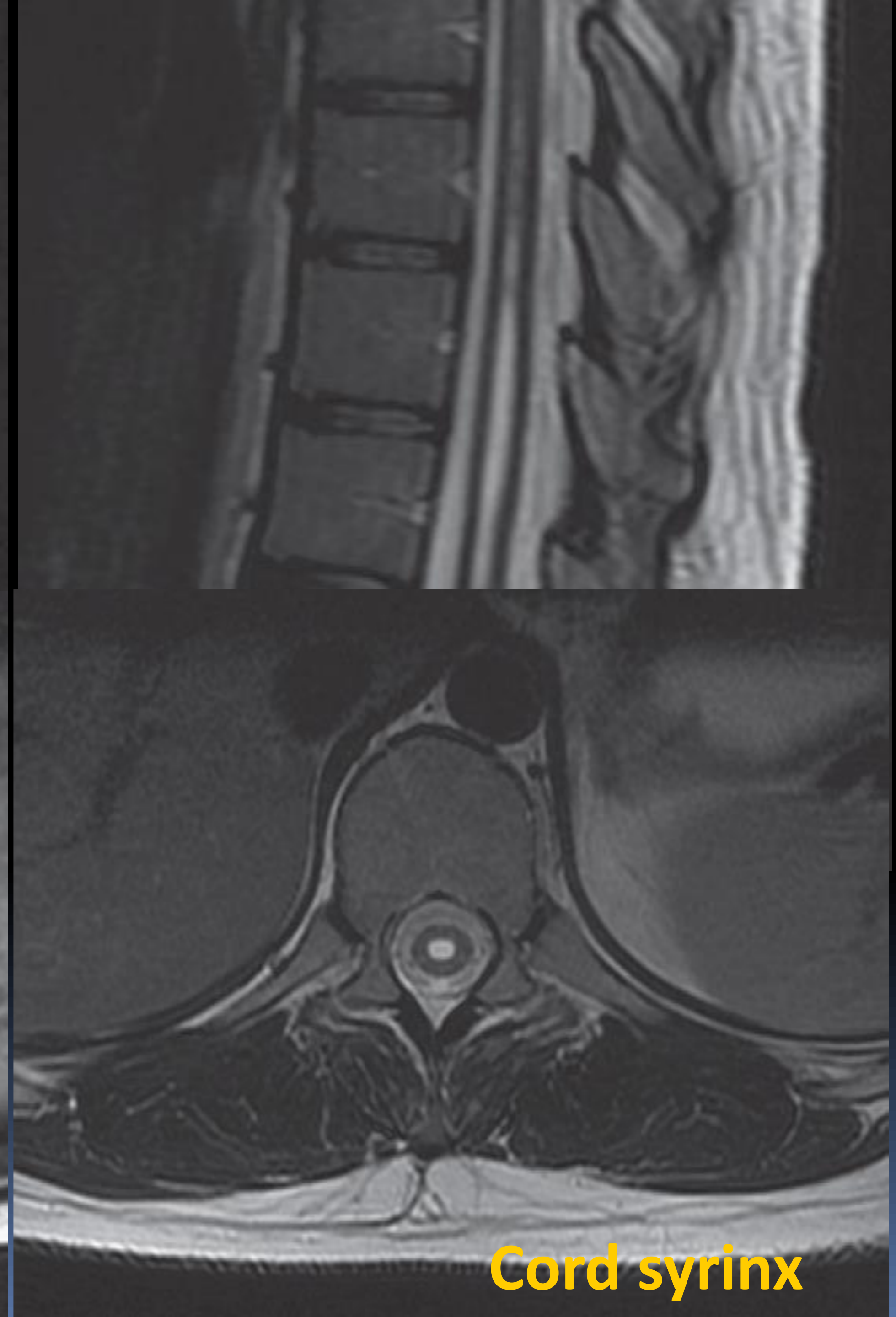

AM
10:36:39
39393939


F.T



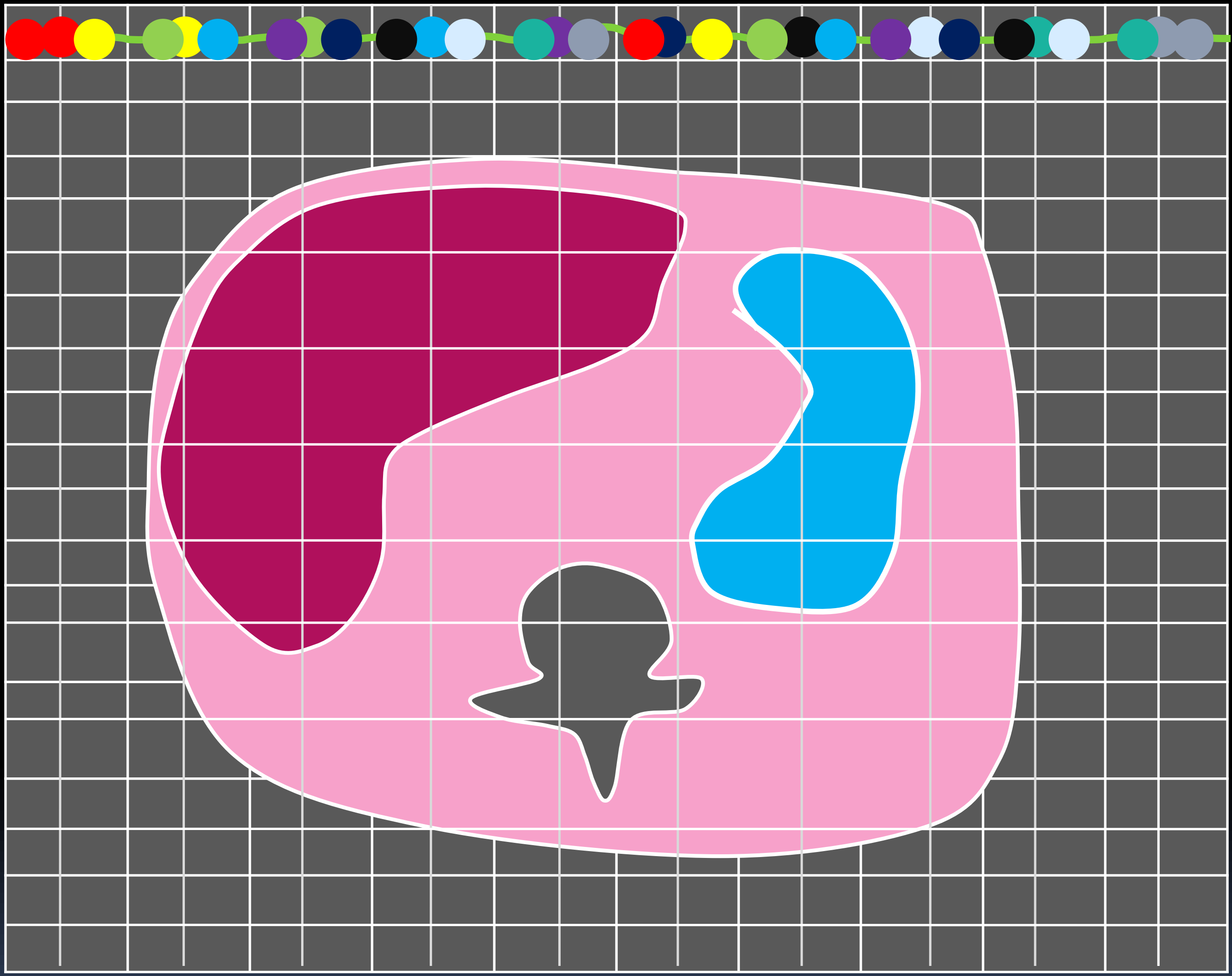
Proton density sagittal image of the knee shows truncation artifact mimicking posterior medial meniscus tear (white arrow). Note extension of high signal beyond the meniscus (black arrow).


Gibbs artifact


Cord syrinx

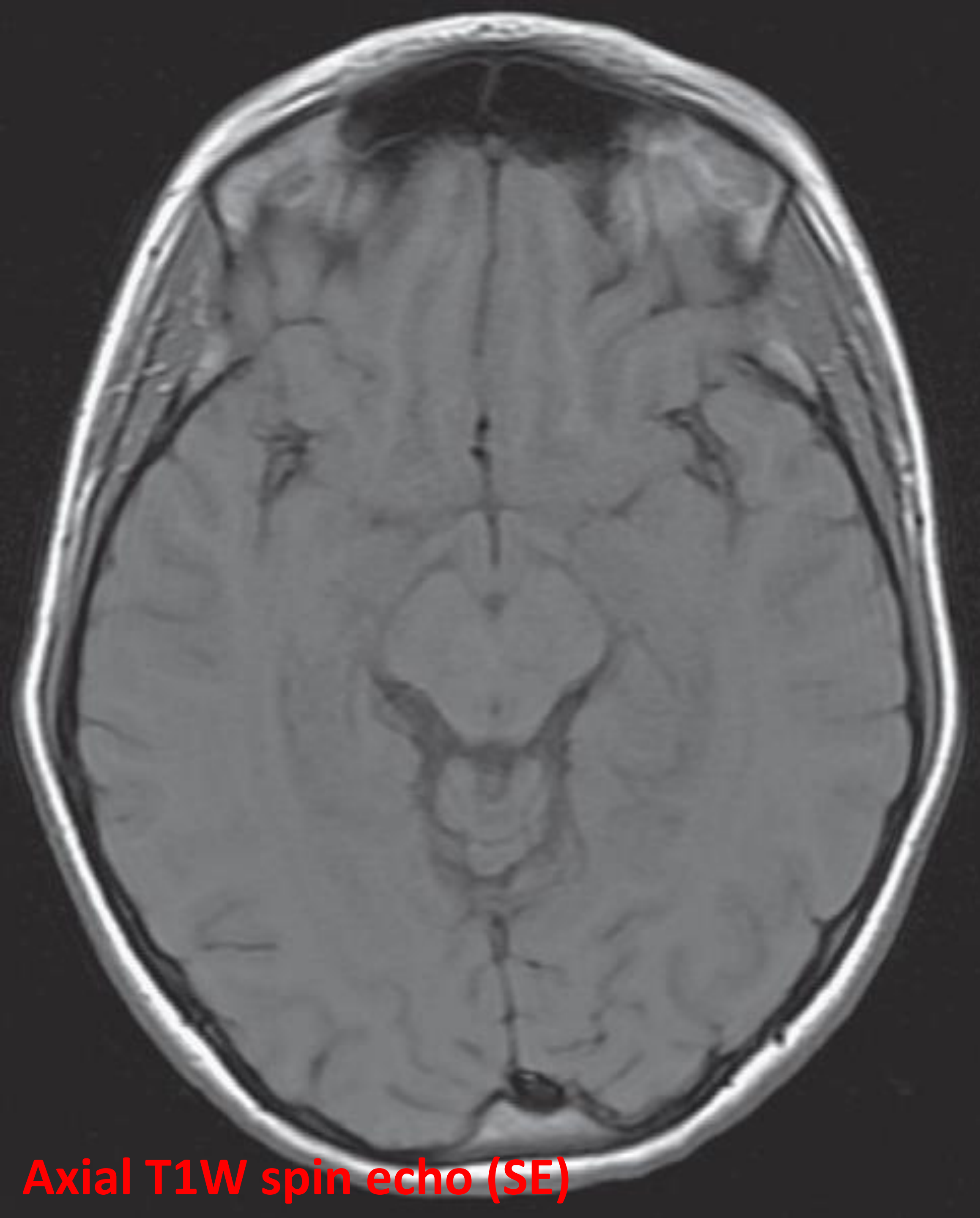
Remedies

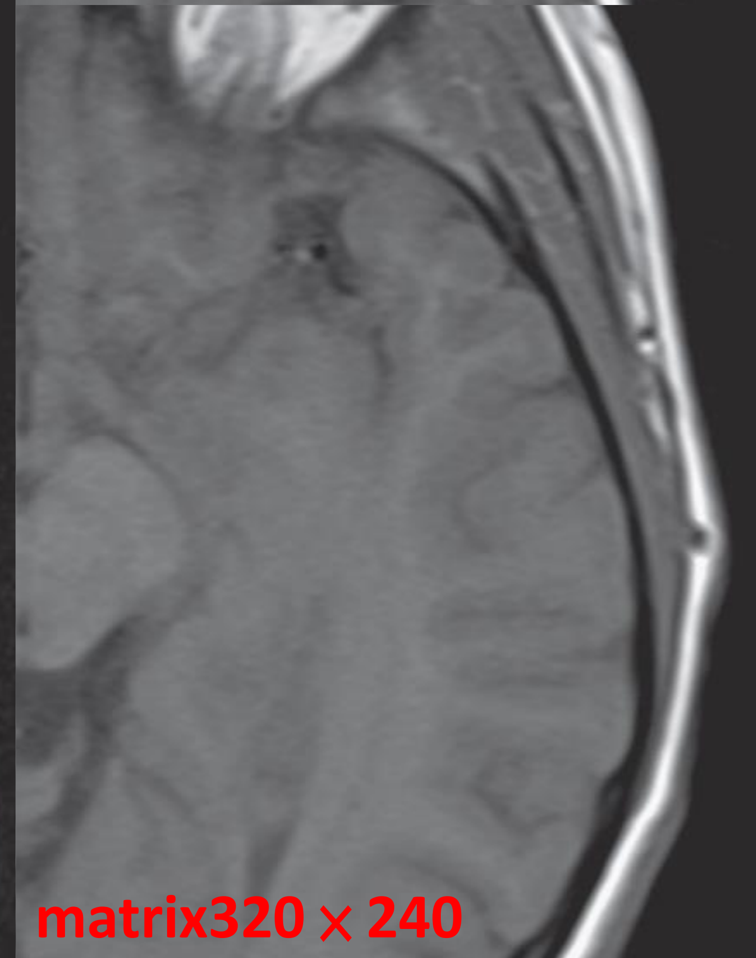
- Increase sampling time (↓BW) to reduce the ripples.
- Increasing the matrix size (i.e. sampling frequency for the frequency direction and number of phase encoding steps for the phase direction)
- Use of smoothing filters
- If fat is one of the boundaries, use of fat suppression

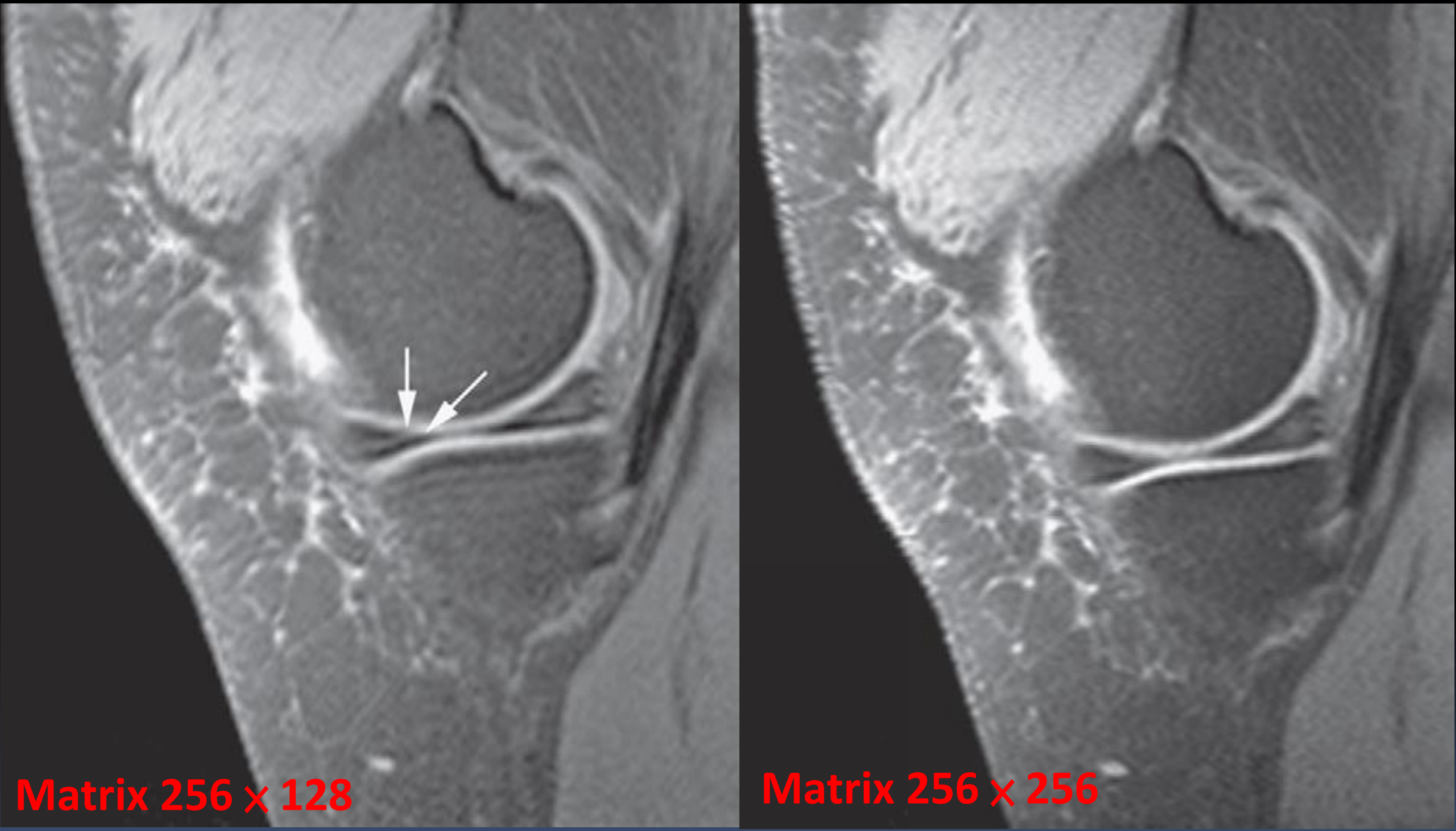


Matrix ⬆ Phase and Frequency encoding steps ⬆


256 x 256 matrix

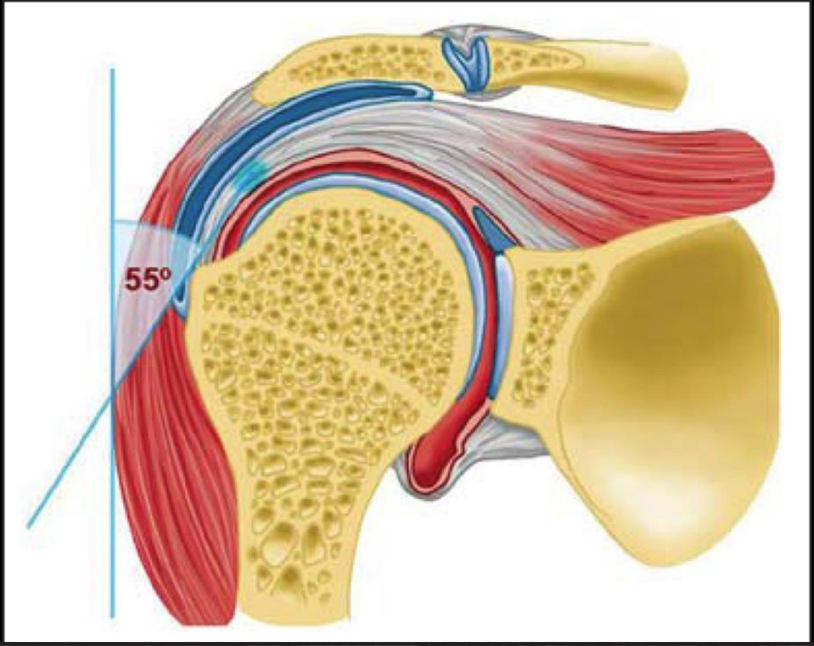

Axial T1W spin echo (SE)

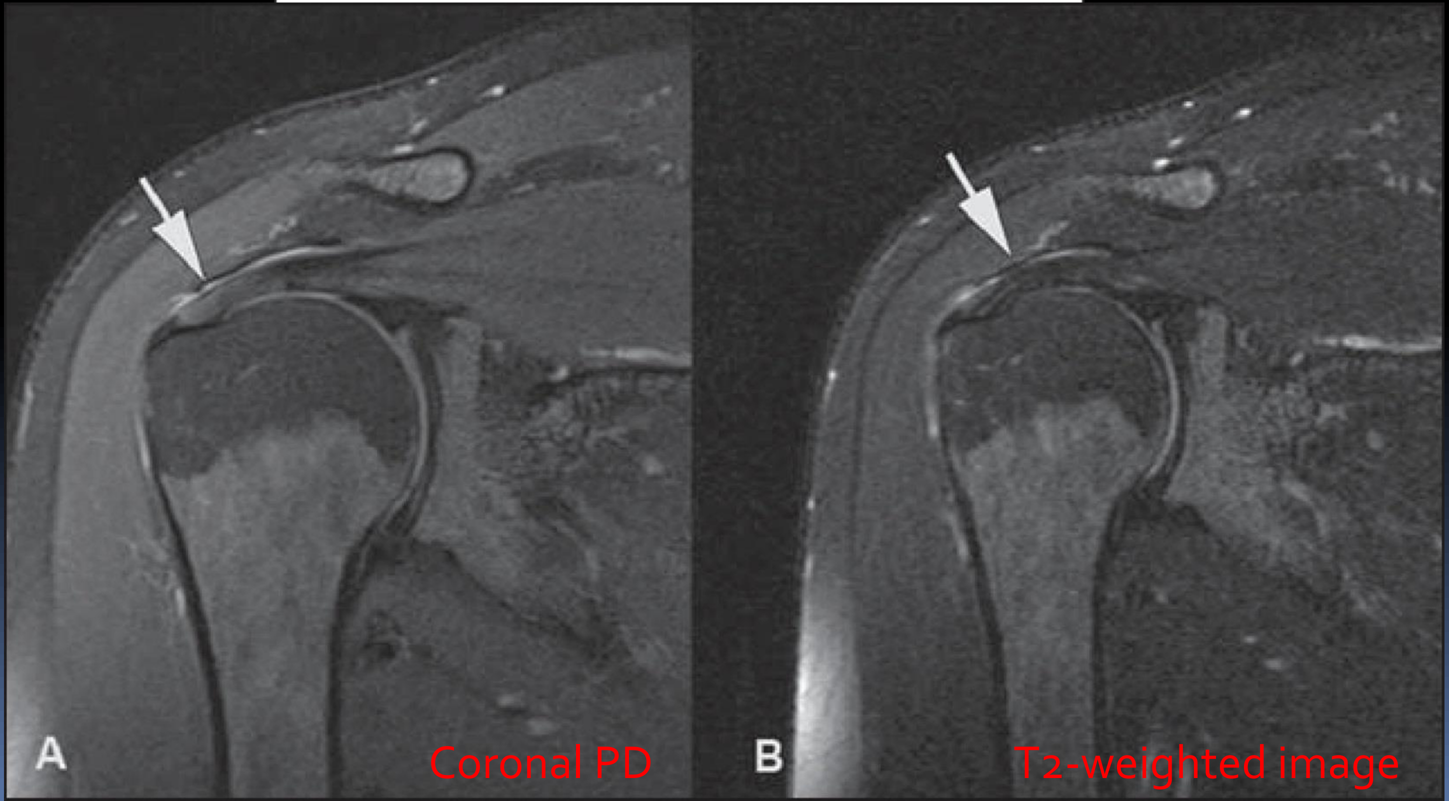

matrix320 × 240


Matrix 256 × 128
Matrix 256 × 256

Magic Angle Artifacts

- In imaging the joints, if a tendon is oriented at a certain angle (55°) relative to the main magnetic field, then the tendon appears brighter on T1- and proton density (PD)-weighted images, but normal on T2-weighted images. This artifactual increased intensity might potentially be confused with pathology

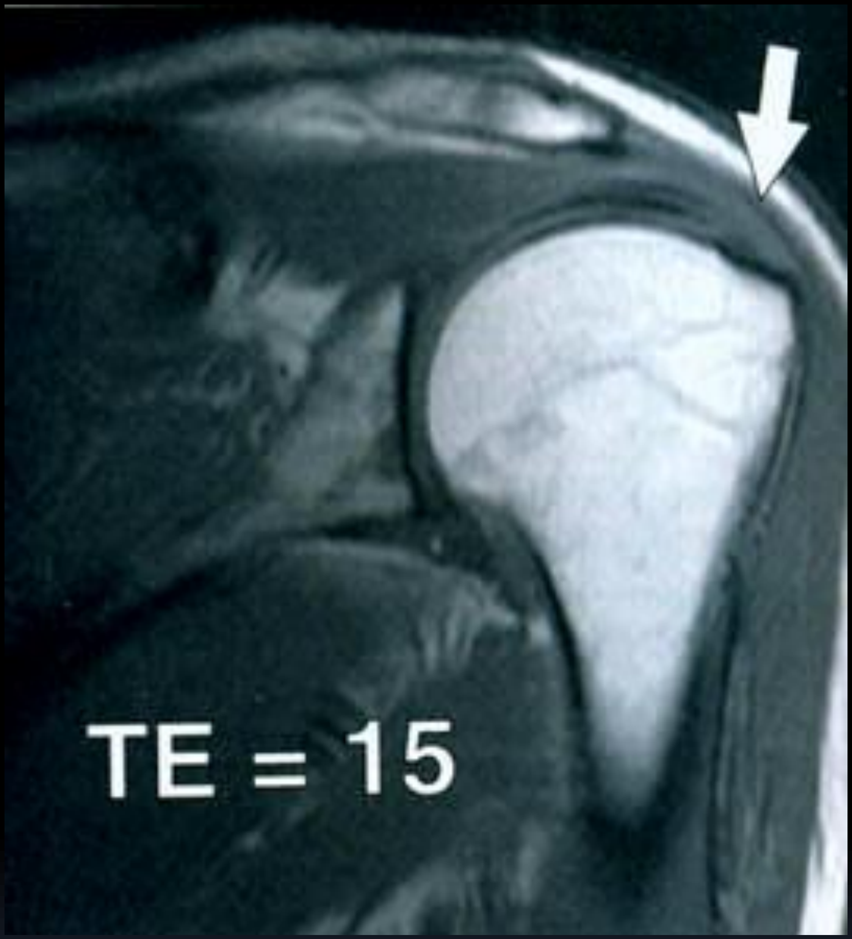

55º


A
Coronal PD
B
T2-weighted image

Sagittal PD (A) and T2 (B) fat-saturated images of the knee show magic angle artifact as seen by increased signal on the short TE PD image (arrow in A), whereas the tendon itself is not thickened and has dark signal on the T2 image (B). Joint effusion is also seen.

Remedies

- The intensity of signal variation induced by the magic angle will vary according to TE: it is maximal for relatively short TE (of the order of T_2) and regresses when TE is lengthened. Variation in the relative hypersignal will depend on the angle.
- Allowing classic analysis with T_1 and T_2-weighting

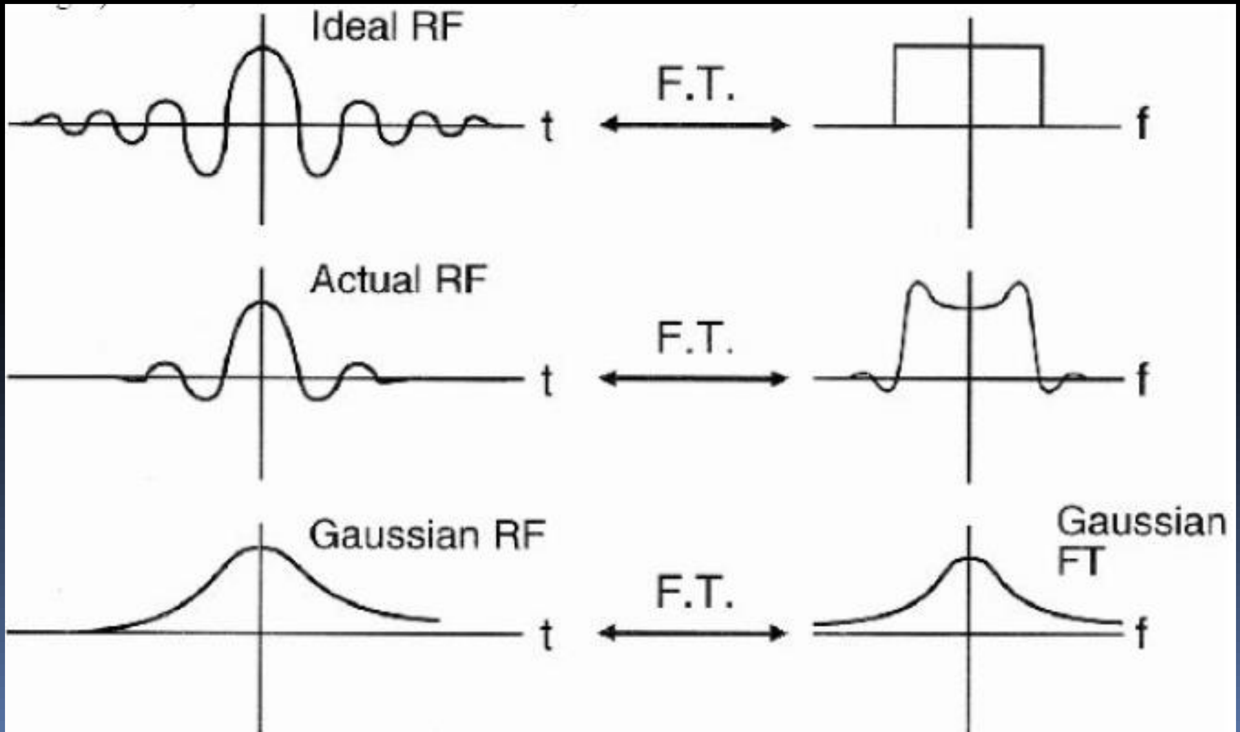


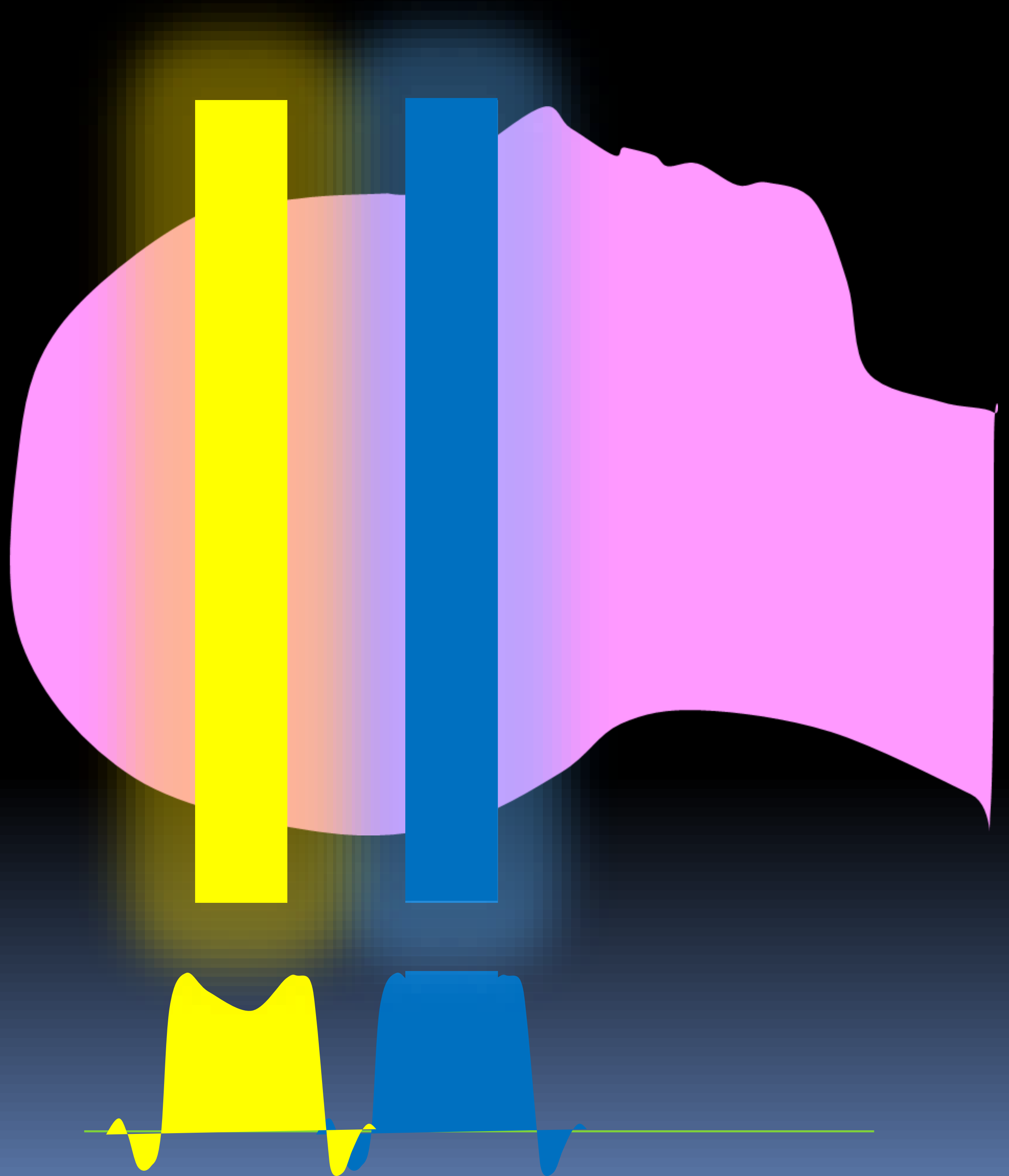
Magic angle affect causes increased signal intensity of the supraspinatus tendon (arrow). Note TE is short

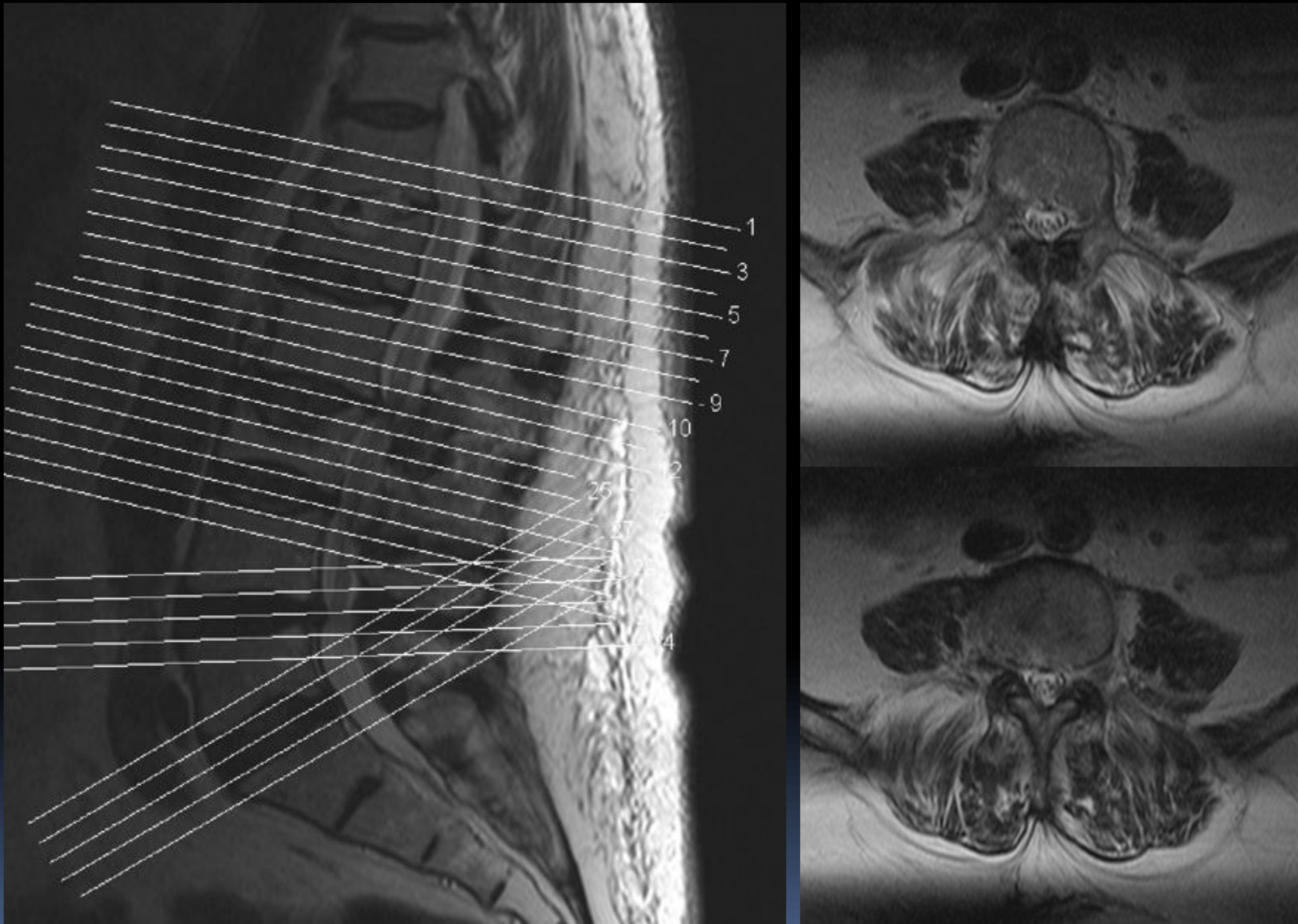
The supraspinatus tendon has low signal intensity on long TE

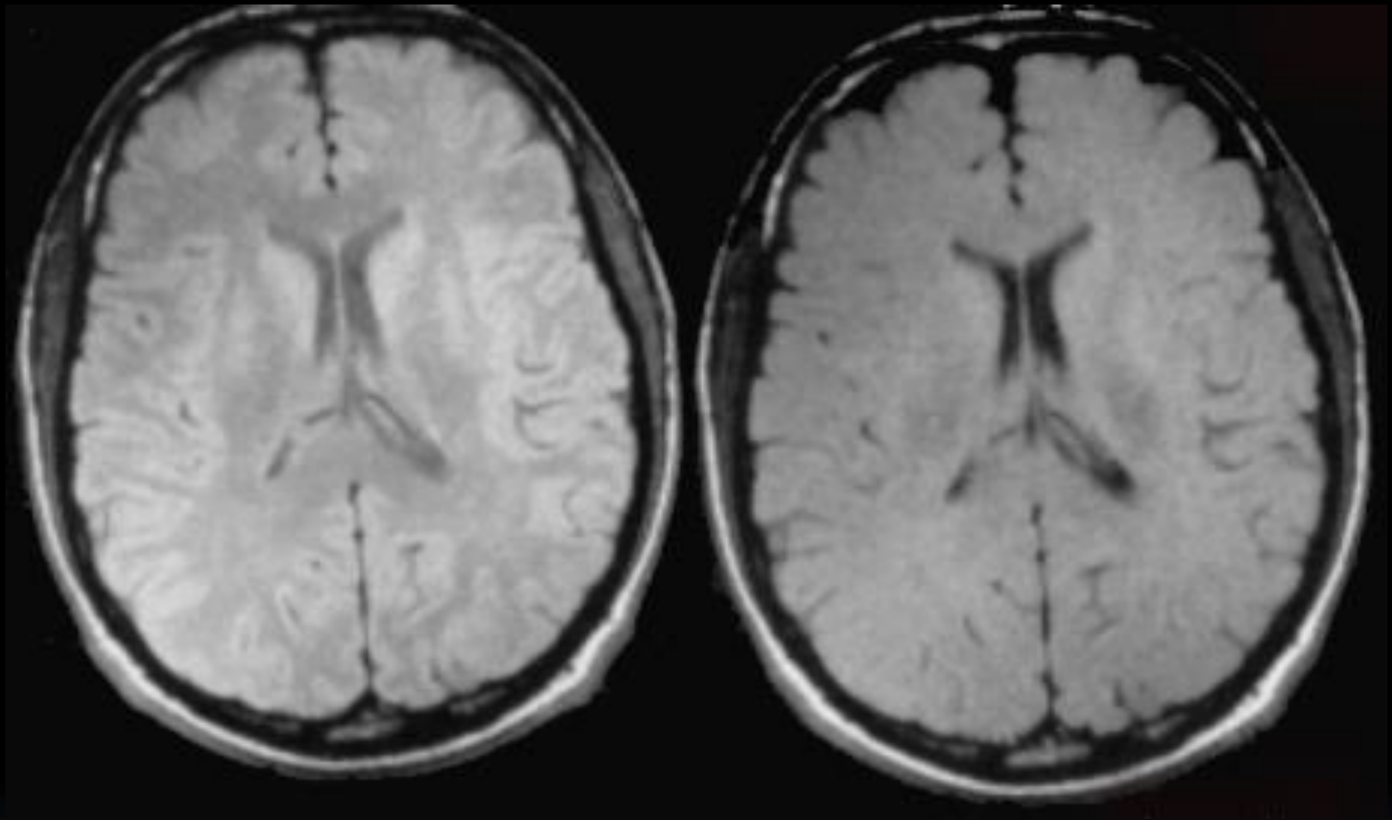
Cross-talk

- The problem arises from the fact that the Fourier transform (FT) of the RF pulse is not a perfect rectangle but rather has side lobes





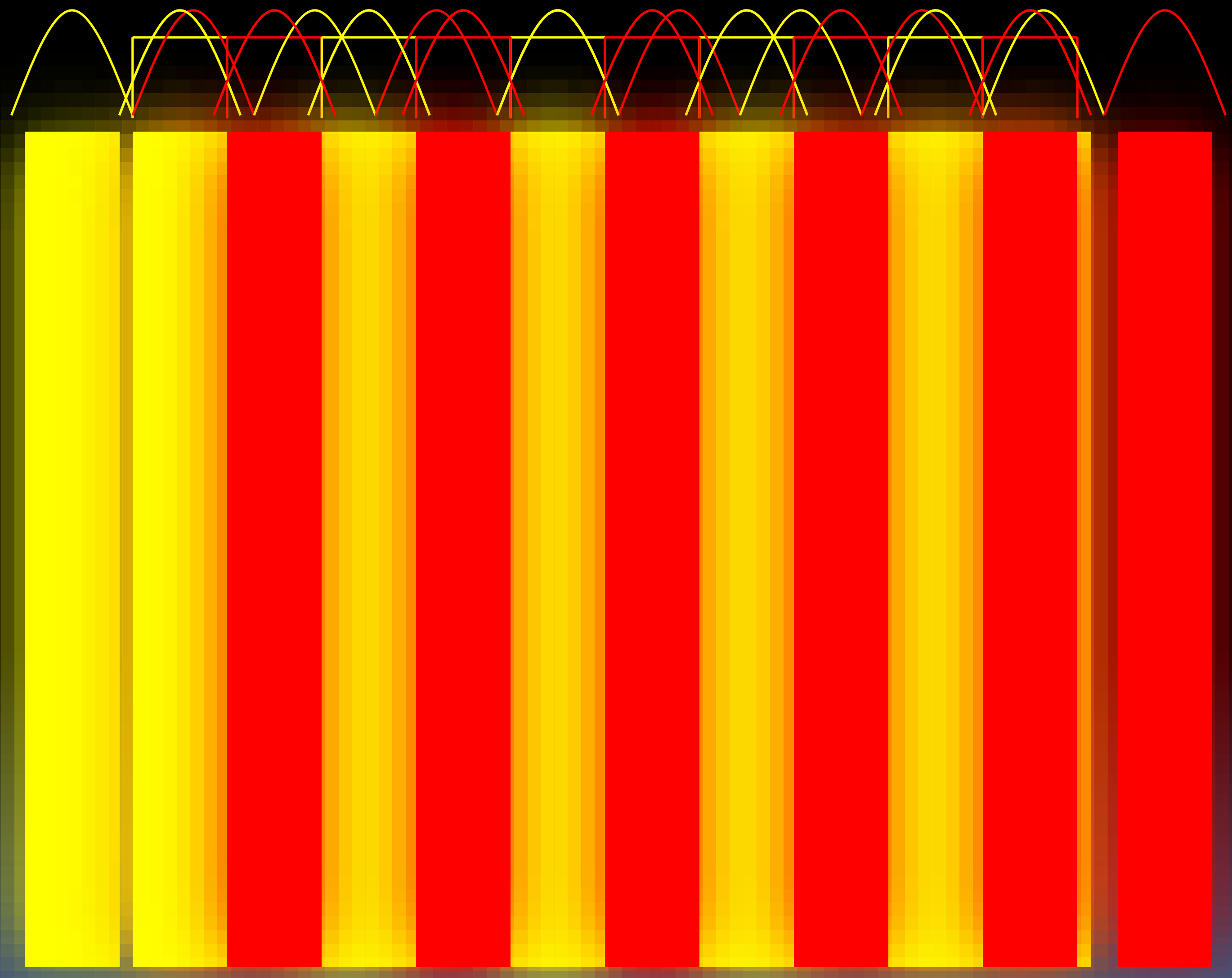

1
3
5
7
9
10
12
25



Effect of cross-talk on image contrast. On left is a SE 2000/20 image with 50% gap showing expected spin-density contrast. On right the same sequence with 0% gap demonstrating impaired contrast.

Remedies

- Gaps can be introduced between adjacent slices
- Two acquisitions with 100% gaps can be interleaved.
- The RF pulse can be lengthened to achieve a more rectangular pulse profile.



Interslice spacing

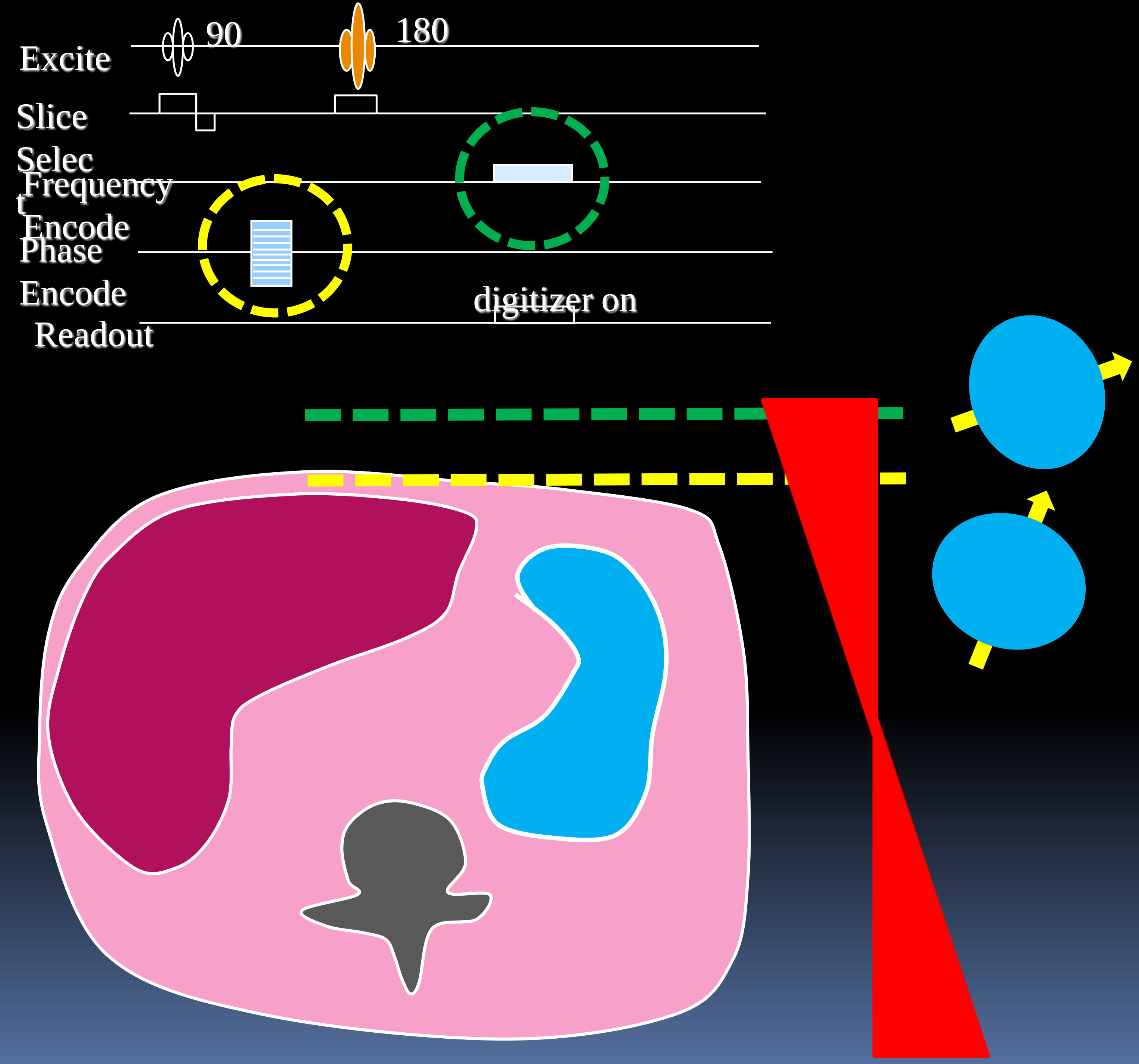
- Gap-GE, Philips, and Toshiba
- Slice interval-Hitachi
- Distance factor-Siemens

  distance factor of 20%(5mm)

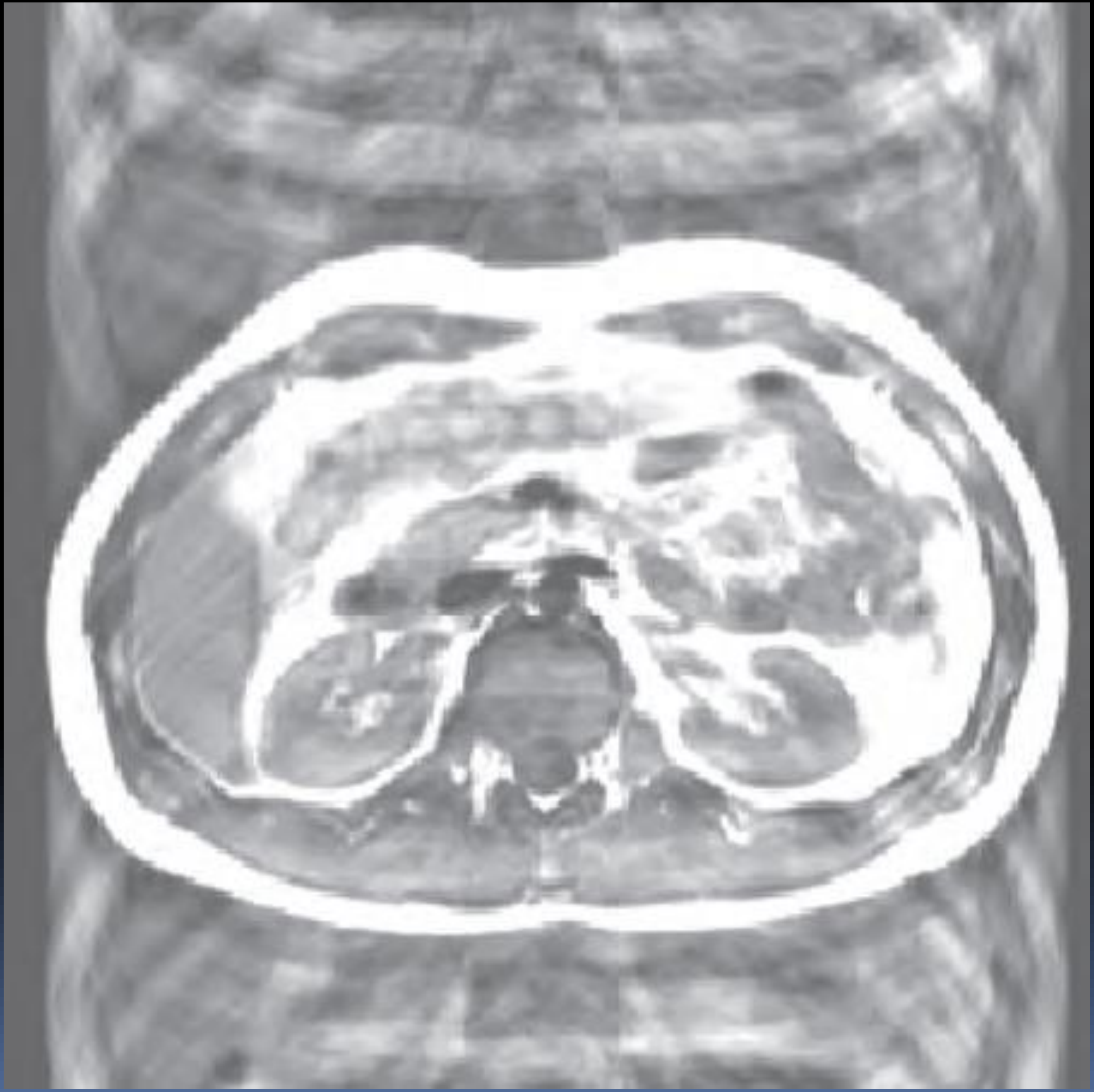
  1-mm gap

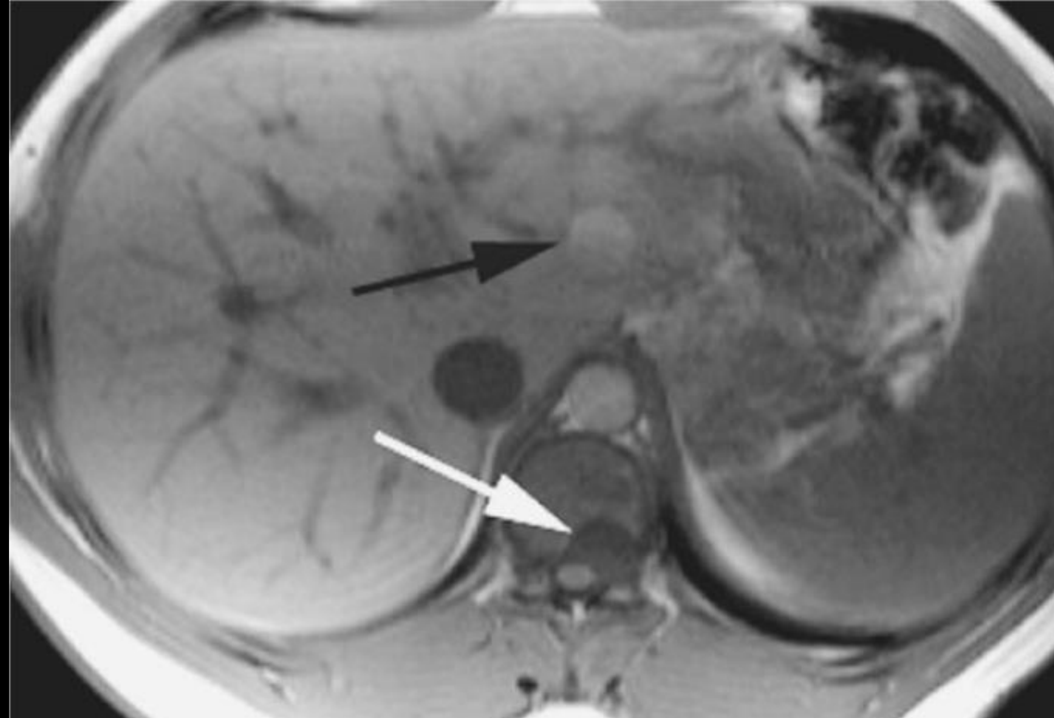
Motion Artifact

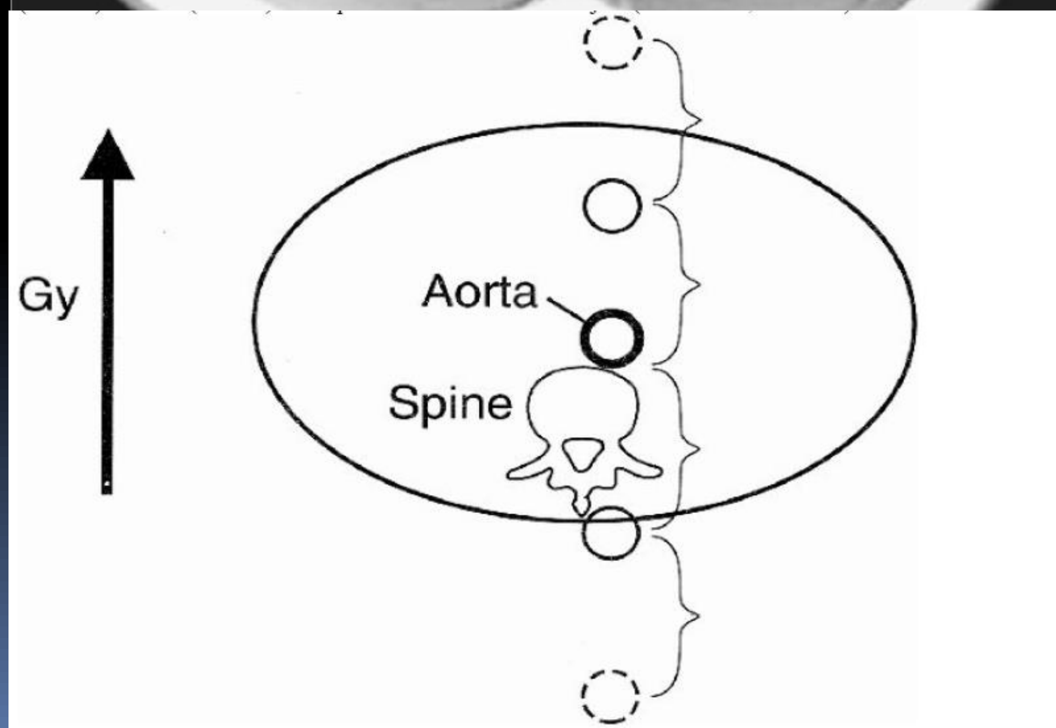
- Motion artifact is caused by the patient's (voluntary or involuntary) movements (random) or by pulsating flow in vessels (periodic). We only get motion artifacts in the phase-encoding direction.



Excite
90
180
Slice
Selec
t
Frequency
Encode
Phase
Encode
Readout
digitizer on






Gy
Aorta
Spine

Remedies

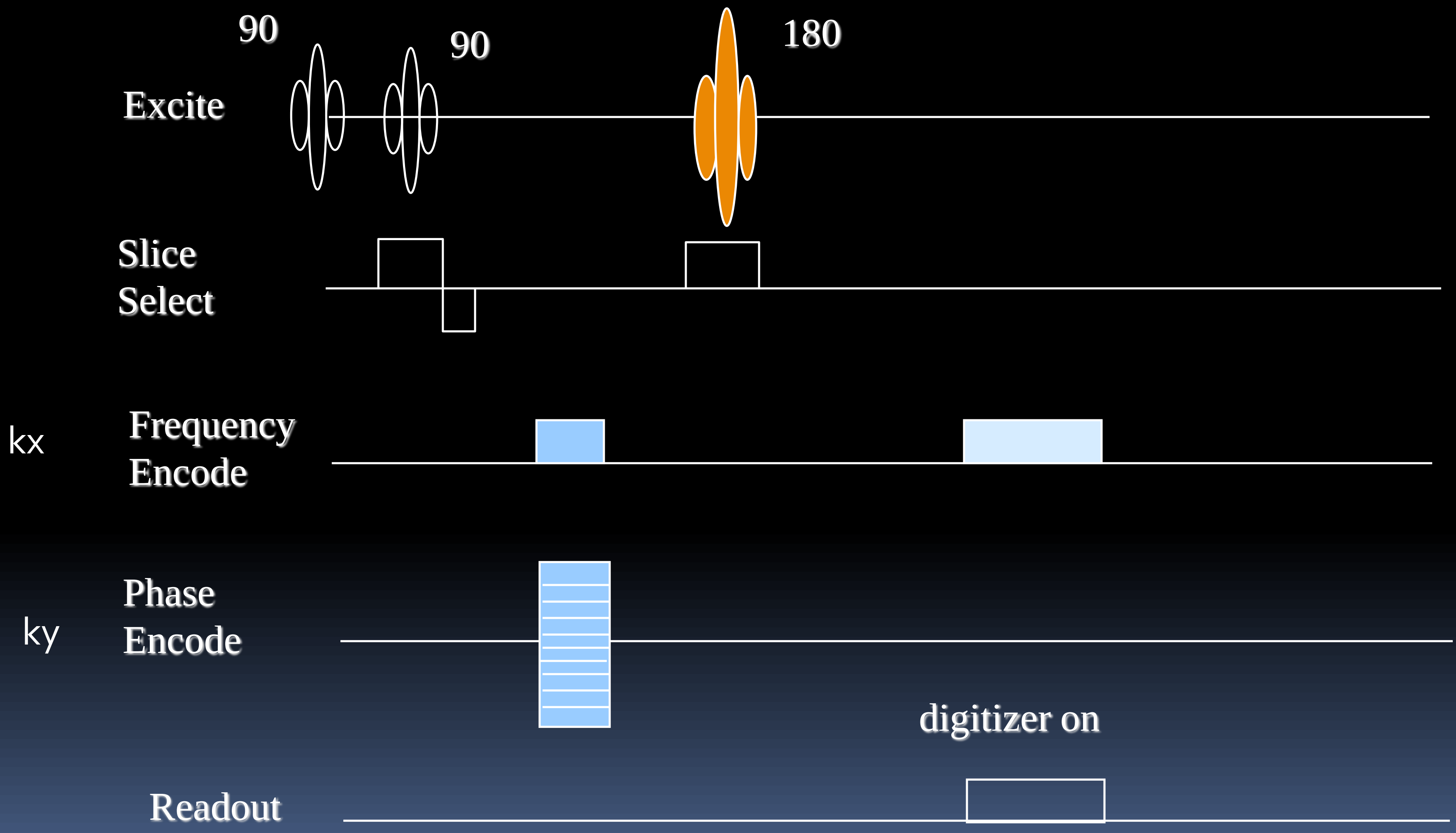
- Use spatial presaturation pulses to saturate inflowing protons and reduce the artifacts.
- Swap phase and frequency
- Respiratory Compensation(RC).

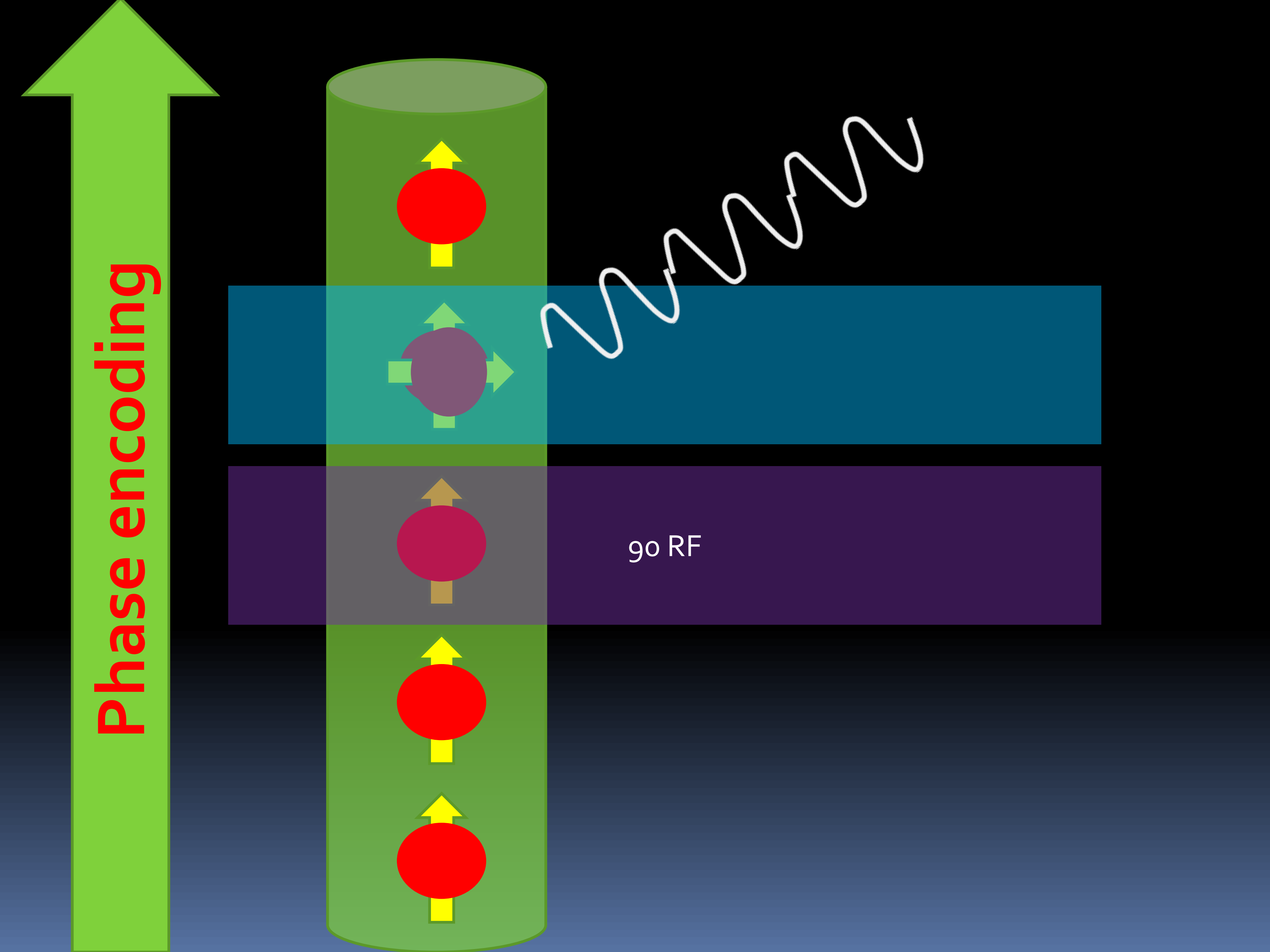
  ROPE and Rspiratory triggering
- Use flow compensation(Gradient moment nulling)
- Faster scanning (FSE, GRE, EPI, etc.); sequential 2D rather than 3D scanning
- Navigator echo
- Propeller

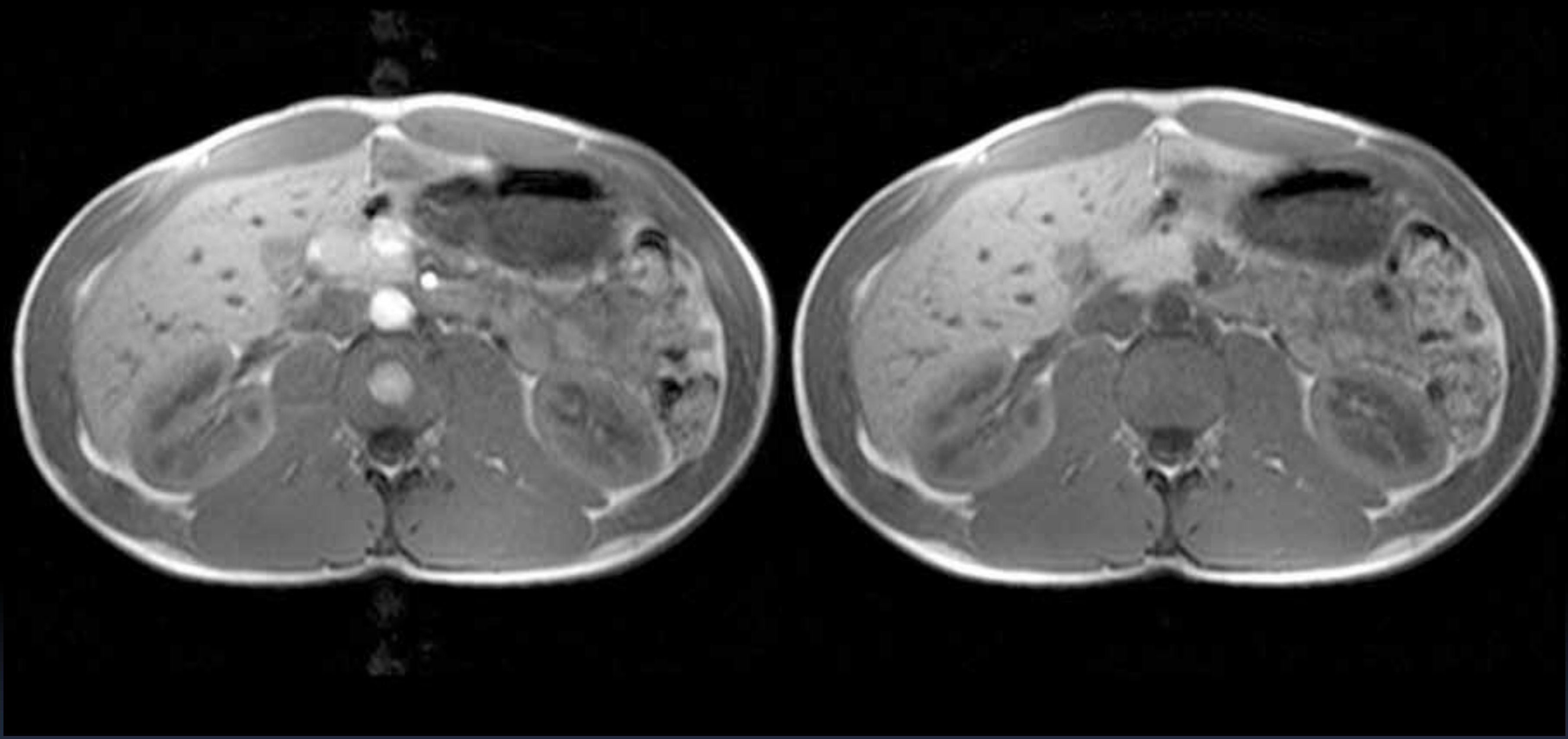
Spatial presaturation pulses

example: Artifacts caused by cardiac motion or blood flow may be included in the sagittal image of the thoracic spine.

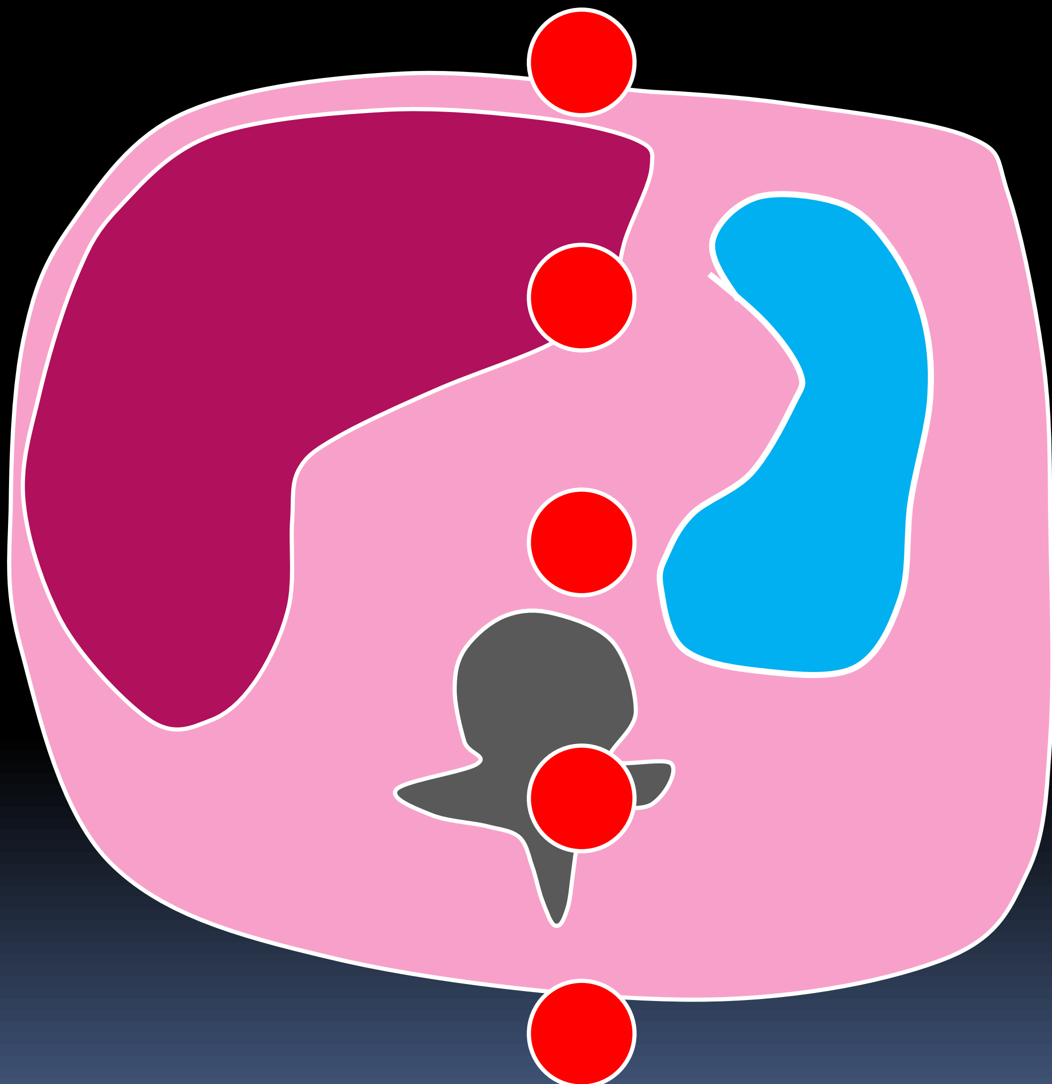
presaturation pulse sequences




Phase encoding
90 RF



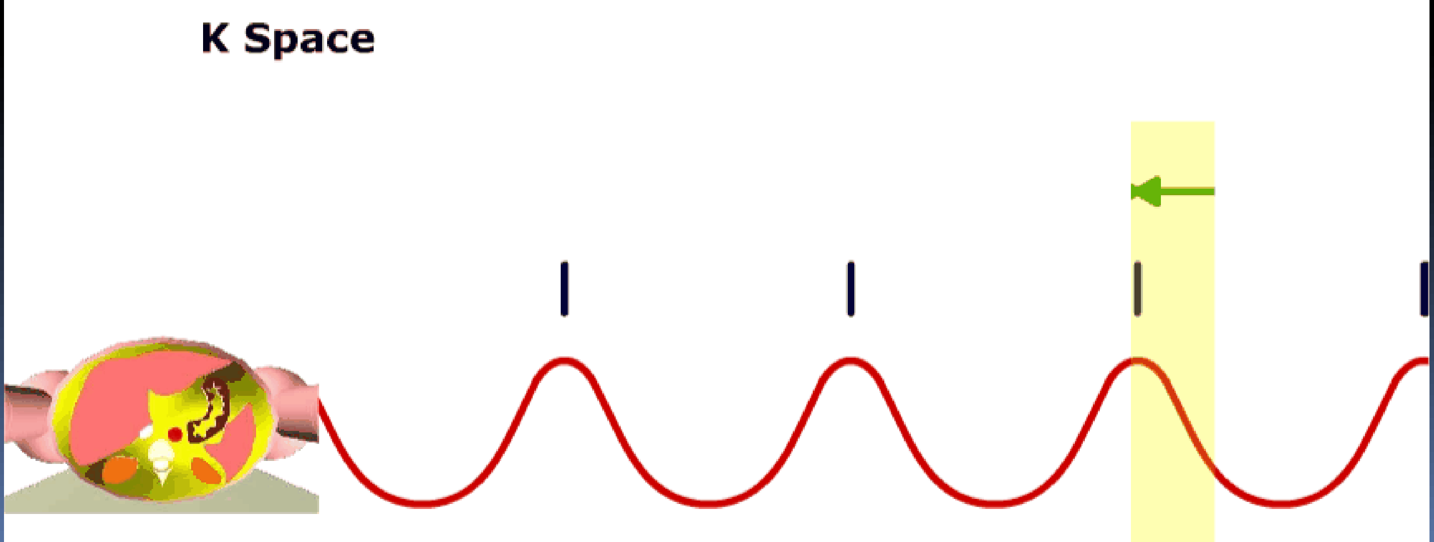
To avoid flow artifacts,a parallel saturation slice is positioned in front and in back of the slice to be imaged. In this way,both arterial and venous blood are saturated.
Flow artifacts are suppressed.



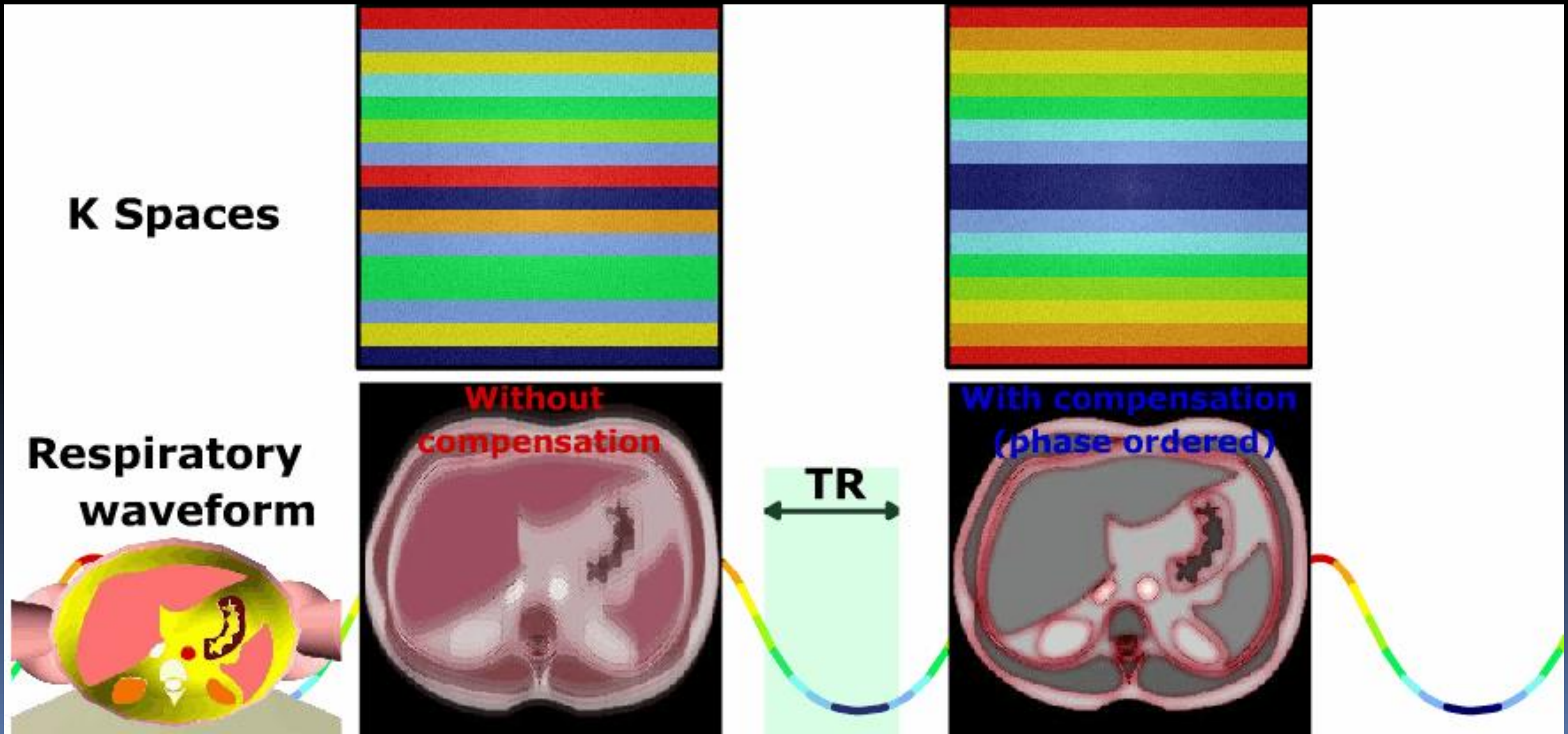
Frequency encoding (FOVy)
Phase encoding (FOVy)

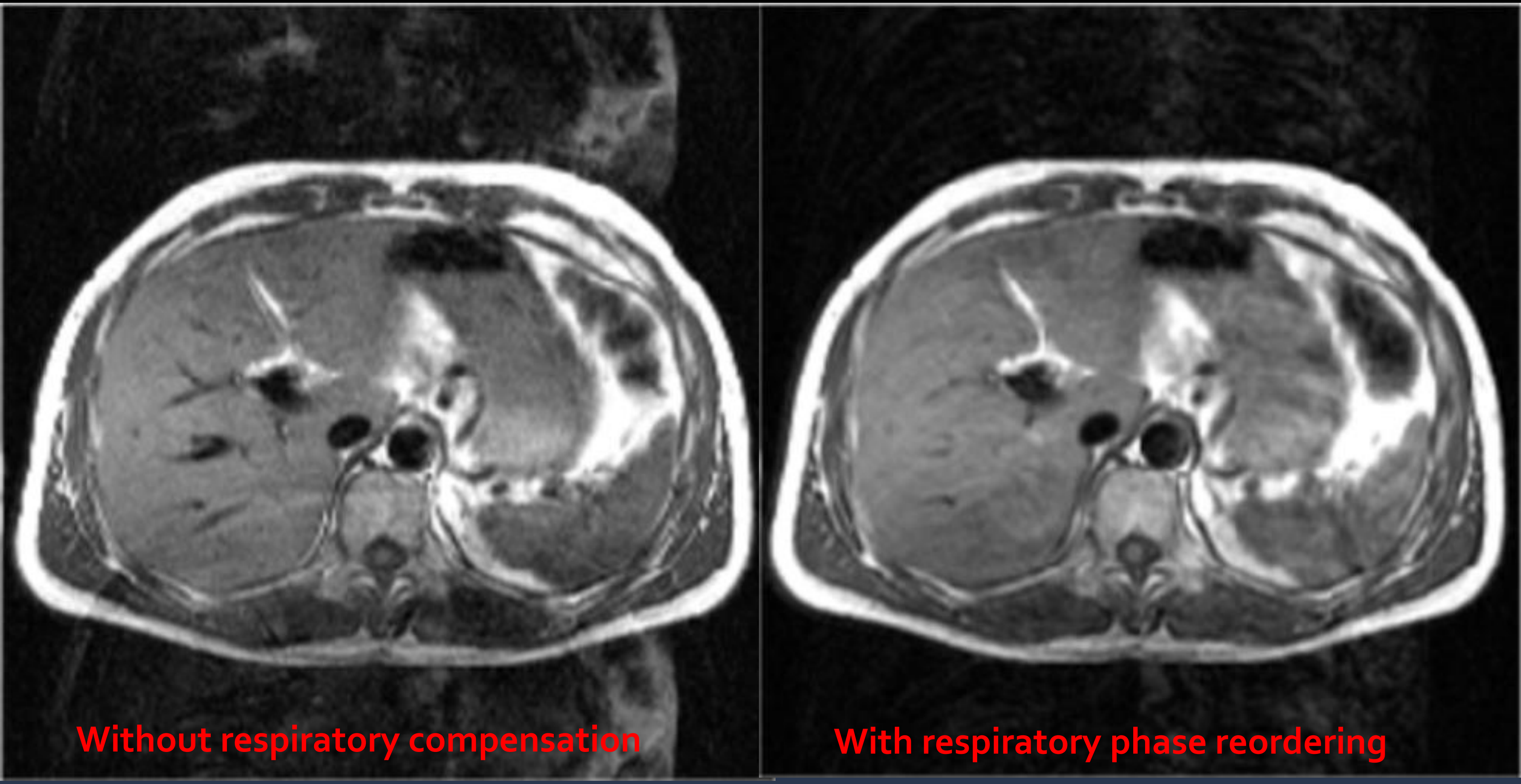
Phase encoding (FOVx)
Frequency encoding (FOVx)

Respiratory triggering

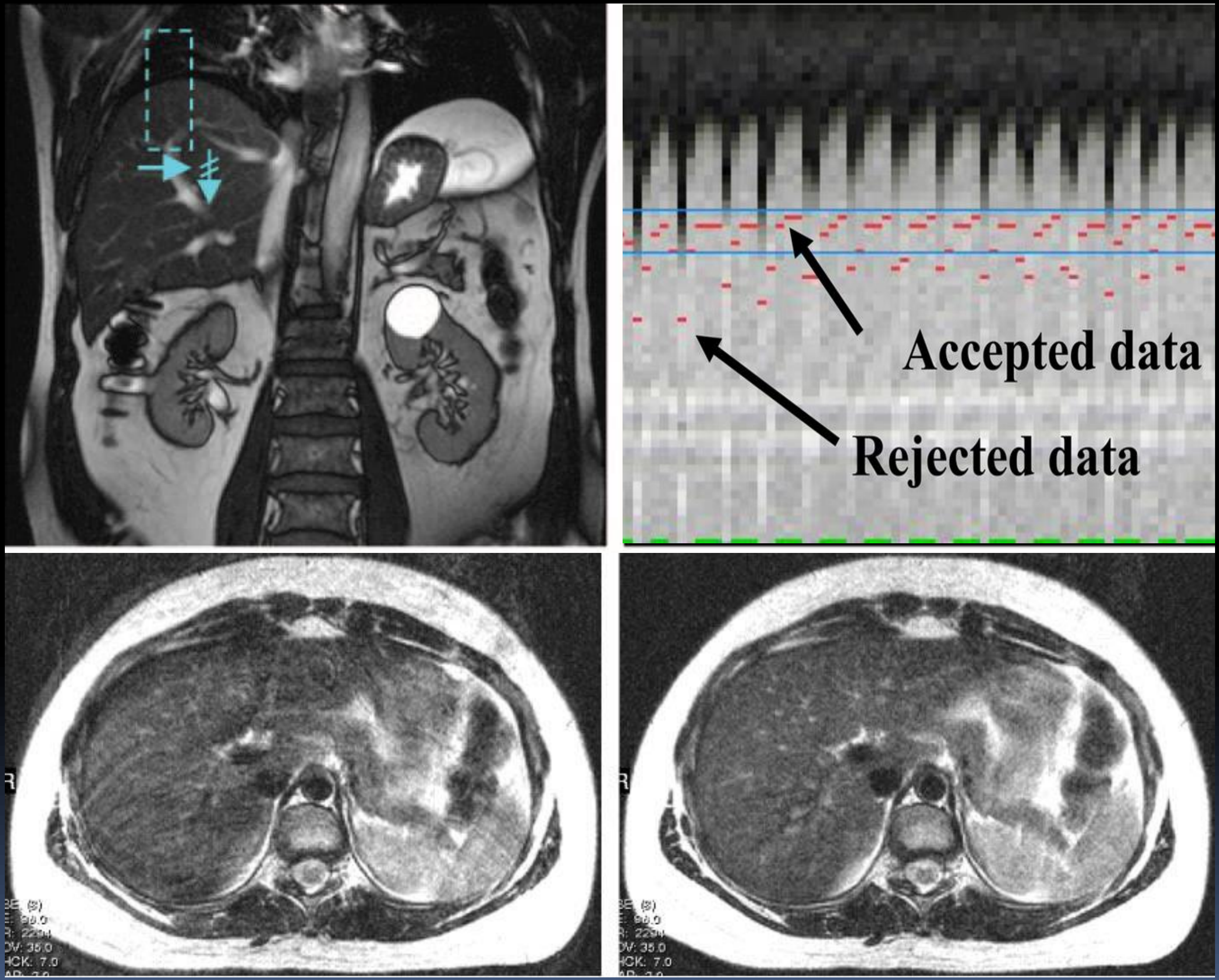


Respiratory ordered phase encoding (ROPE)



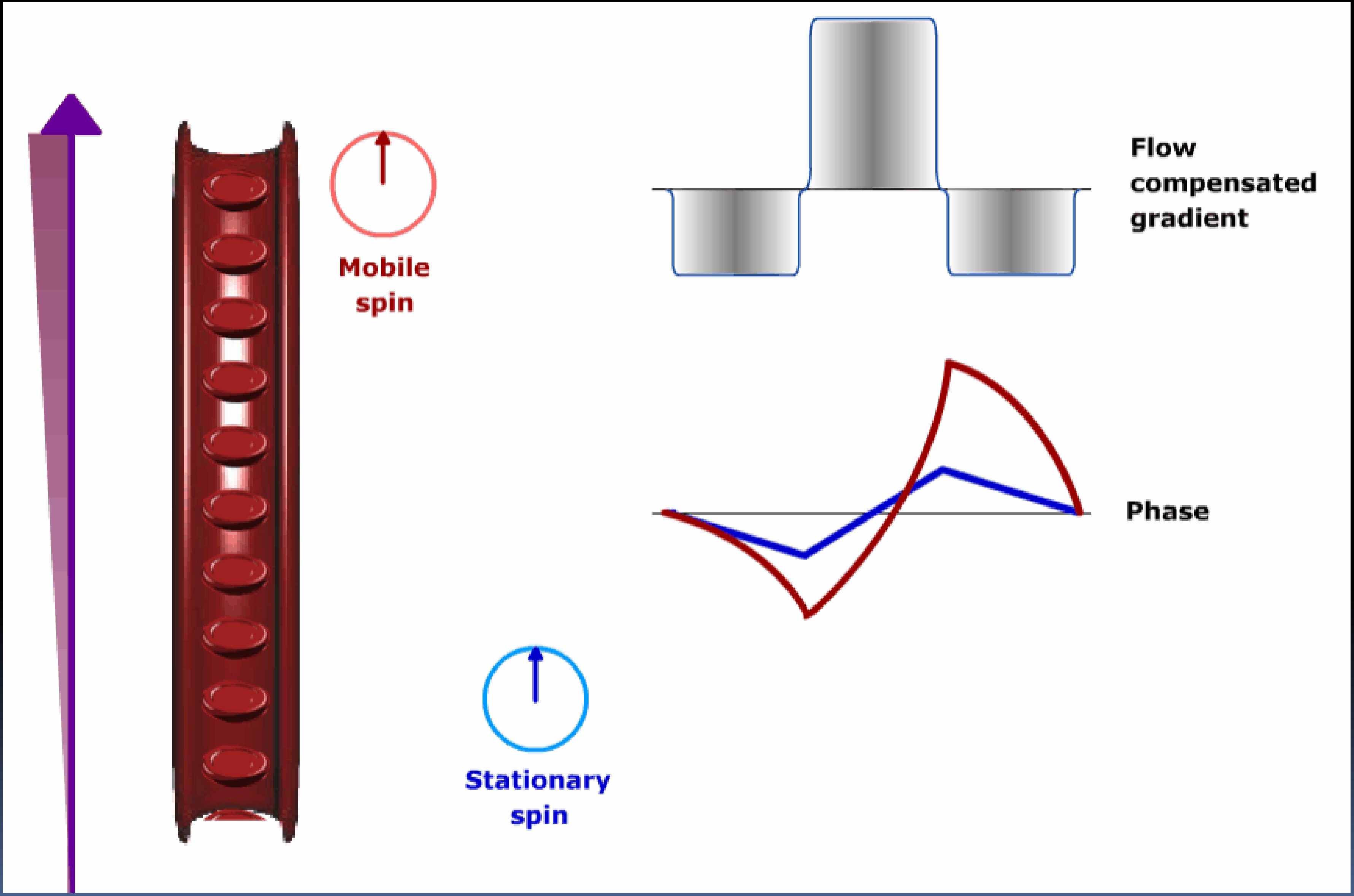

Without respiratory compensation
With respiratory phase reordering

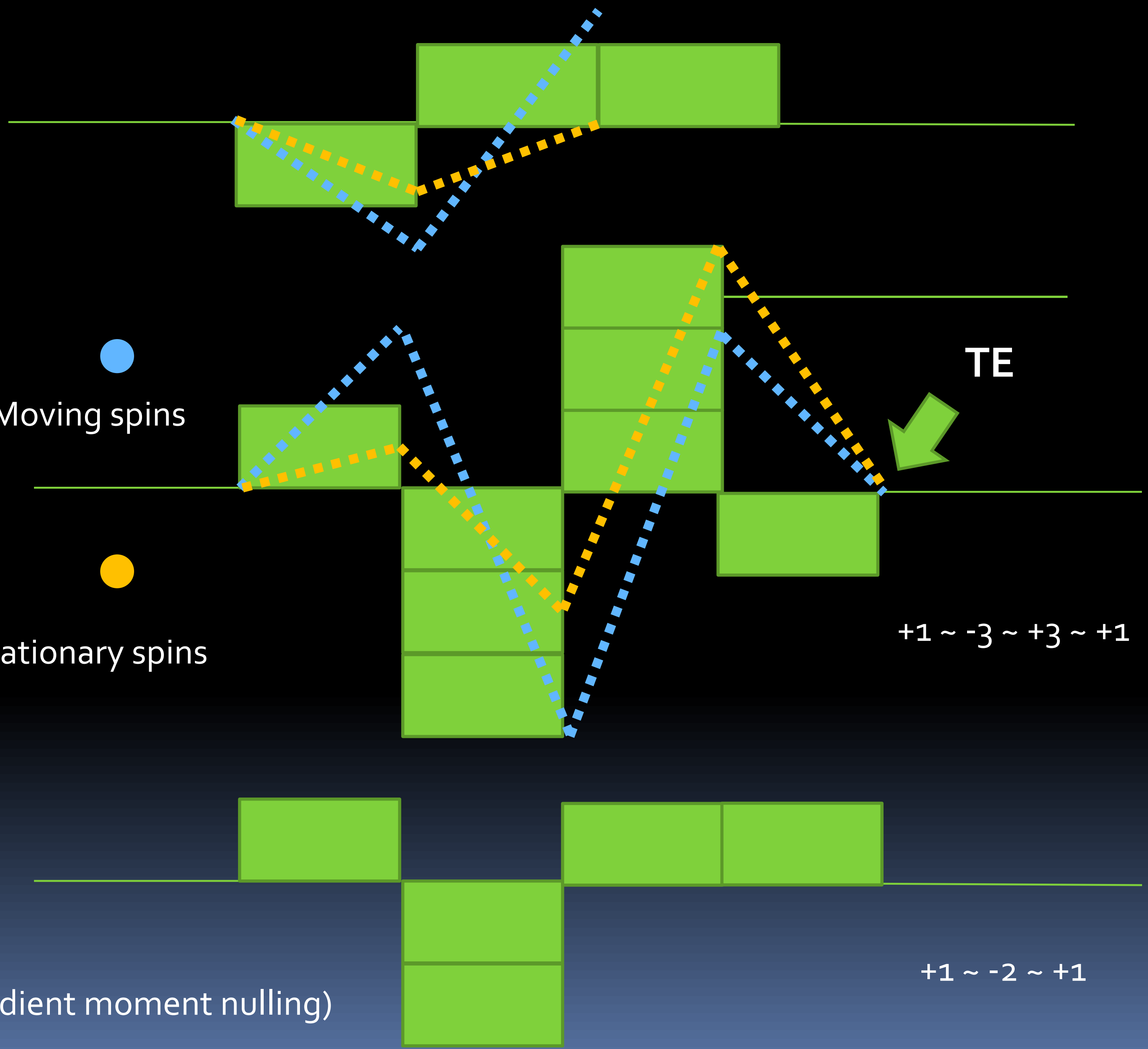
Navigator echo



Placement of the navigator section for respiratory motion compensation.

Flow compensation(Gradient moment nulling)

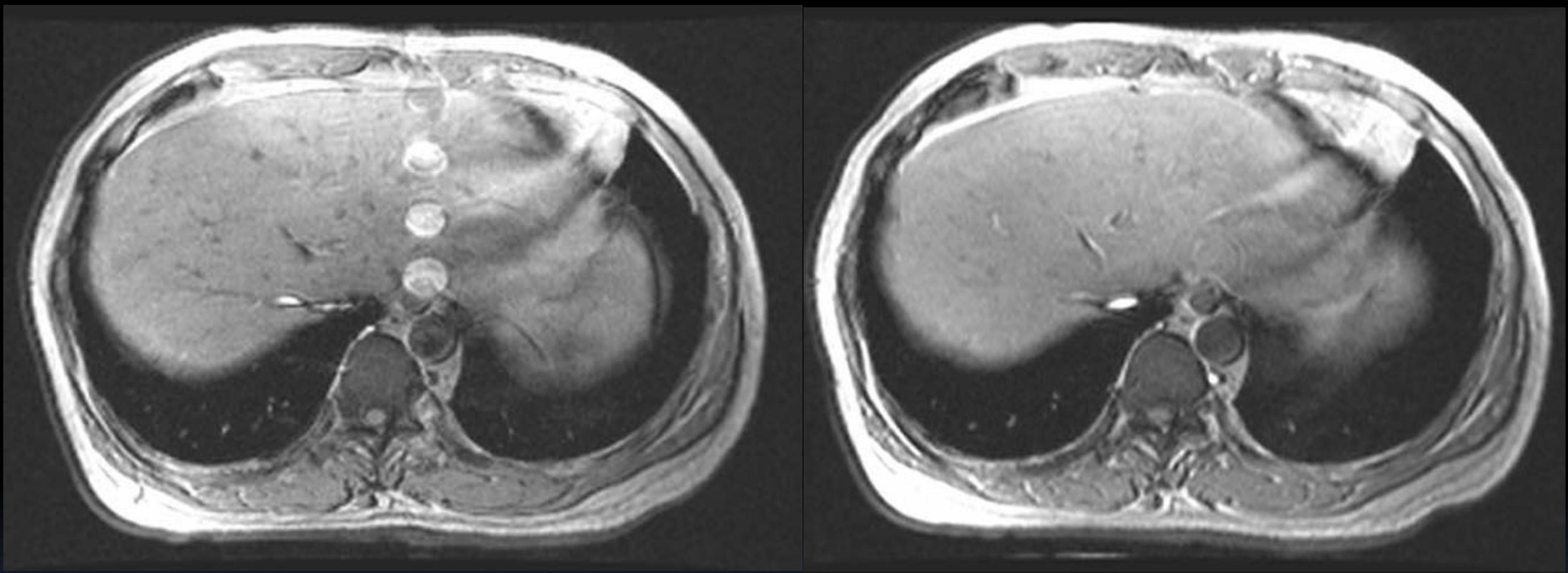




Moving spins

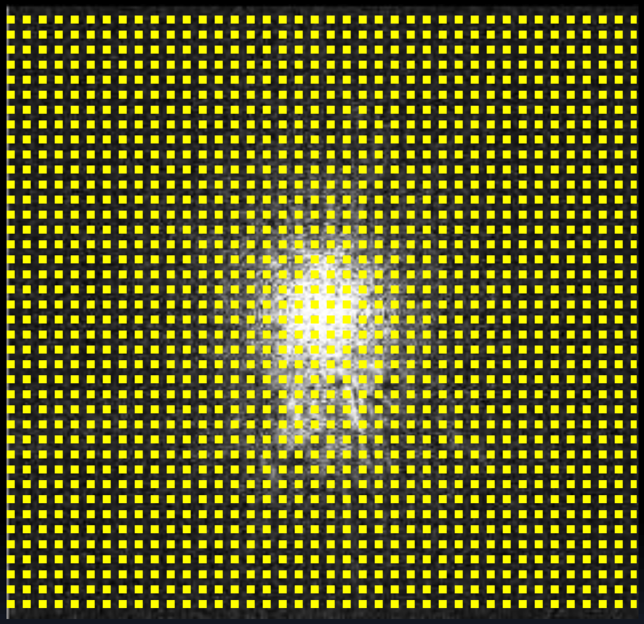
Stationary spins

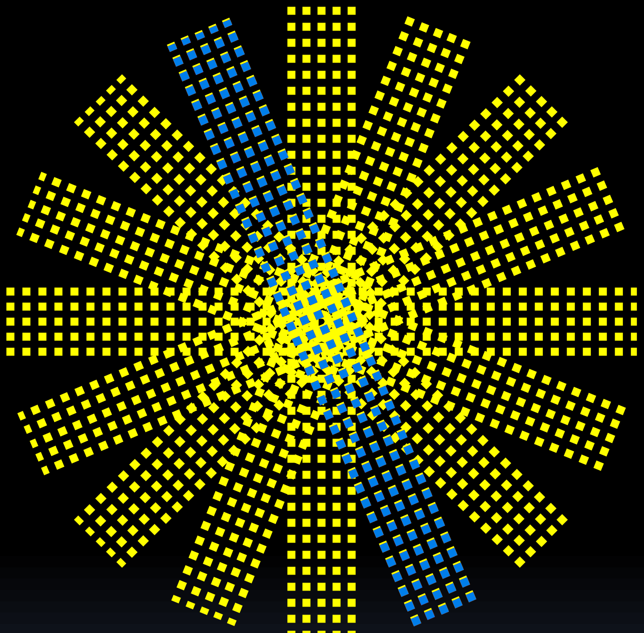
Gradient moment nulling)



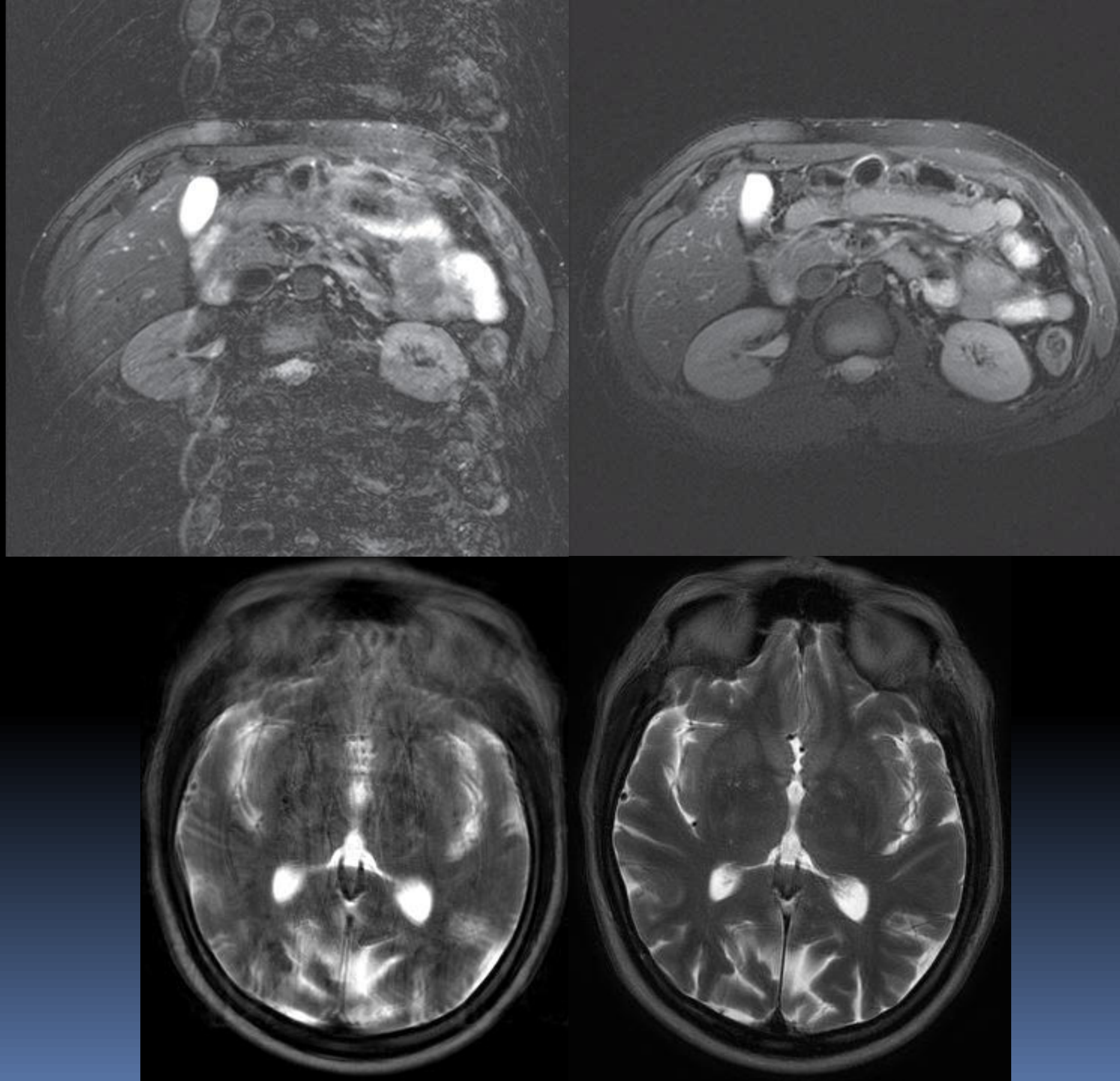
Control of flow-related artifacts. (a) Image shows a cardiac pulsation artifact. (b) and with first-order motion compensation

Propeller



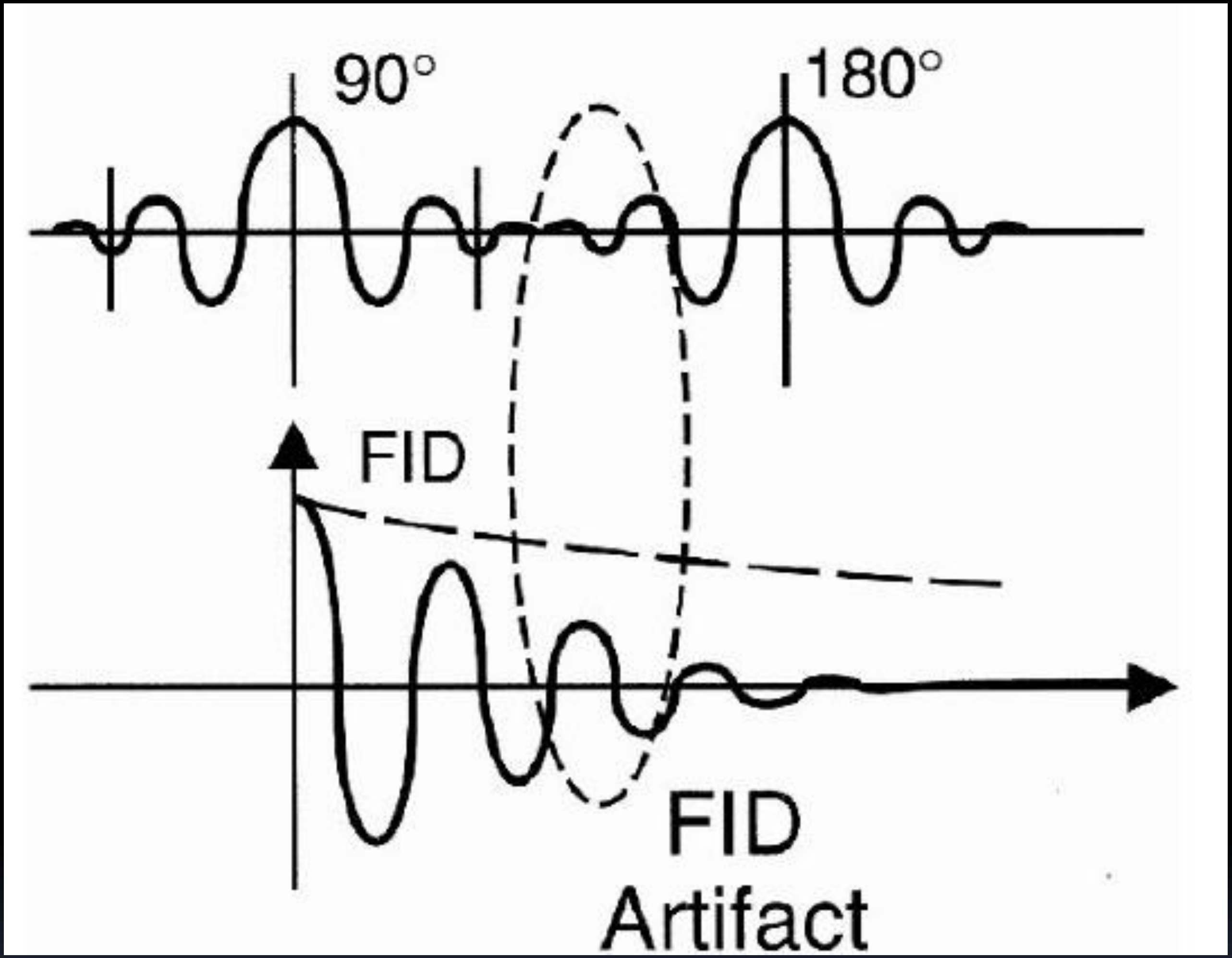


GE (***PROPELLER***)
Siemens (***BLADE***)
Philips (***MulitVane***)
Hitachi (***RADAR***)
Toshiba (***JET***)

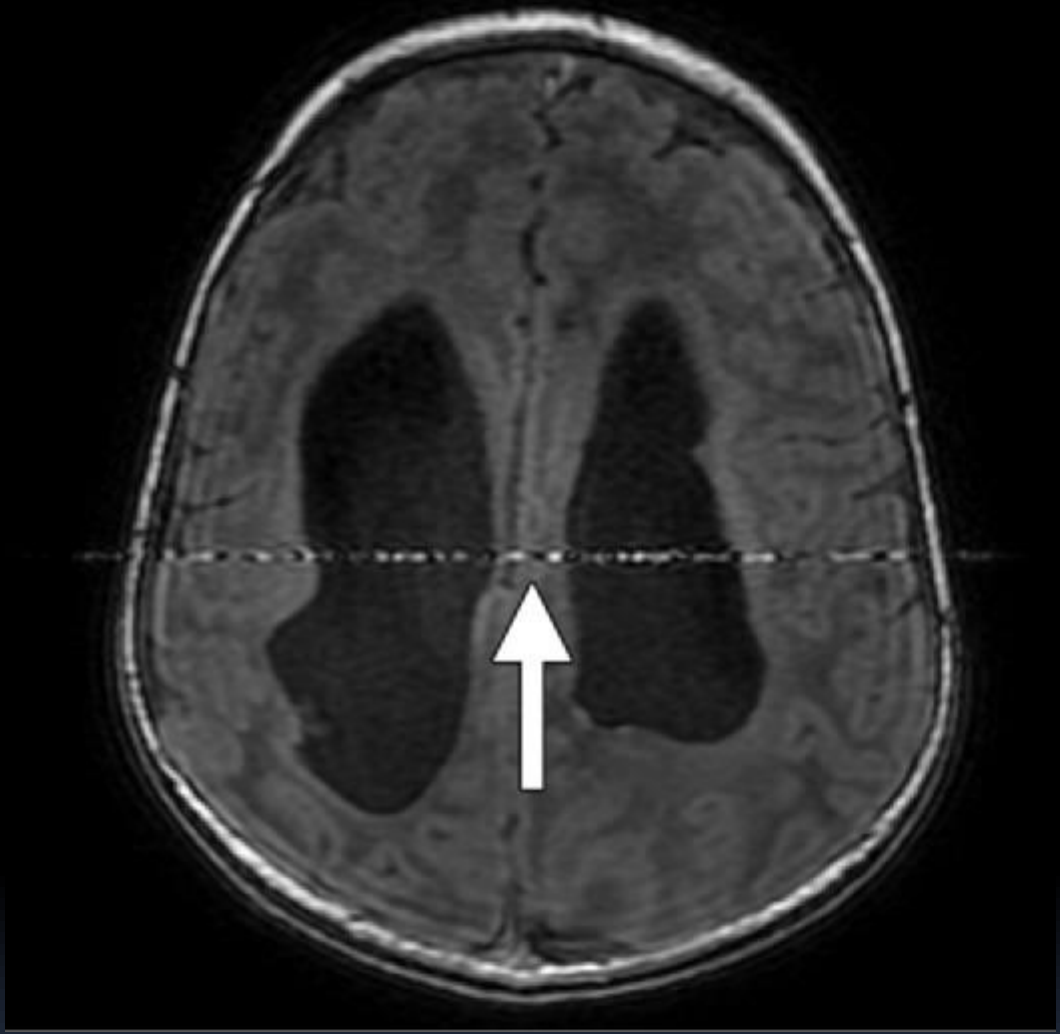


RF Zipper Artifact

- This artifact is one form of central artifacts .They are referred to as zippers due to the formation of a central stripe of alternating bright and dark spots along the frequency-encode axis (at zero phase)



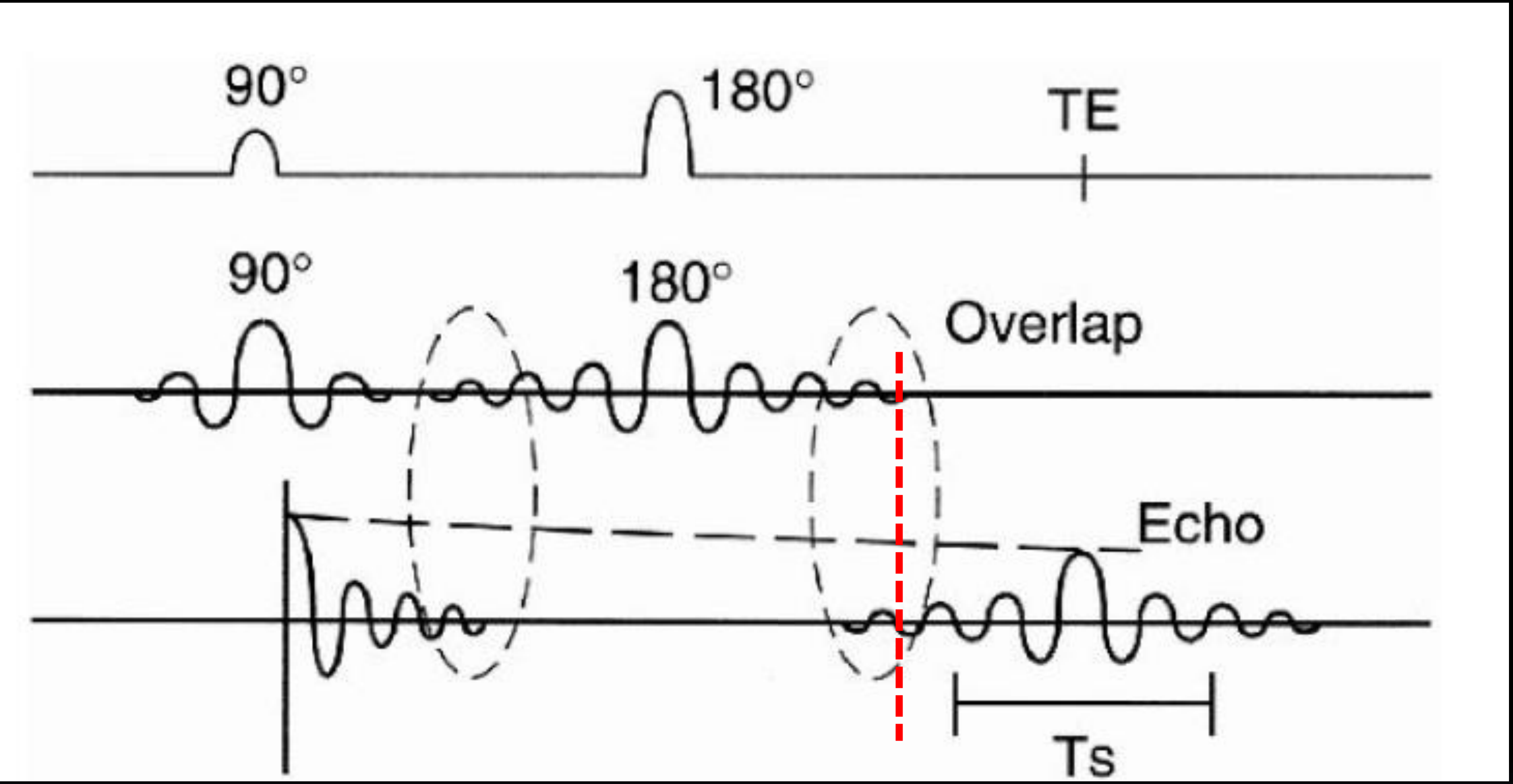
FID artifact. The side lobes of the 180° and the FID may overlap, causing a zipper artifact at zero frequency along the phase direction.



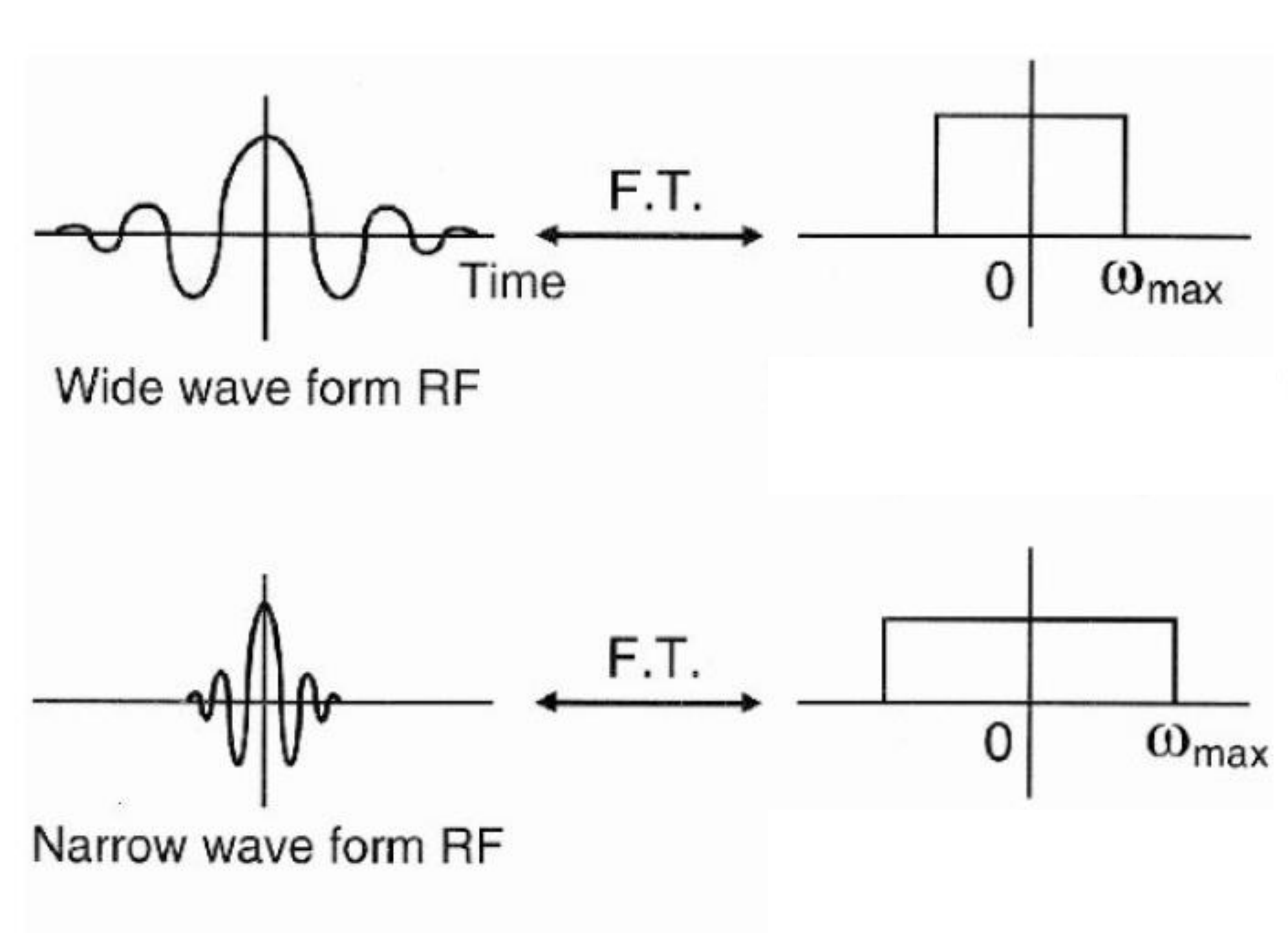
Axial T1-weighted parallel MR calibration image shows a zipper artifact (arrow) with frequency encoding along the anterior-posterior axis.

Remedies

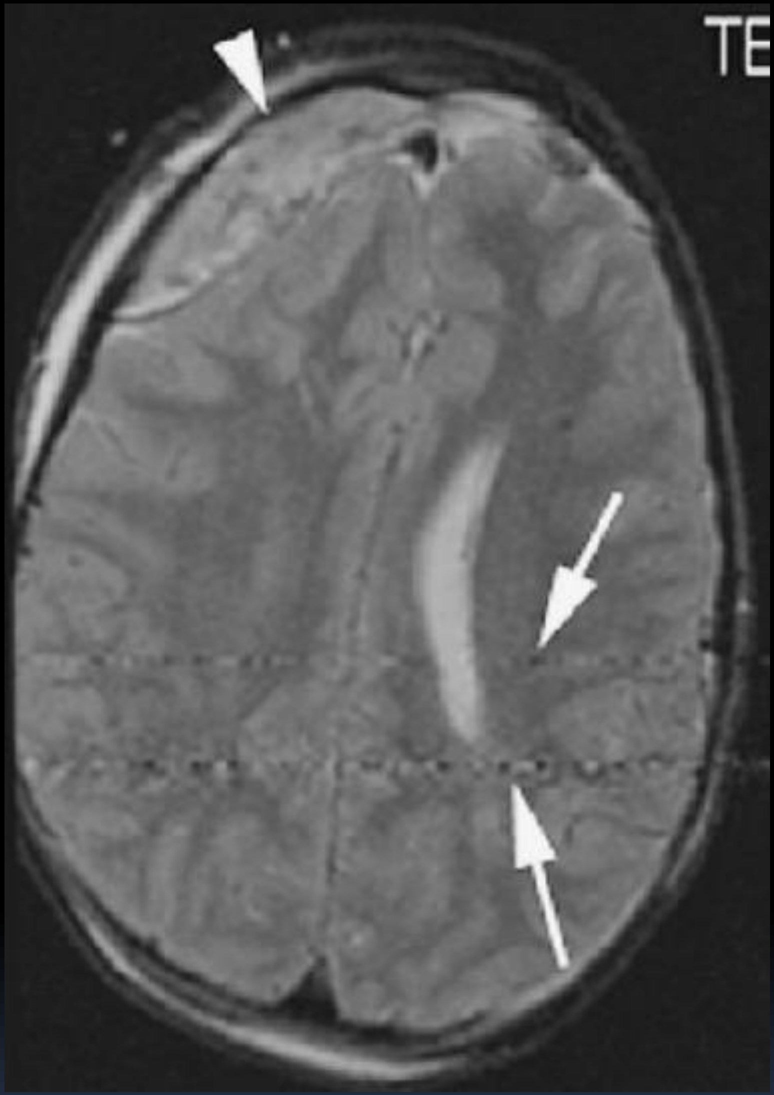
- Increase the TE (increases the separation between the FID and the 180° RF pulse).
- Increase slice thickness (oz). This in effect results from selecting a wide RF BW, which narrows the RF signal in the time domain, thus lowering chances for overlap.



To avoid overlapping of the FID and the side lobes of the 180° pulse, you need to increase TE. This increase is one cause of lengthening the minimum TE.



Bandwidth = range of frequencies (determines the slice thickness) If we have a narrower signal, we get a wider frequency bandwidth



Axial T2 image shows RF noise (arrows) from monitoring devices in this recent postoperative patient. There is also an epidural hematoma (arrowhead).

Remedies

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

Magnetic Susceptibility Artifacts

- Diamagnetic substances

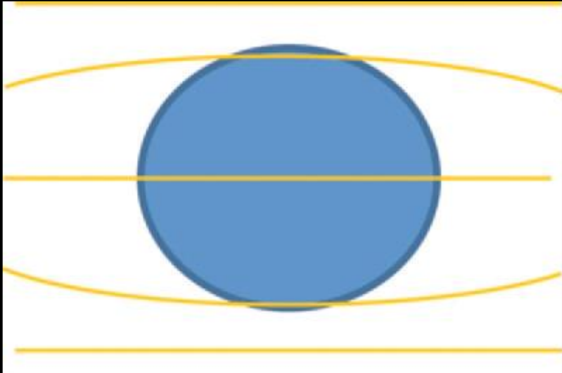
  with no unpaired electrons have negative magnetic susceptibility

- Paramagnetic substances

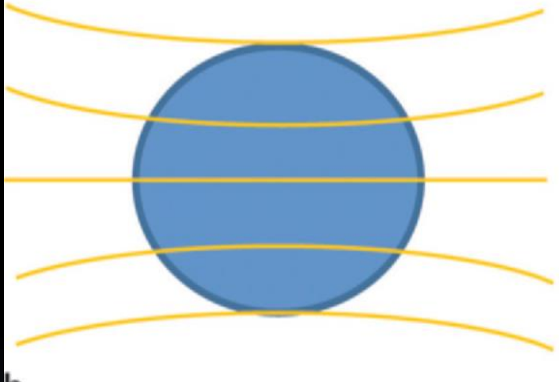
  contain unpaired electrons, have a small positive and are weakly attracted by the external magnetic field

  Gadolinium(Gd)

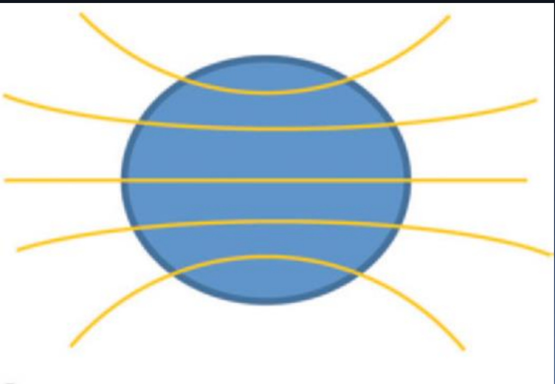
- Ferromagnetic substances



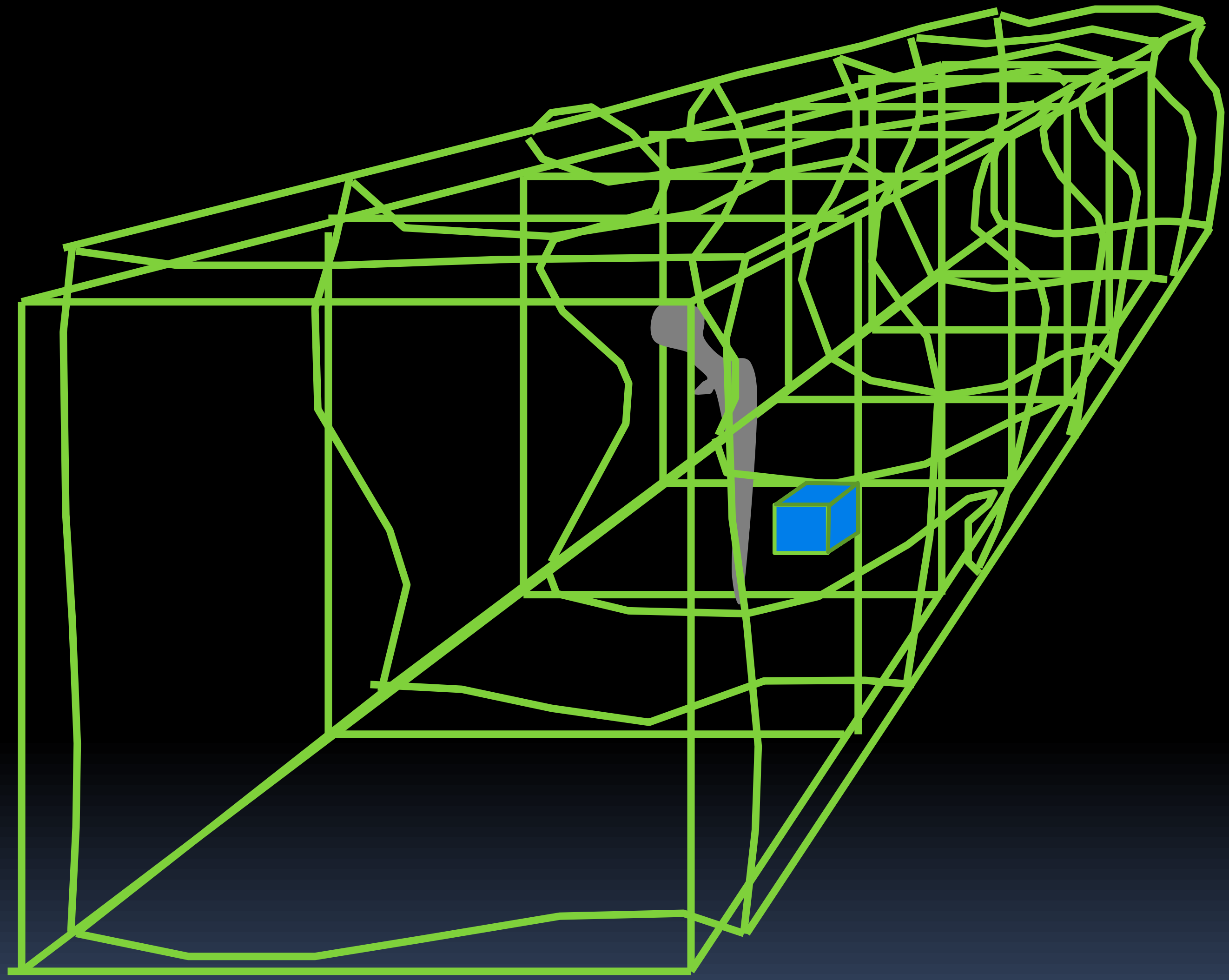
a.



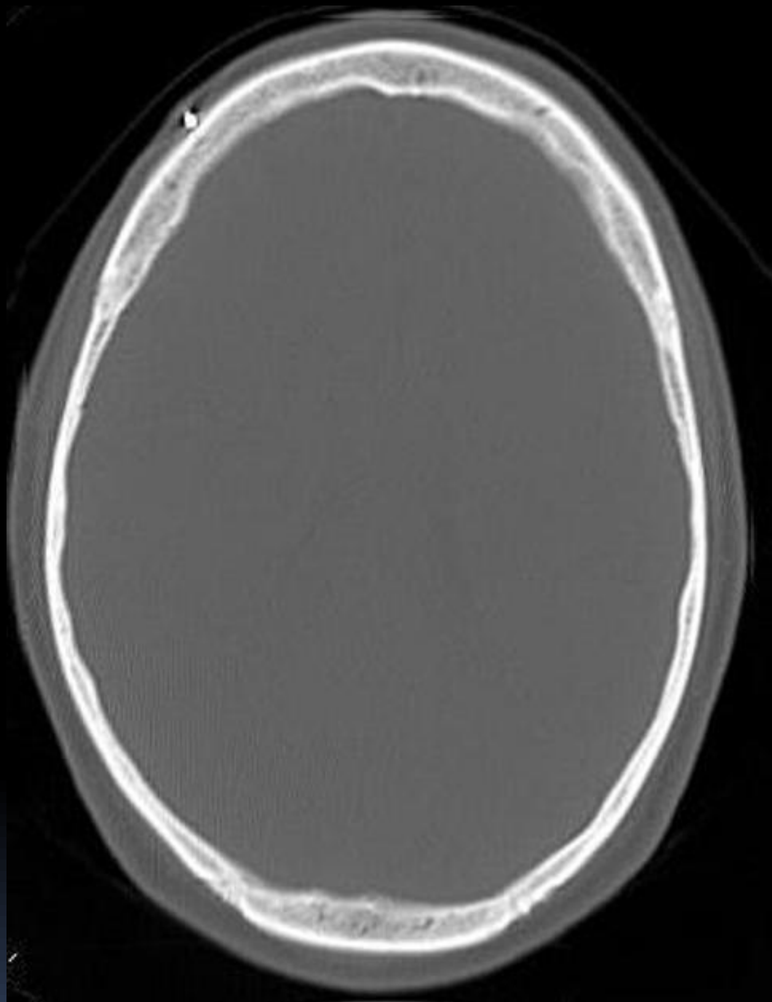
b.

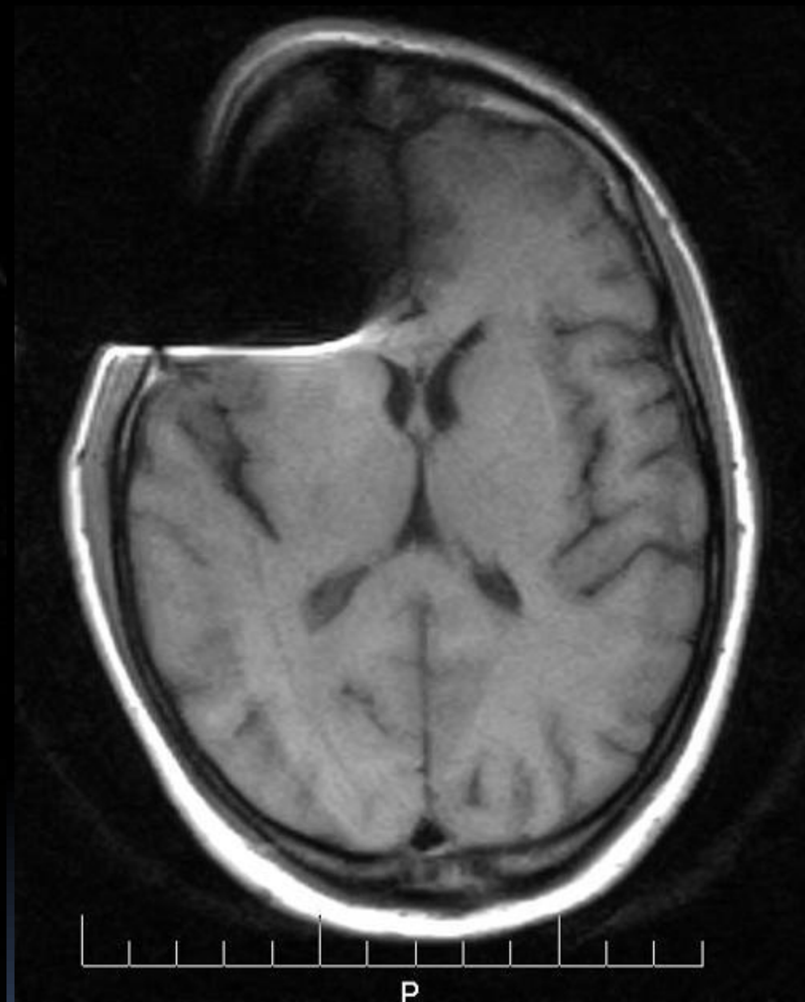


c.



$$\text{Susceptibility Artifact Size} \propto \frac{(\Delta\ \text{Susceptibility}) \cdot B_o \cdot TE}{\text{Bandwidth}}$$




P

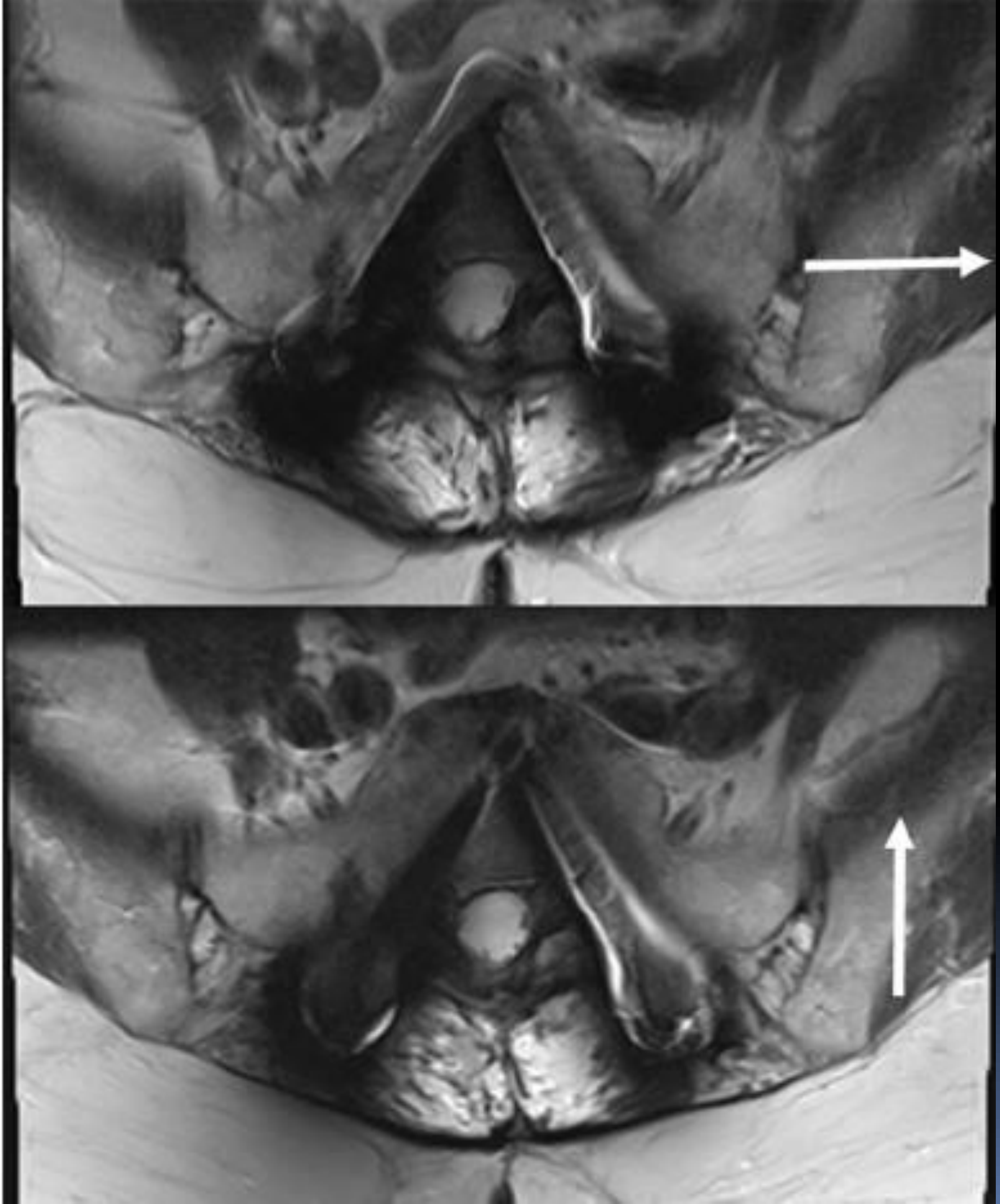
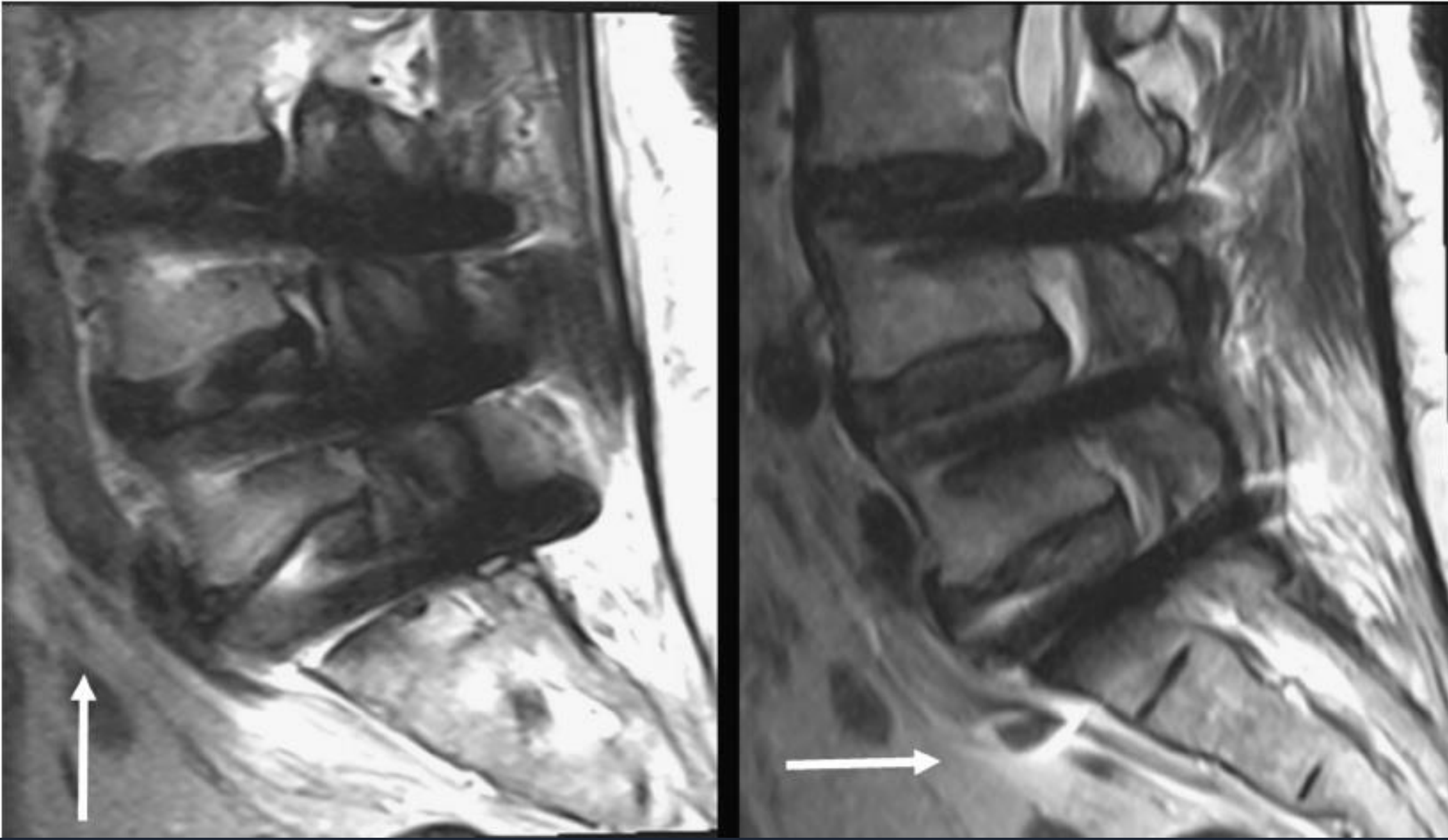
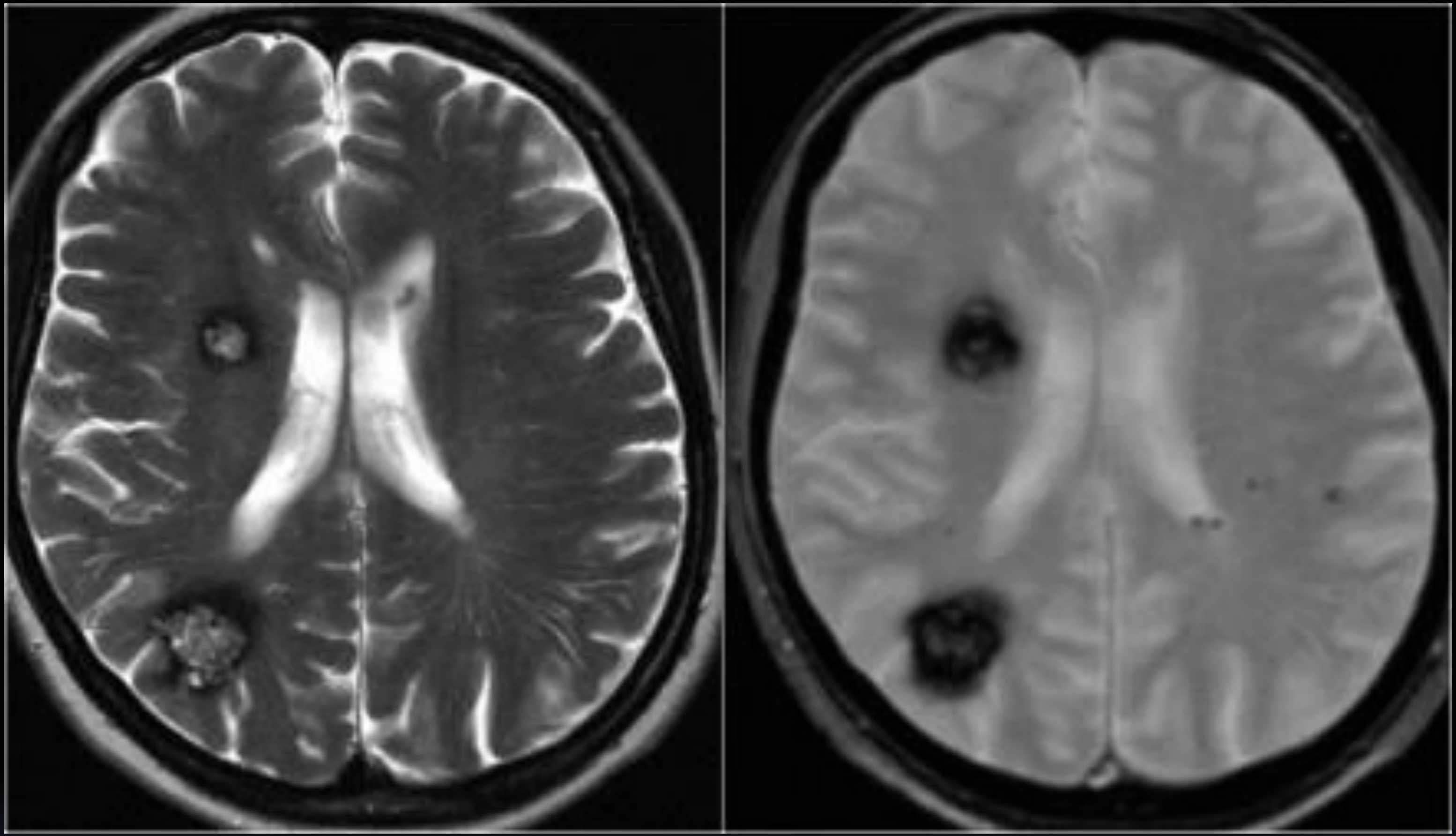


Fig. 14. Effect of frequency encoding direction. Note the more discrete appearance of the screws with the frequency encoding A-P (bottom) compared with right to left (RL) (top).

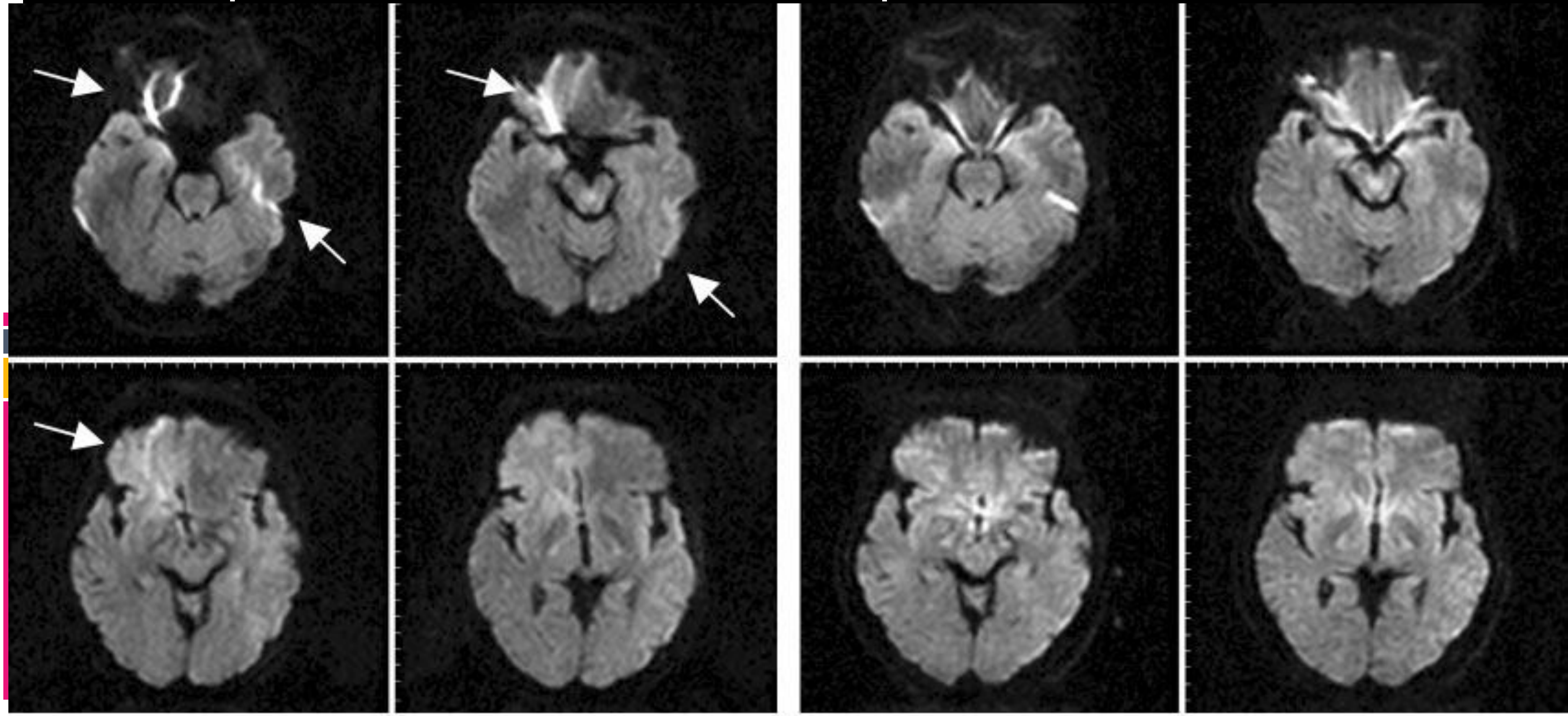


Effect of frequency encoding direction. Note the more discrete appearance of the screws with the frequency encoding A-P (right) compared with superior inferior (SI) (left).



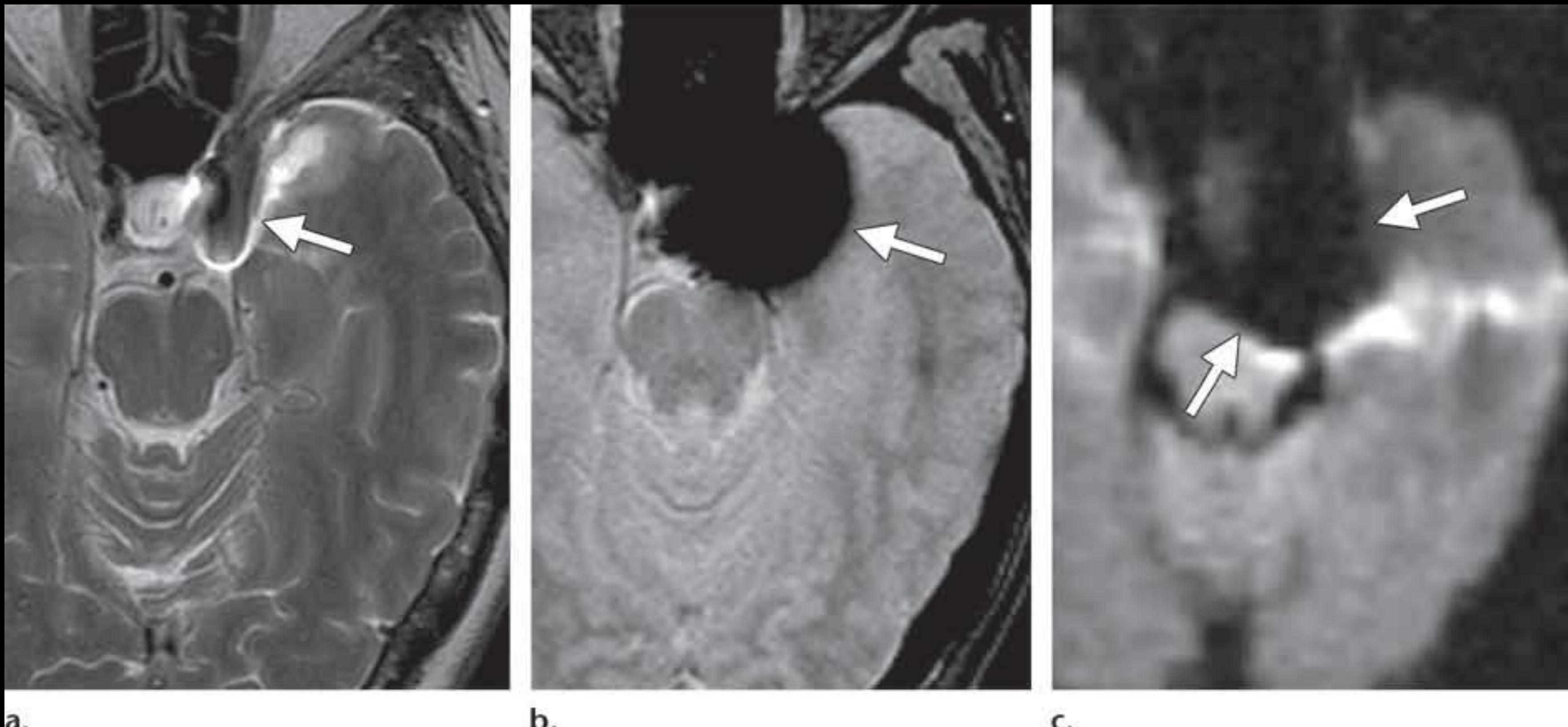
T2WI and T2* gradient echo show multiple cavernomas. Notice the popcorn appearance with peripheral rim of hemosiderin on the T2WI

- More subtle susceptibility distortions may be seen at natural interfaces (e.g., trabecular bone, paranasal sinuses, skull base, and sella). The shape (diffuse or focal) and intensity (high or low) of the artifact depend on local anatomic relationships, field strength, difference in susceptibilities, echo time (*TE*) as well as bandwidth (or readout gradient strength and direction) as expressed to the relationship

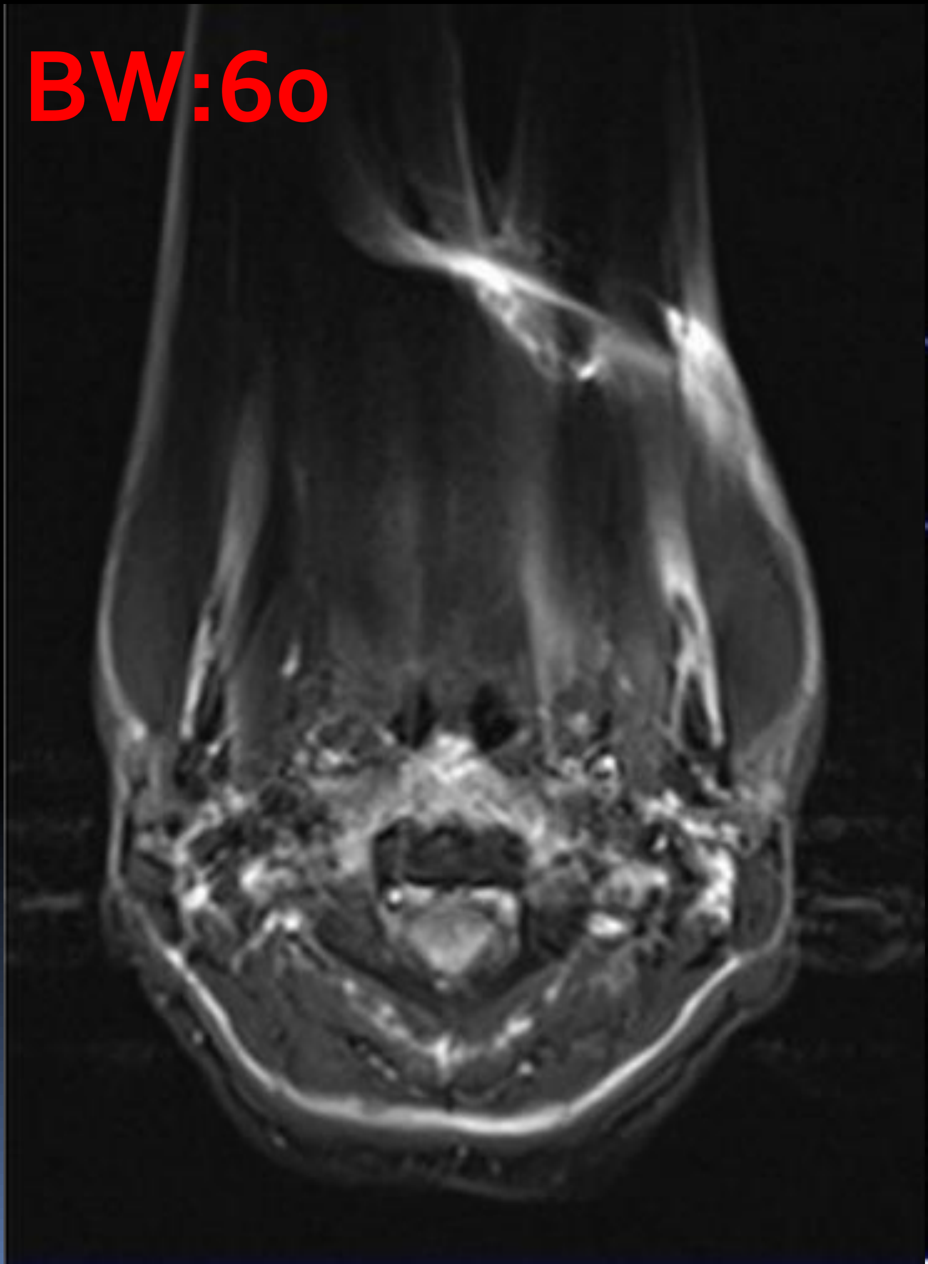


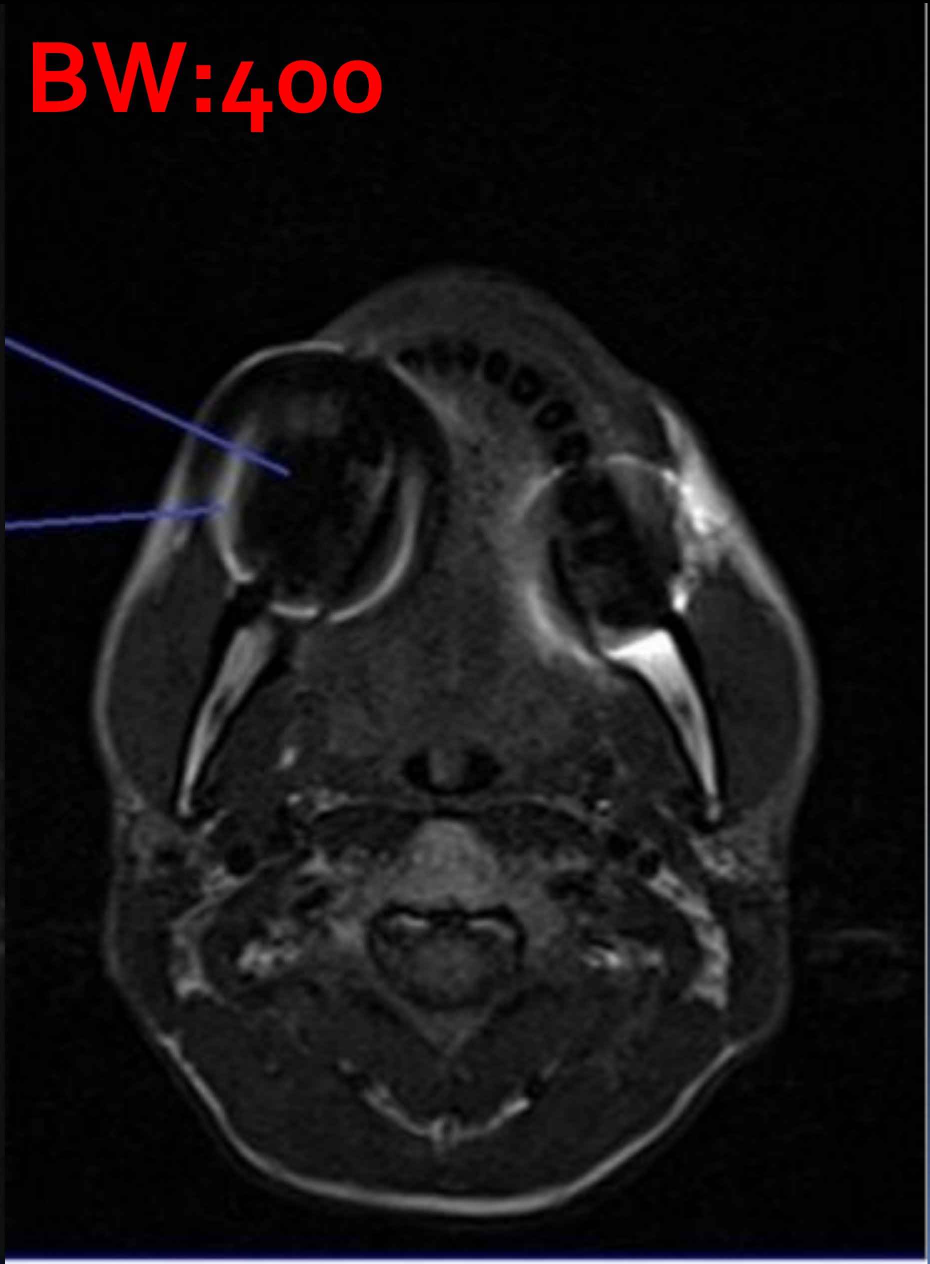
Remedies

- Spin echo sequences are less prone to susceptibility artifacts than gradient echo sequences.
- Swapping the frequency-encode and phase-encode directions
- Short TE allows less time for dephasing and reduces signal loss.
- A large receiver bandwidth (strong gradients) shortens the minimal TE available
- Commerical software : VAT SEMAC MAVRIC

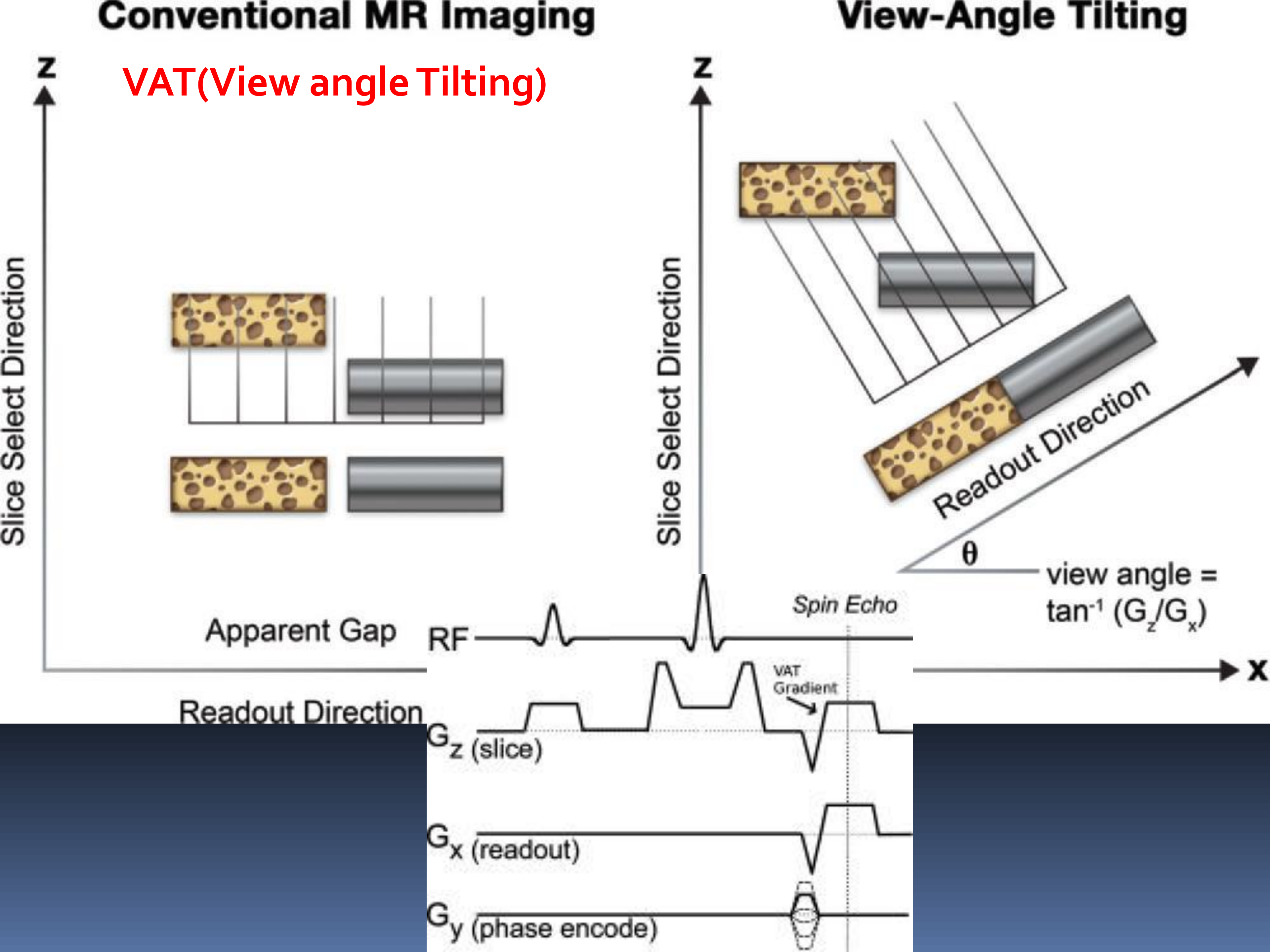


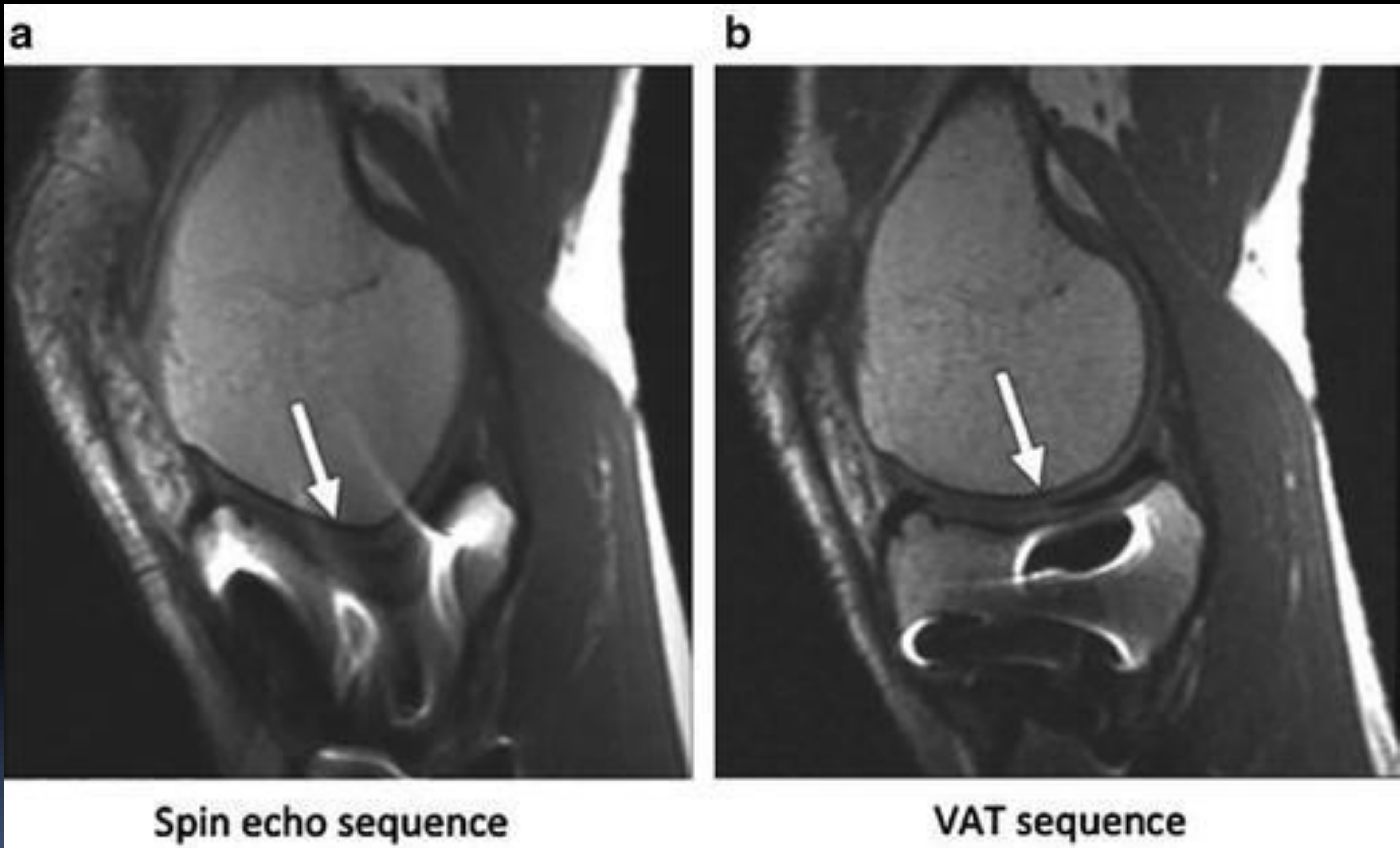
a nonferromagnetic object. (a) T2-weighted turbo spin-echo image of the brain demonstrates a minor artifact resulting from an aneurysm clip (arrow) made of a nonferromagnetic material (titanium). Because of the 180° refocusing pulse included in this sequence, the clip is clearly depicted despite the artifact. (b) T2-weighted gradient-echo image, obtained without a refocusing pulse, is more severely degraded by the artifact (arrow) produced by the aneurysm clip. (c) Diffusion-weighted echo-planar image obtained with a parallel imaging technique also exhibits a substantial artifact (arrows).


BW:60

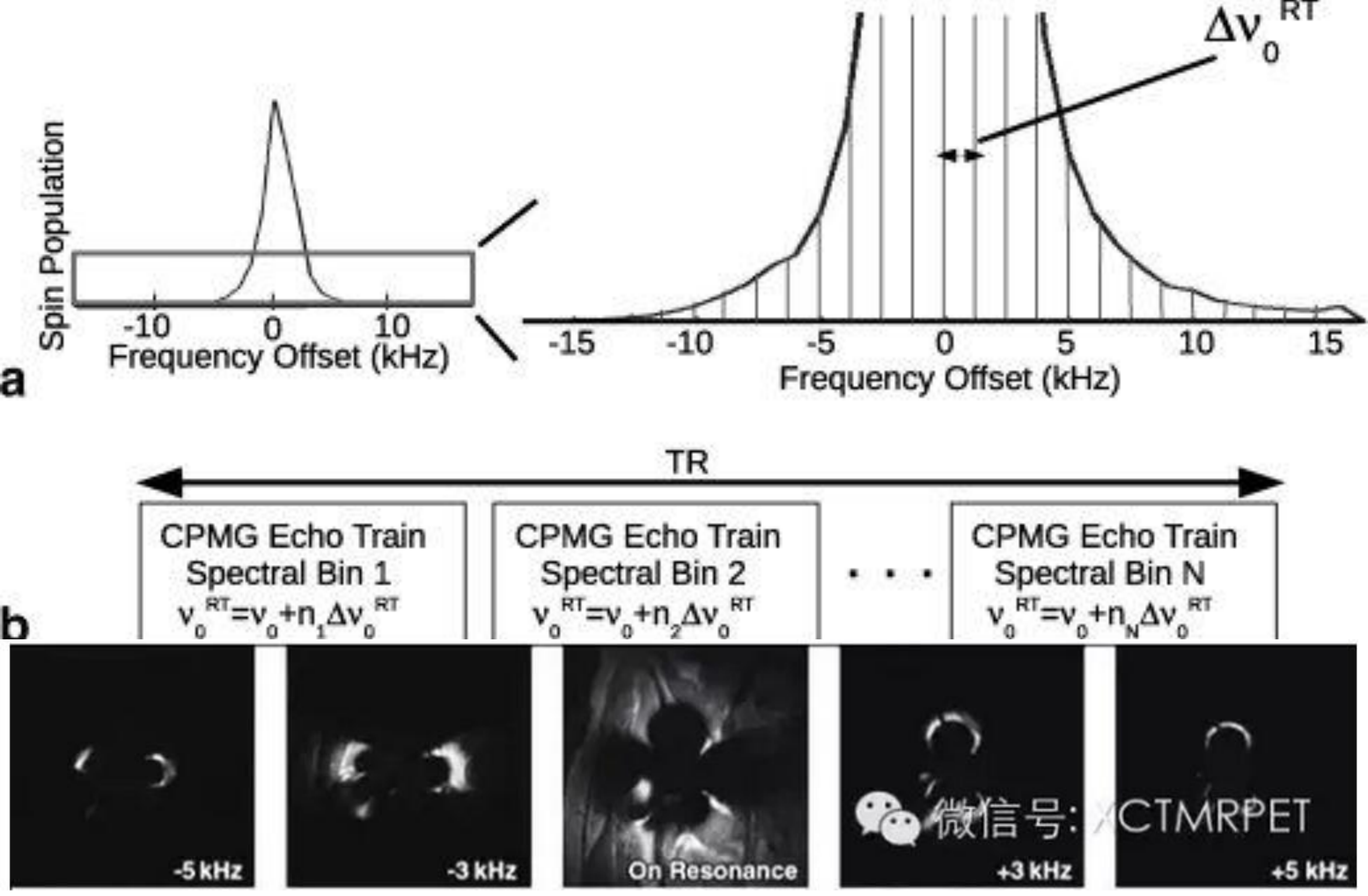

BW:400

VAT(View angle Tilting)

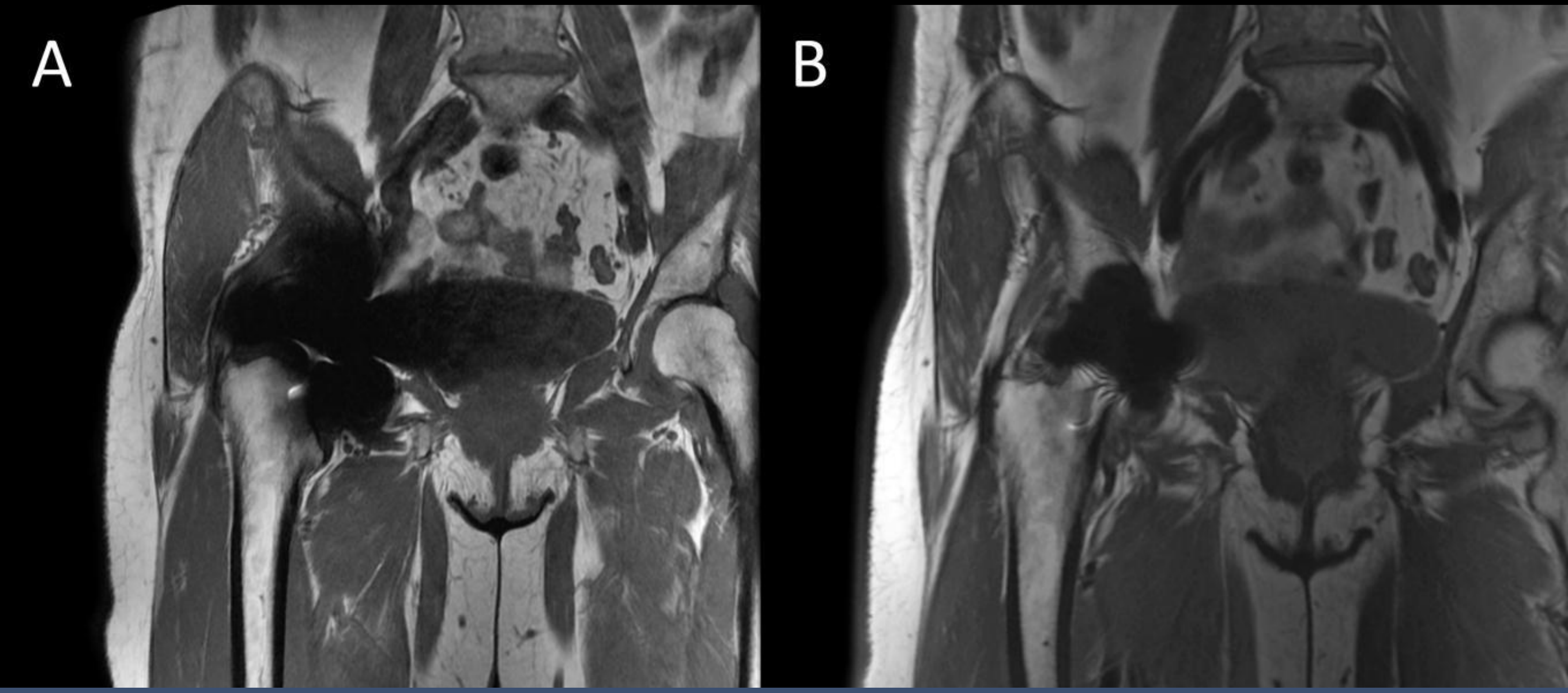



a
b
Spin echo sequence
VAT sequence

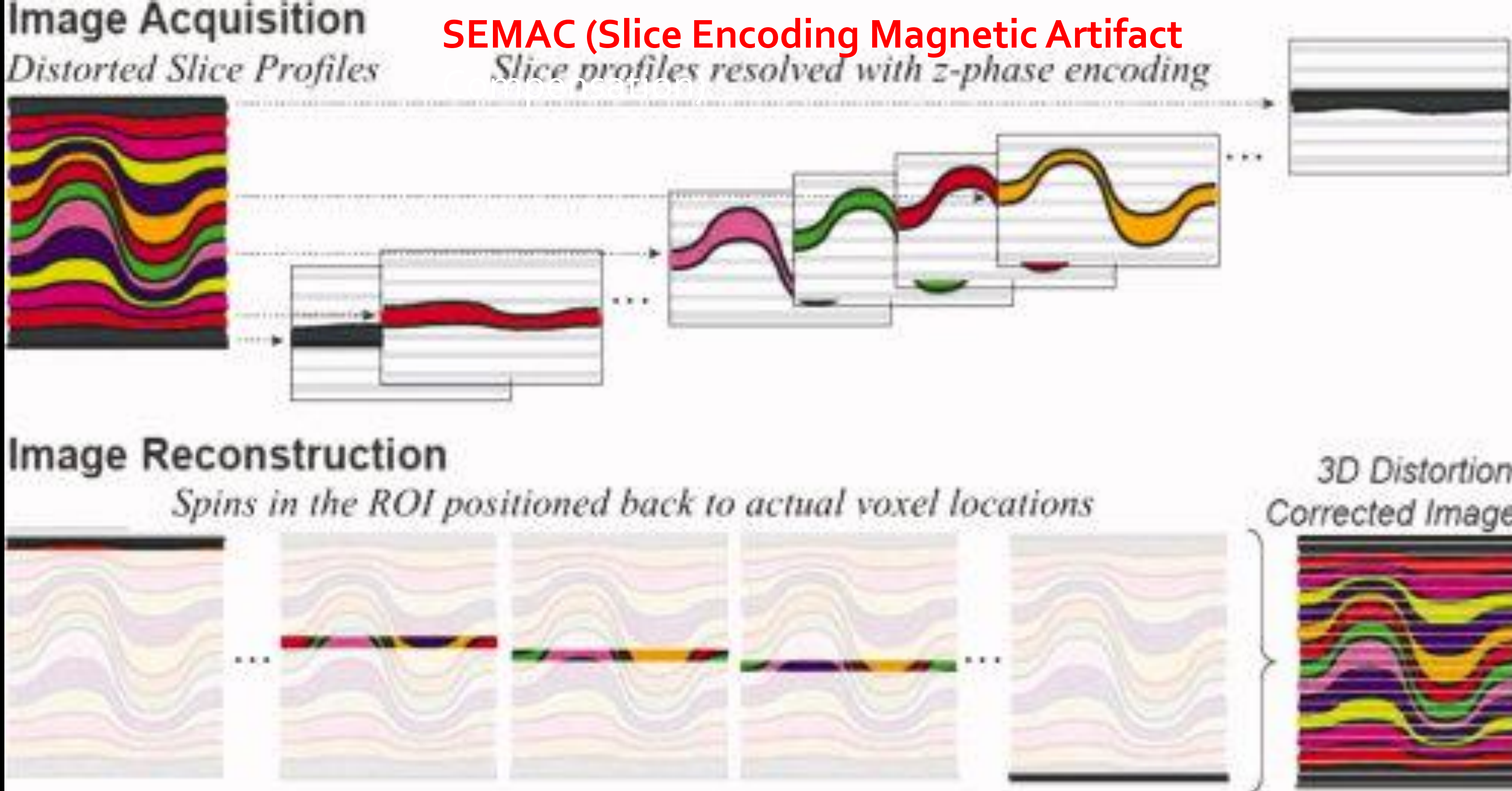
Multiacquisition variable-resonance image combination (MAVRIC)

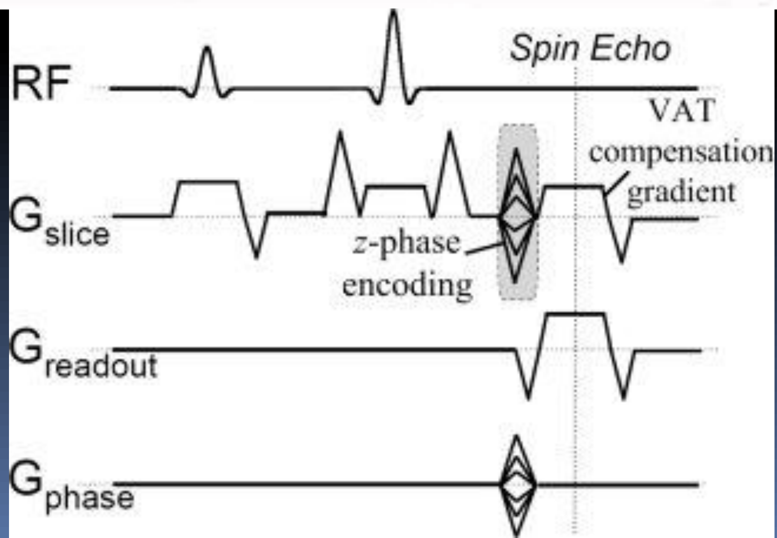


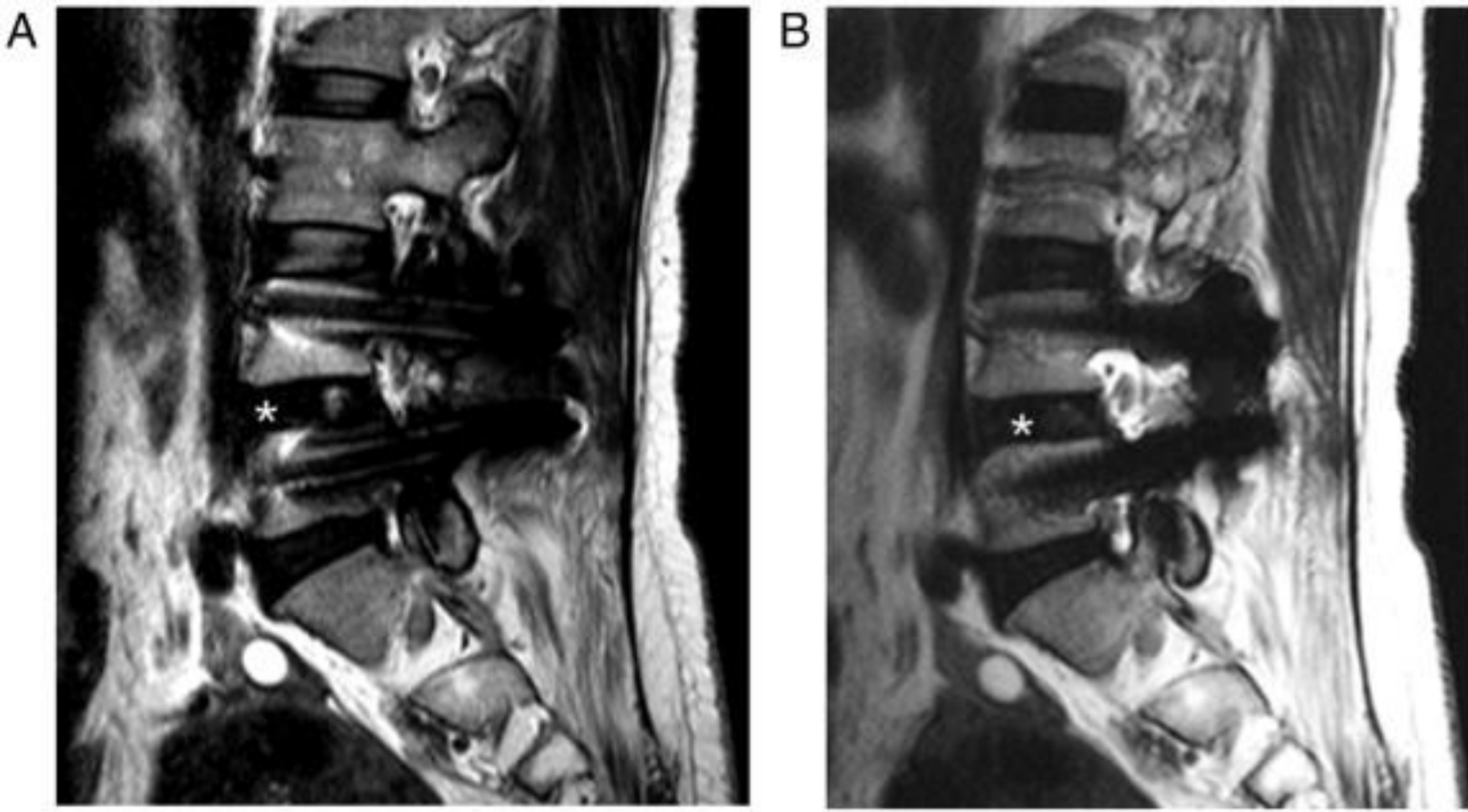
Multiacquisition variable-resonance image combination (MAVRIC)



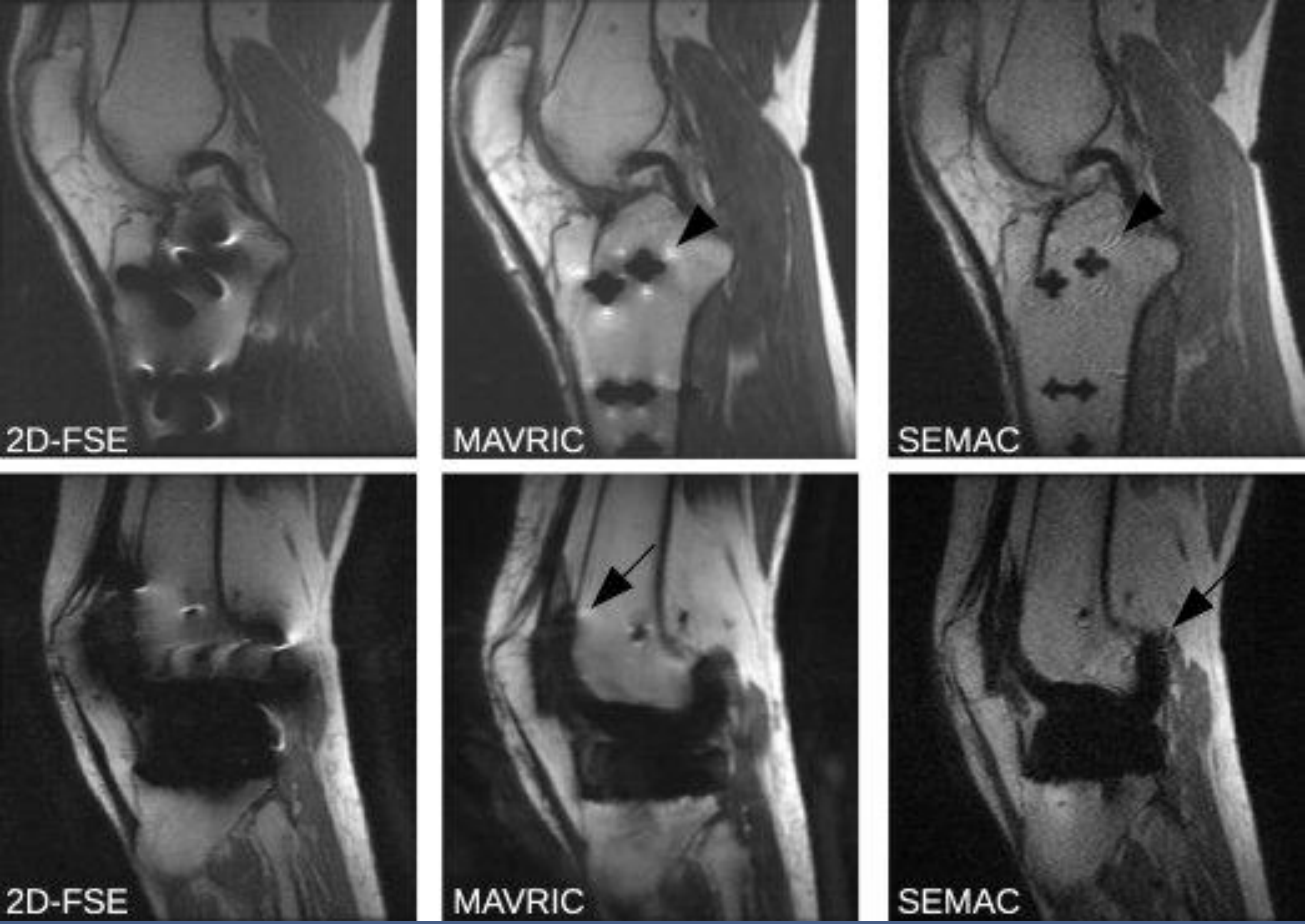
SEMAC (Slice Encoding Magnetic Artifact Compensation)





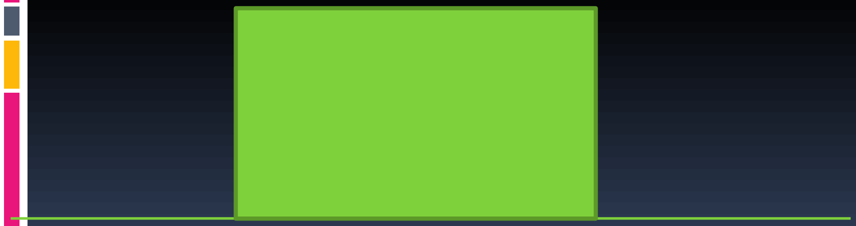


(A) Conventional T2w sagittal image shows metallic artifact around the pedicle screws. (B) SEMAC-corrected image at the same level shows decreased artifacts at the vertebral body, pedicle and neural foramen.

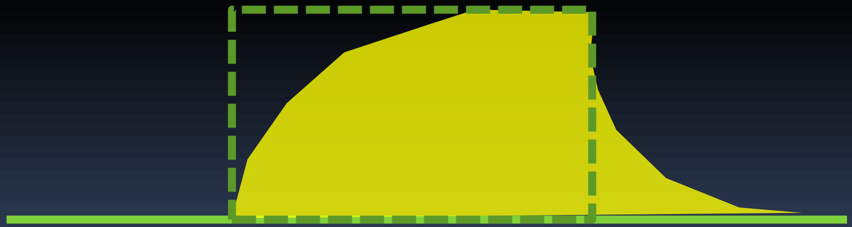

2D-FSE
MAVRIC
SEMAC
2D-FSE
MAVRIC
SEMAC

Gradient-Related Artifacts

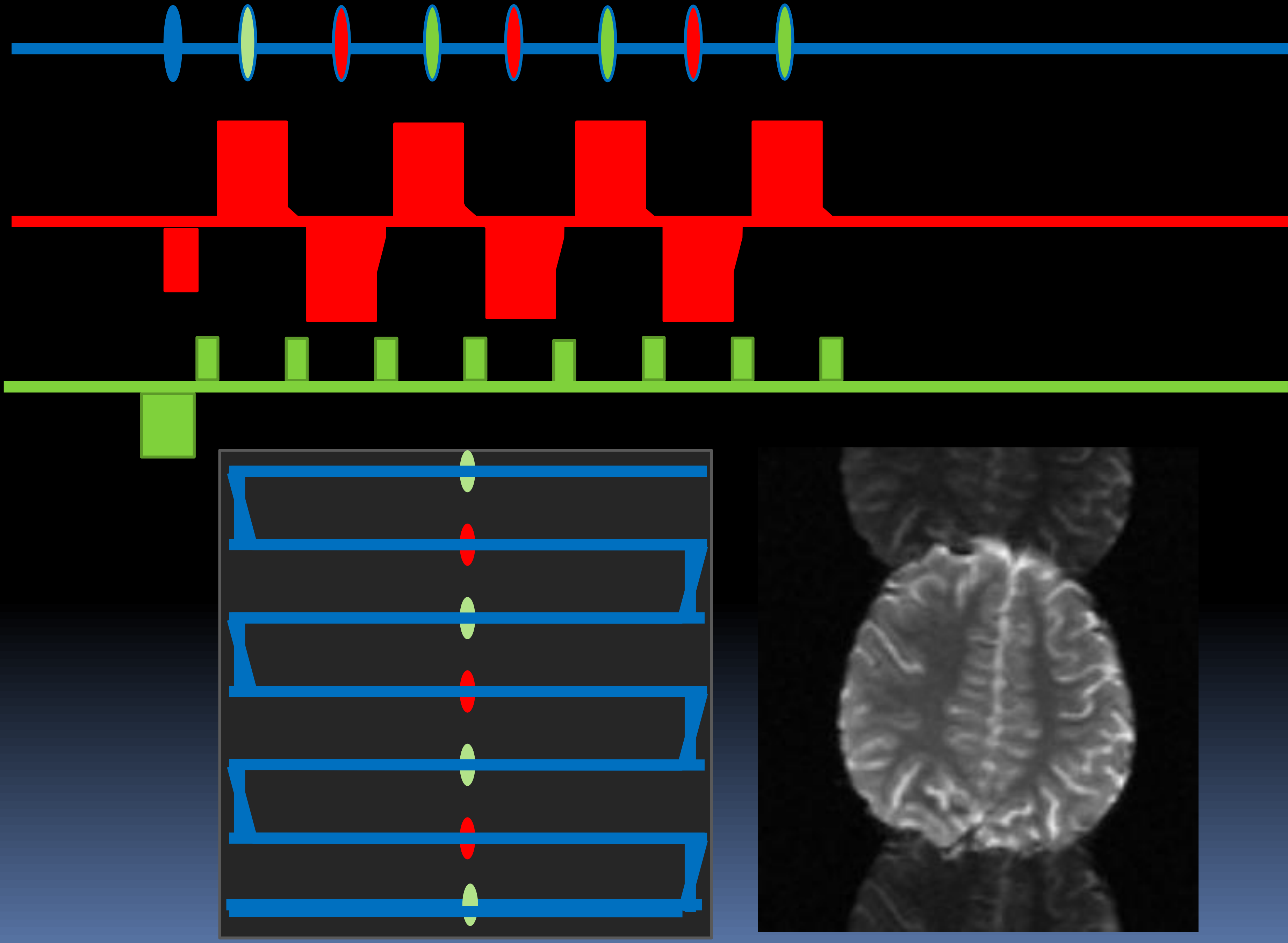
- Eddy currents are small electric currents that are generated when the gradients are rapidly switched on and off (i.e., the resulting sudden rises and falls in the magnetic field produce electric currents).



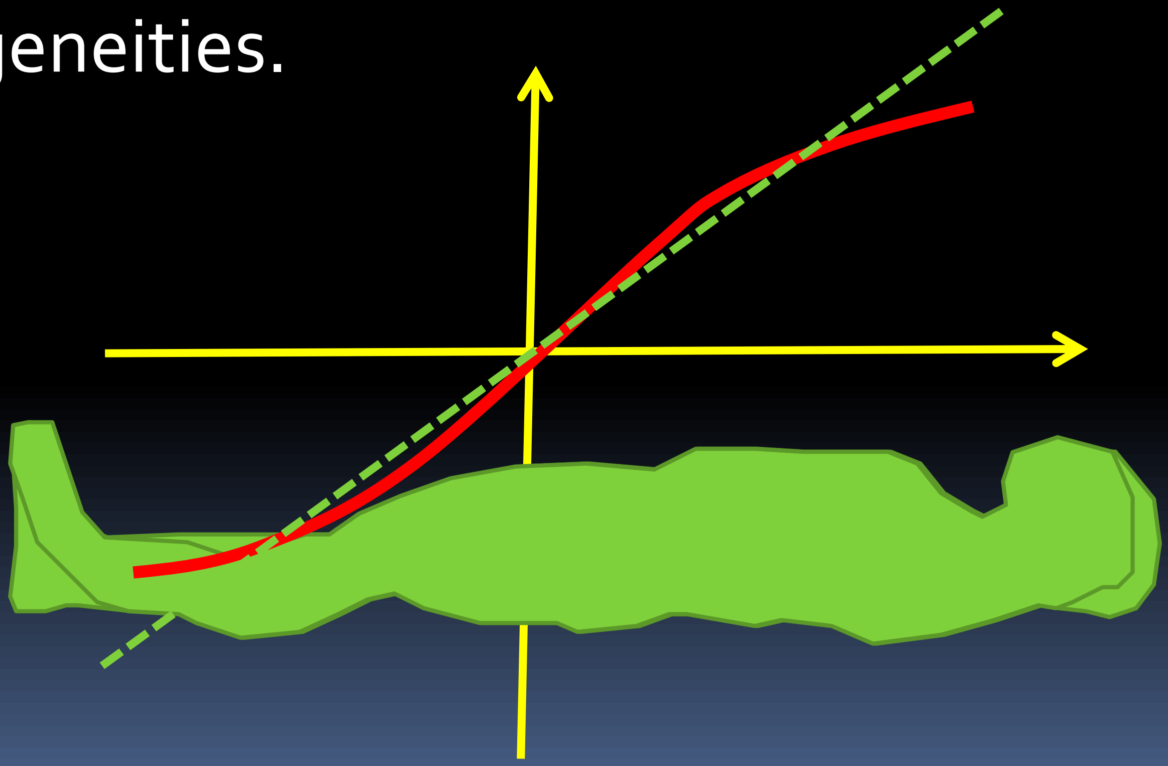
Ideal gradient

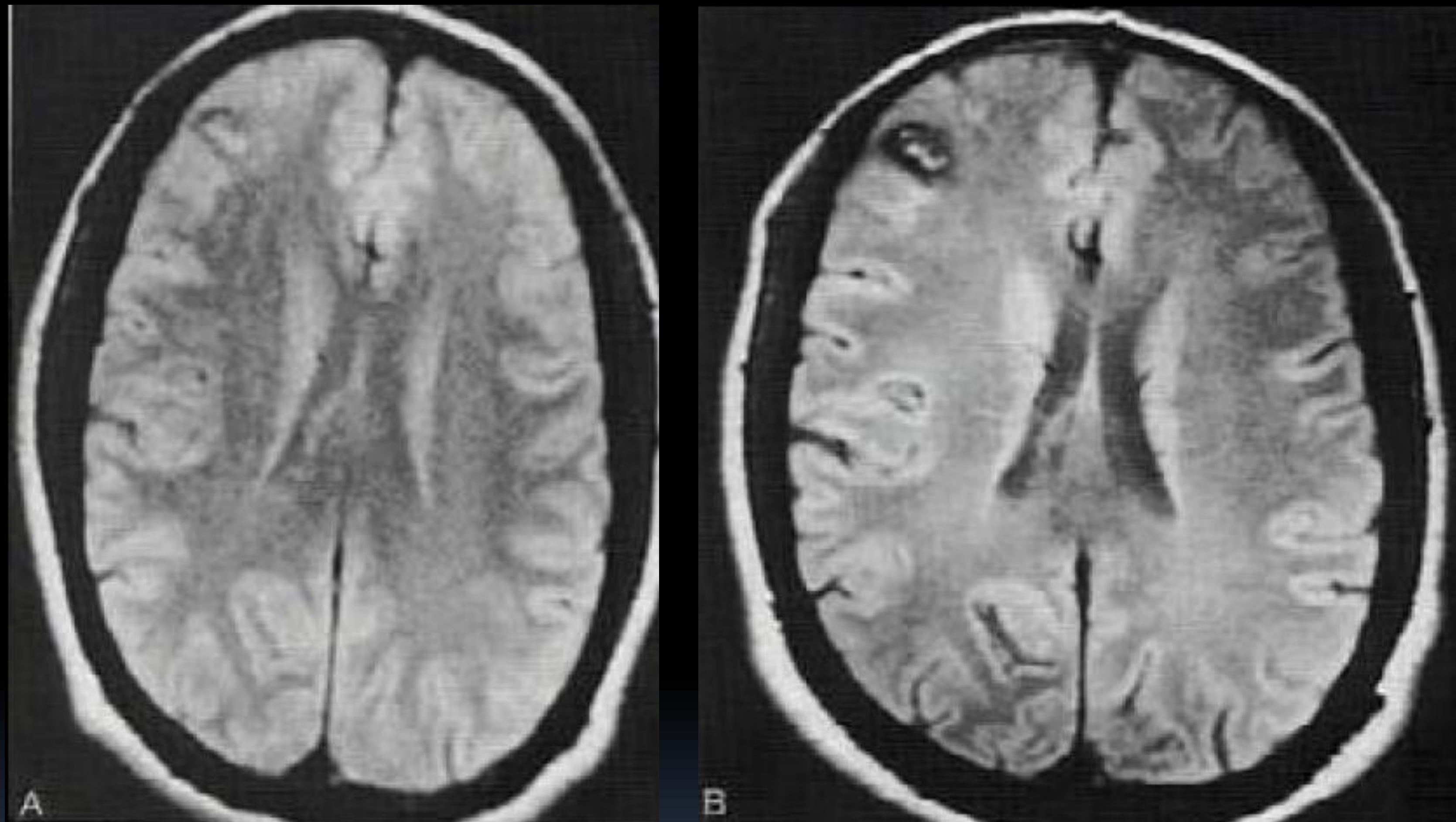


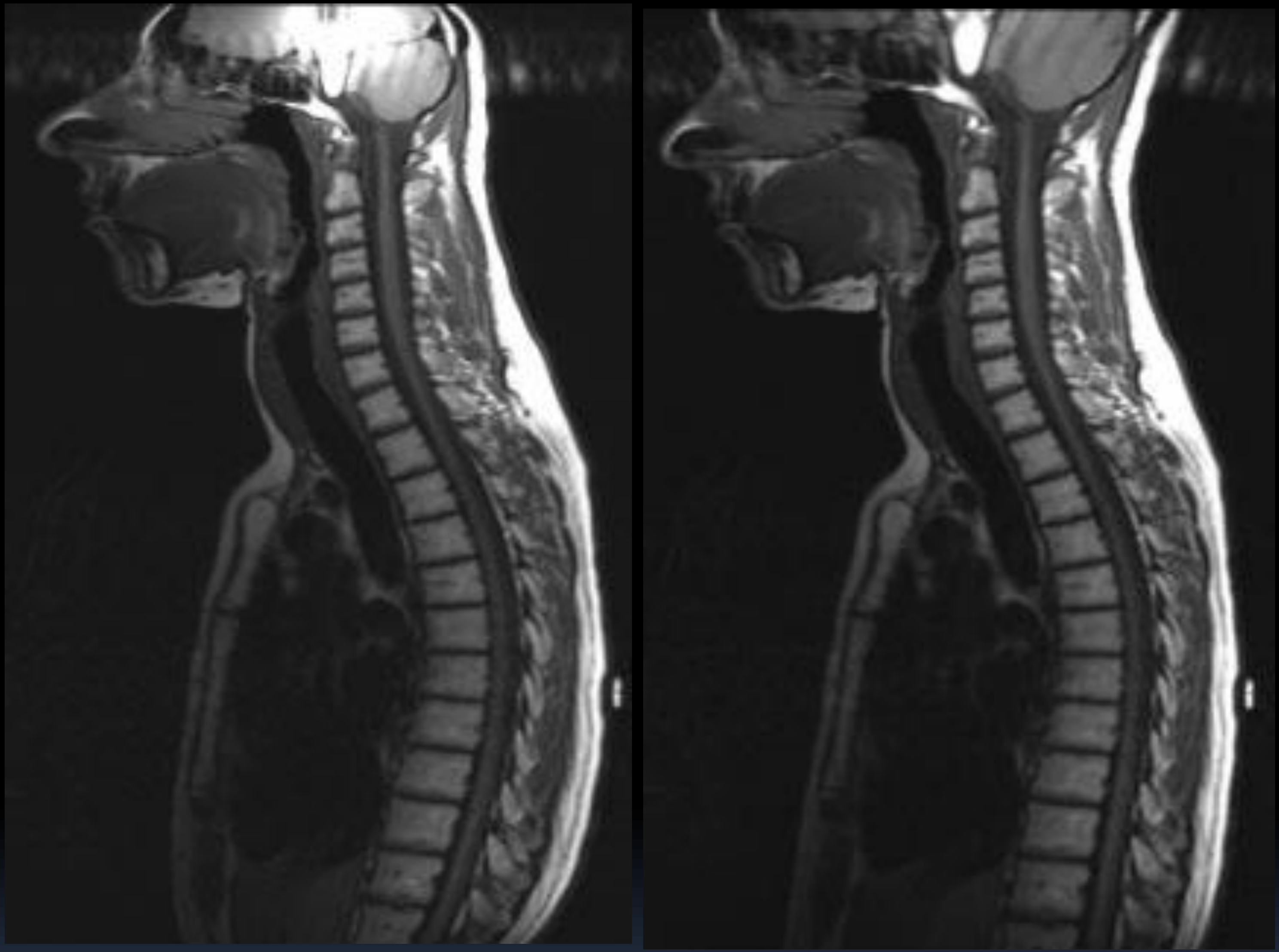
Distorted gradient



- Ideal gradients are linear. However, as in other aspects of life, there is no such thing as an idealgradient. These nonlinearities cause local magnetic distortions and image artifacts. The effect is similar to artifacts related to Bo inhomogeneities.




A
B



(a) SE image obtained with a large field of view shows the result of gradient geometric distortion.(b) Image obtained with a vendor-supplied correction algorithm shows correction of the geometric distortion.

Thanks for your attention