MR Brain Protocols

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Making Cancer History®

Routine Brain Protocol

ACR Requirement:

Sag T1 (or 3DT1)
AX T2
AX FLAIR
AX DWI

+C if breakdown of BBB
AXT1+C

Slice <= 5mm, gap <= 2.5mm

- Sagittal T1W
- Axial DWI
- Axial T2W
- Axial FLAIR
- Axial T1W
- Post contrast Axial T1W
- Post contrast 3DT1W

ACR–ASNR–SPR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of the Brain Res. 17 – 2019

Protocol Consideration

- Signal to Noise Ratio (SNR)

$$SNR \propto x\Delta y\Delta z \frac{\sqrt{N_x N_y NEX}}{\sqrt{BW}} B_0 f$$

- Contrast to Noise Ratio (CNR)
- Resolution
- Scan time

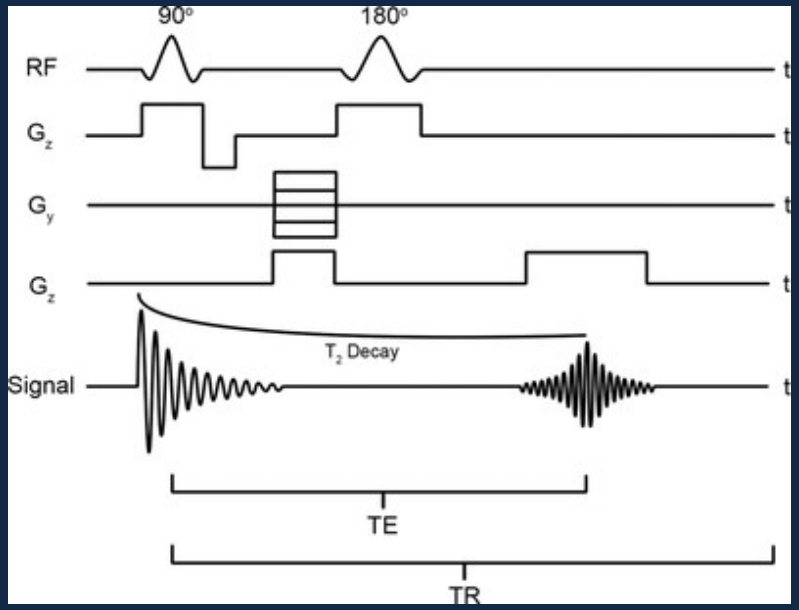
Tissue Characters

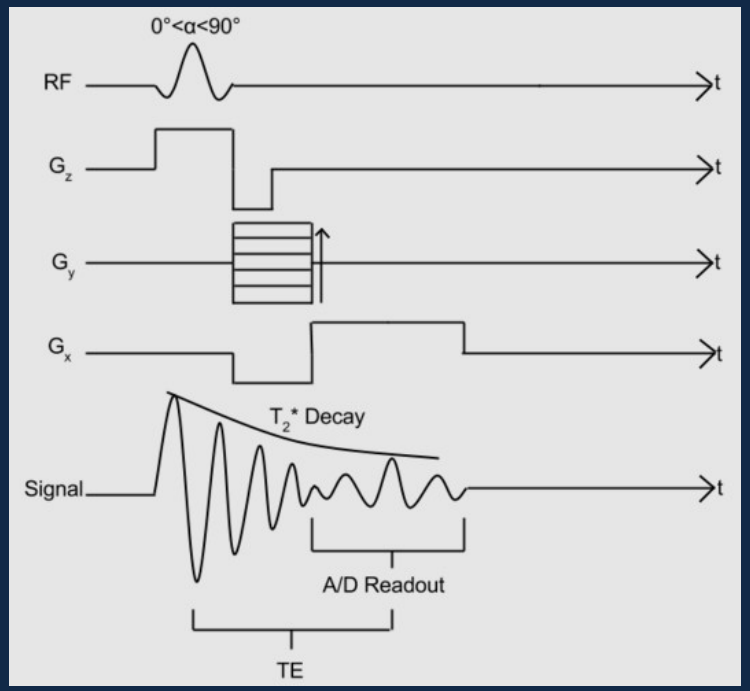
- *Tissue Characters at 1.5T**

Tissue	ρ	T1 (msec)	T2 (msec)
CSF	1.0	4500	2200
WM	0.65	600	80
GM	0.8	950	100
FAT	0.9	250	60

Magnetic Resonance Imaging, Haacke, Brown, Thompson and Venkatesan, p. 457

Pulse Sequences





- Spin Echo Sequence (SE)

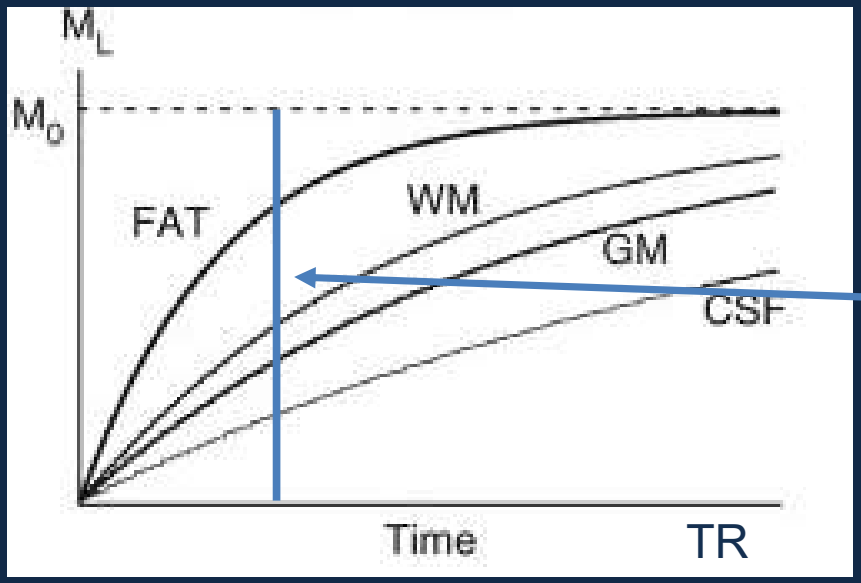
$$S_{SE} \propto \rho_{1_H} e^{-TE/T_2}\left(1-e^{-TR/T_1}\right)$$

- Gradient Echo Sequence (GRE)

$$M_{xy}(t) = M_0 \frac{(1-e^{-TR/T_1})e^{-TE/T_2^*}\sin\alpha}{(1-e^{-TR/T_1}\cos\alpha)}$$

- FSE,SSFSE belongs to SE family
- SPGR, MPRAGE belongs to GRE family
- Advanced sequences: EPI, Propeller, Spiral, ASL

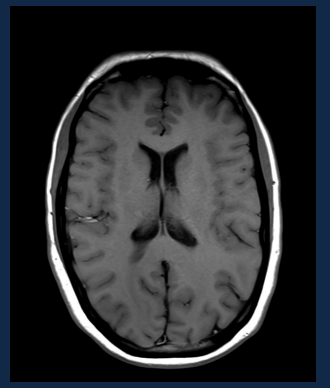
http://199.116.233.101/index.php/Pulse_Sequences

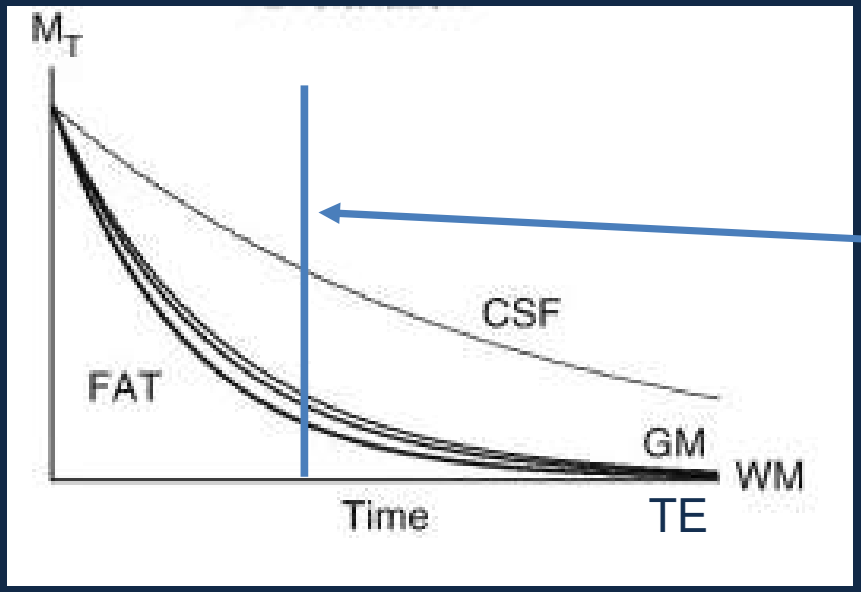


- Let TE ==> 0 and TR << ∞, then

$$S \sim S_0(1 - e^{-TR/T1})$$

T1 Weighted images, TR ~500msec. Short T1 substances will be bright (FAT), long T1 substances will be hypointense (CSF).

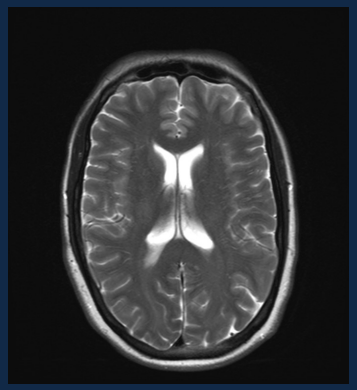




- Let TE > 0 and TR ==> ∞, then

$$S \sim S_0\, e^{-TE/T2}$$

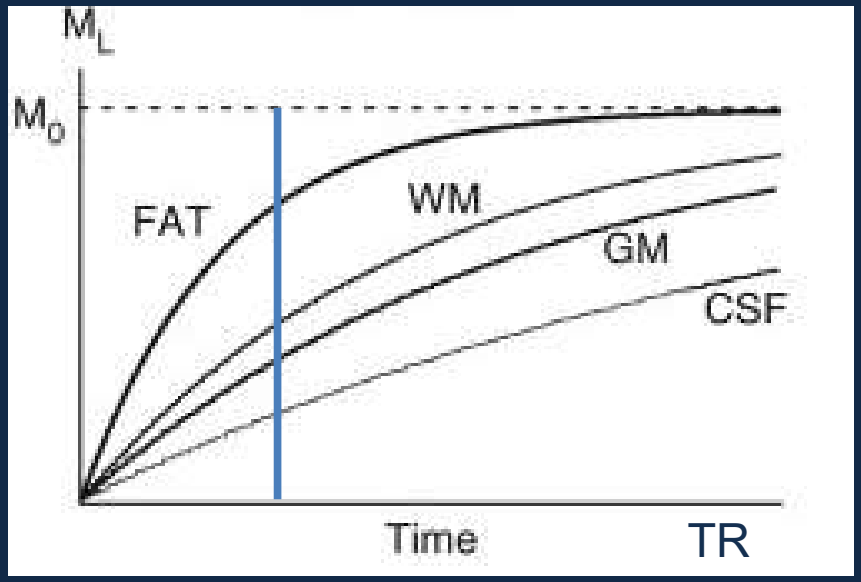
T2 Weighted images, TE ~100msec. Short T2 substances will be dark, long T2 substances will be hyperintense (CSF).

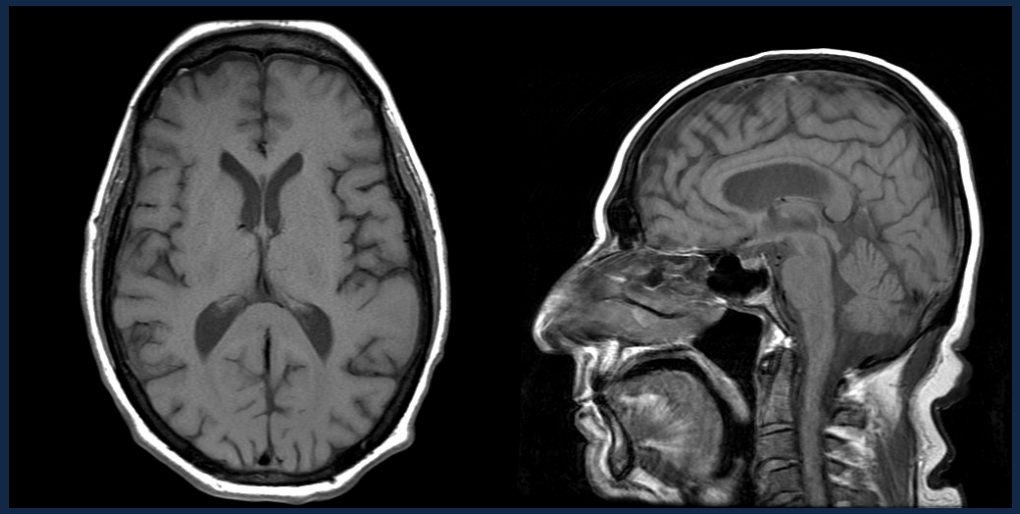


- Let TE==>0 and TR ==> ∞, then $S \sim S_0$

Proton density weighted image – not popular!

T1-Weighted image protocol

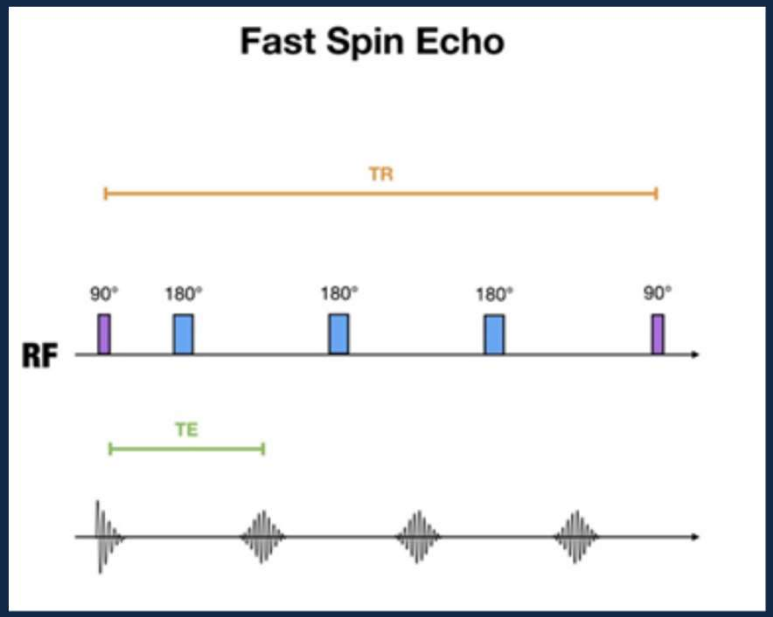


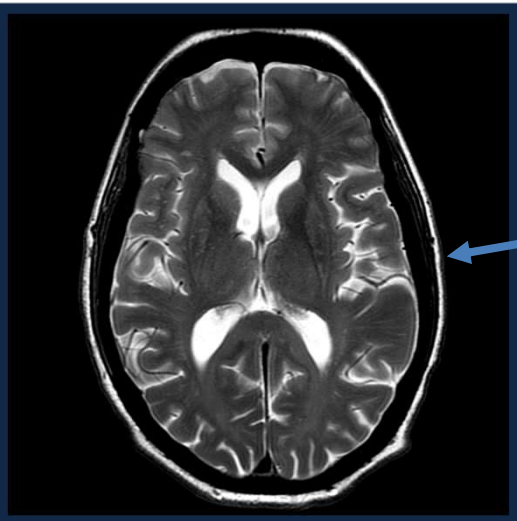


SE, AX or SAG
TR = 500-700 msec
TE = min (10 – 20 msec)
FOV = 220 – 240 mm, no FC
Matrix = 256x192 (1.5T), (352x224) (3T)
slice thickness = 5.0 mm, gap = 1.0mm
Phase encoding dir = RL
BW = 20.83 (31.25, 3T) kHz, 1NEX
180 mm SI coverage
Scan time ~ 2- 4 minutes

Gray matter – dark gray
White matter – lighter gray
CSF – black
Fat - white

T2-Weighted image



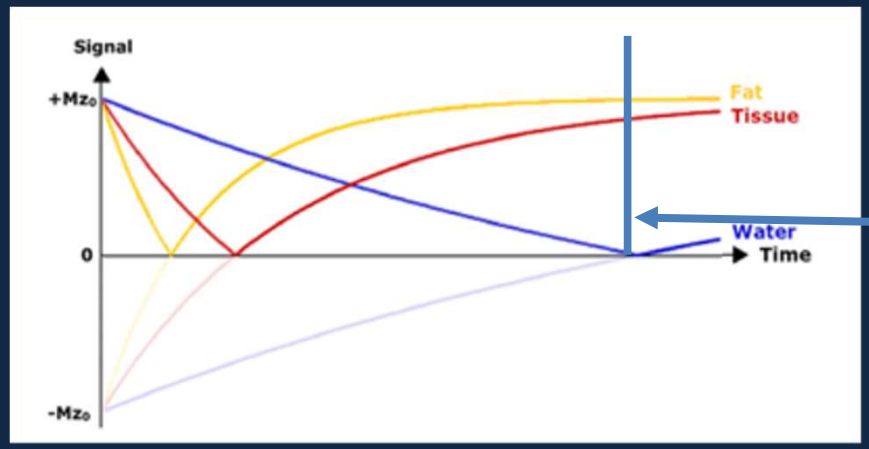


FSE, AX
TR > 3500 msec
TE = 80 – 140 msec, etl >= 16
FOV = 220 – 240 mm
Matrix = 288x224 (1.5T), (352x256) (3T)
slice thickness = 5.0 mm, gap = 1.0mm
Phase encoding dir = RL,
BW = 20.83 (41.67, 3T) kHz, 2NEX
Scan time ~ 2- 4 minutes

Gray matter – light gray
White matter – darker gray
CSF – bright
Fat – less bright than CSF (T2 increase due to elimination of J-coupling between adjacent fat protons).

Andrew Murphy, https://radiopaedia.org/articles/spin-echo-sequences?lang=us
Henkelman RM, et al, J Magn Reson Imaging 1992; 2:533-540

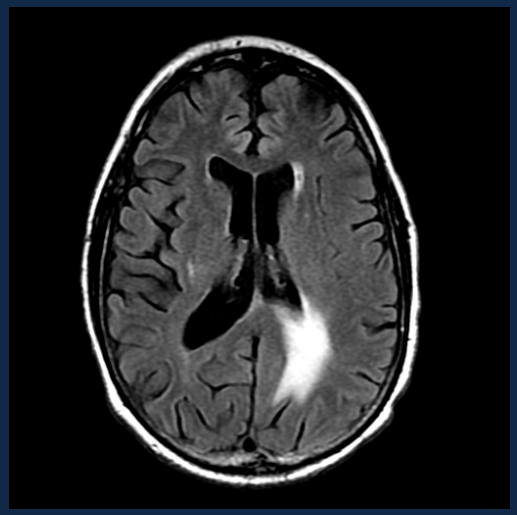
FLAIR Image



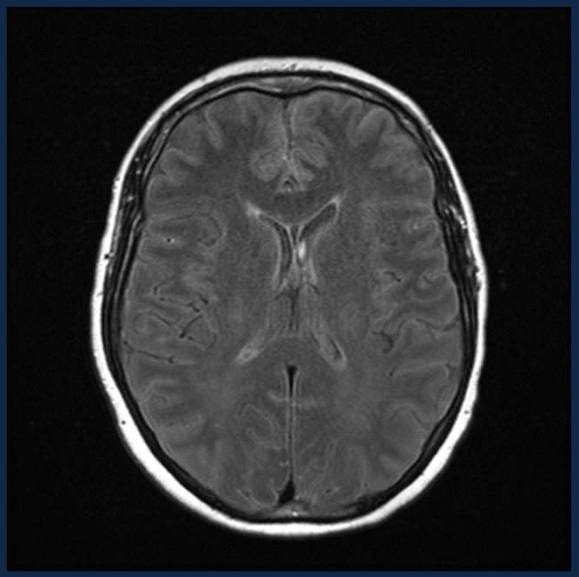
- FLAIR – FLuid Attenuated Inversion Recovery.
- IR + FSE
- IR - flip Mz to –Mz
- Long TI - null the CSF
- Long TR – Mz recovery
- Long TE - T2W image.

$$TI = T1_{csf} * \ln \frac{2}{(1 + e^{-TR/T_1})}$$

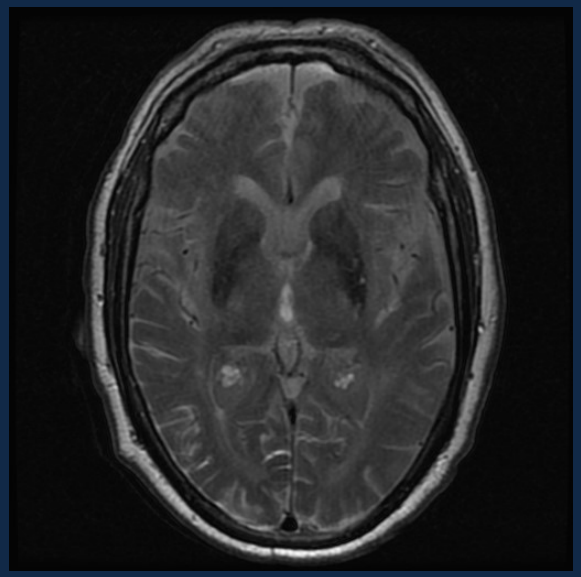
$T1_{csf}$ = 4500 msec, same for 1.5T and 3T



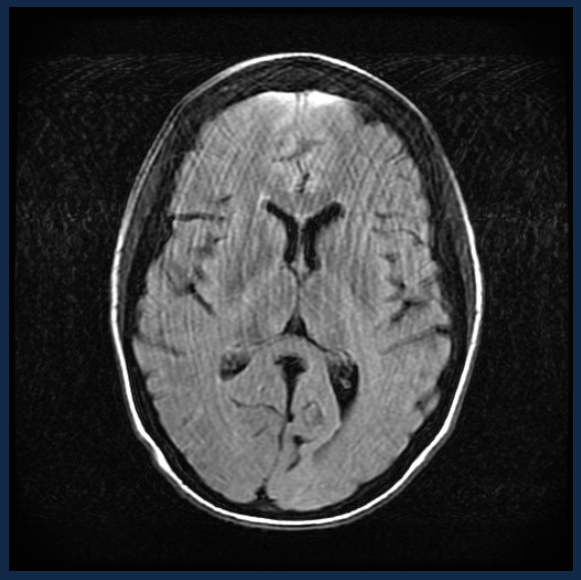
TR = 9000 – 12000 msec (TR >> T1csf)
TI = 2250 – 2500 msec (auto)
TE = 80 – 140 msec (T2W)
FOV = 220 – 240 mm
Matrix = 288x192 (1.5T), (288x224) (3T)
slice thickness = 5.0 mm, gap = 1.0mm
Phase encoding dir = RL, etl >= 16
BW = 20.83 (31.25, 3T) kHz, 1NEX
Concatenation >= 2 (interleave)
Scan time ~ 2- 4 minutes
FLAIR image is almost in all Brain protocols.



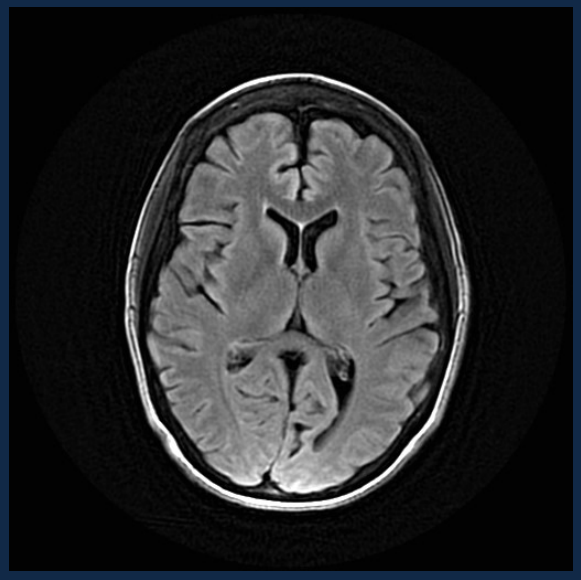
Concats = 1



GFR < 30, contrast < 24 hrs



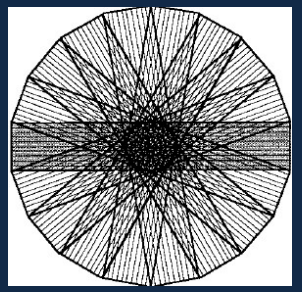
FLAIR - motion



Propeller FLAIR

FLAIR Artifacts

- CSF not suppressed
  - in-flow from neighboring slices
  - TR/TI sensitivity, not correct TI
  - Recent GBCA with low GFR issue
  - Subtle reduced T1 due to high tissue O2 concentration during general anesthesia
- Motion – sensitive to motion due to long TR, TI and TE
  - Traditional uncontrollable motion
  - Occasional motion (movement)



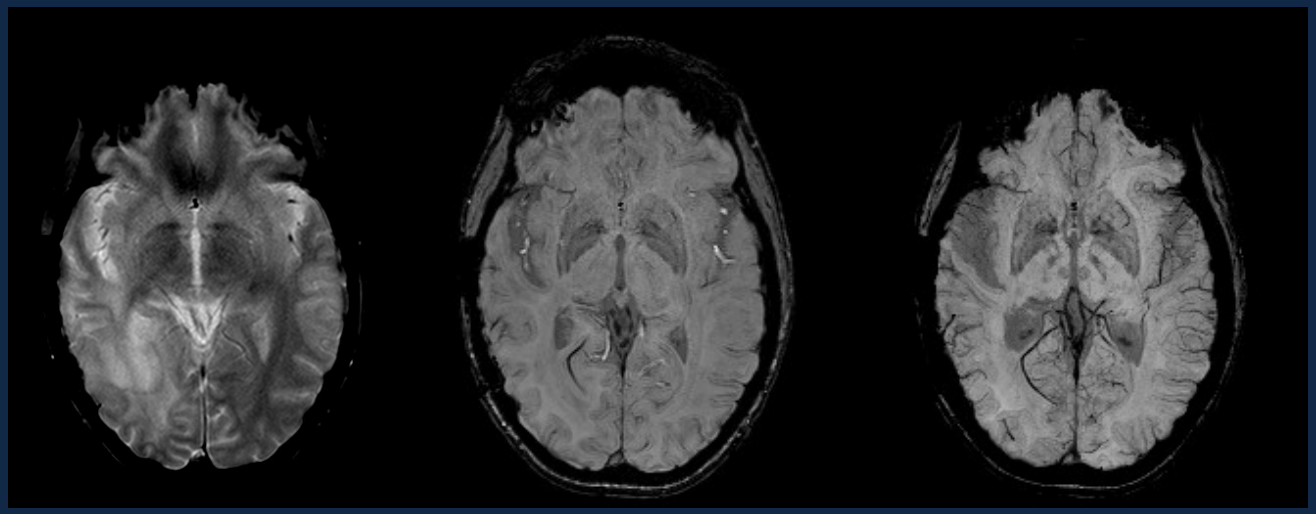
Propeller MRI
Multiple blades to oversample the center of k-space to reduce motion.

Pipe JG. Magn Reson Med 1999; 42:963-969

T2*-Weighted image

- GRE – Sensitive to tissue susceptibility
- GRE signal decay with T2*
- TR is long (>700msec)
- TE is long for GRE (15 – 25 msec)
- FA is small (20)
- 3D SWI – better resolution, minIP

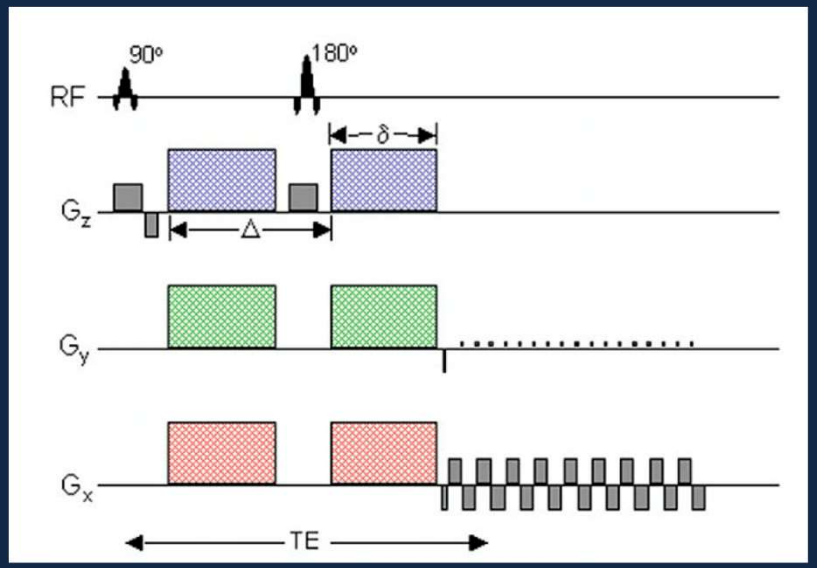
T2*, GRE
Long TR (> 700msec, 1.5T, >600 3T)
Long TE (25 msec, 1.5T, 15msec 3T)
Small FA (20)
FOV = 220 – 240 mm
Matrix = 256x192
slice thickness = 5.0 mm, gap = 1.0mm
Phase encoding dir = RL,
BW = 15.63 (31.25, 3T) kHz, 1NEX



T2*W SWI minIP

SWI – 3D FGRE
TR = 25 – 50msec
TE = 20 -40msec
FA = 15 - 20
FOV = 220 – 240 mm
Matrix = 320x256
Slice thickness <2.0mm, mIP
Mag, Phase image

Diffusion-Weighted Image (DWI)

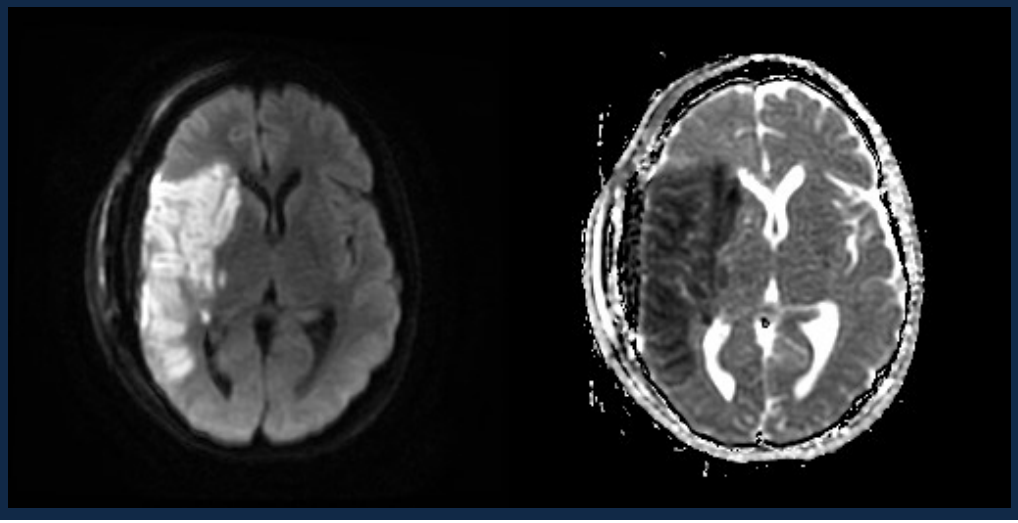


Single shot SE-EPI (most popular)
TR > 5000 msec
TE = min (~ 70)
FOV = 220 – 240 mm
Matrix =128x128
slice thickness = 3.0-5.0 mm, gap = 0
Phase encoding dir = AP
BW = 250 (Max) kHz, shortest esp
b-value = 0, >= 1000, 3 directions, 1NEX
Scan time < 1.0 min
It is essential for Brain study, acquired first

$$b = (\gamma G \delta)^2 \left(\Delta - \frac{\delta}{3} \right)$$

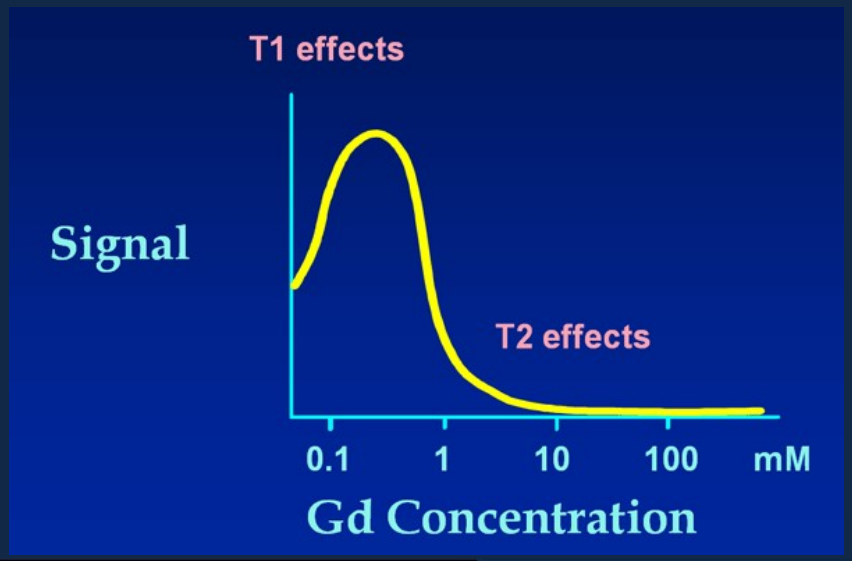
$S/S_0 = e^{-bADC}$

$$ADC = \frac{\lambda_1 + \lambda_2 + \lambda_3}{3}$$



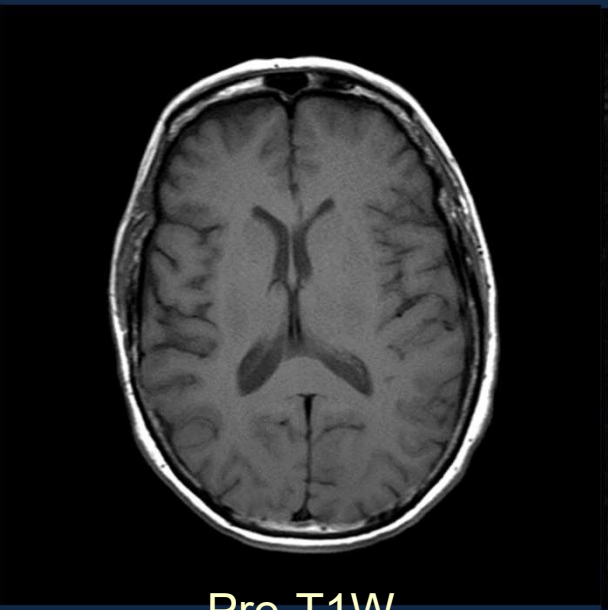
Alexander AL, Neurotherapeutics. 2007

Post contrast T1W

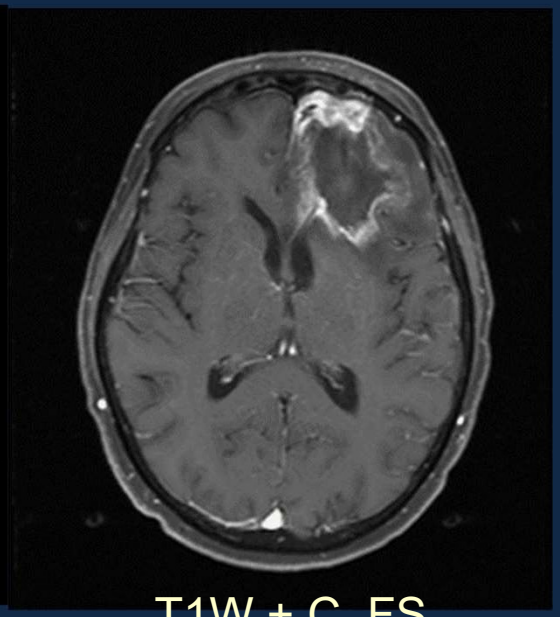


Paramagnetic Contrast Agents

- Gadolinium (Gd) is most common in MR imaging.
- Gd is toxic - must be tightly chelated
- Affect both T_1 and T_2 relaxation time, with the dominant effect being shortening of the T_1 relaxation time (at routine clinical dose).
- Gd is very bright on T1W images. It is very useful in vascular images (MRA) and breakdown of blood-brain barrier.



Pre-T1W

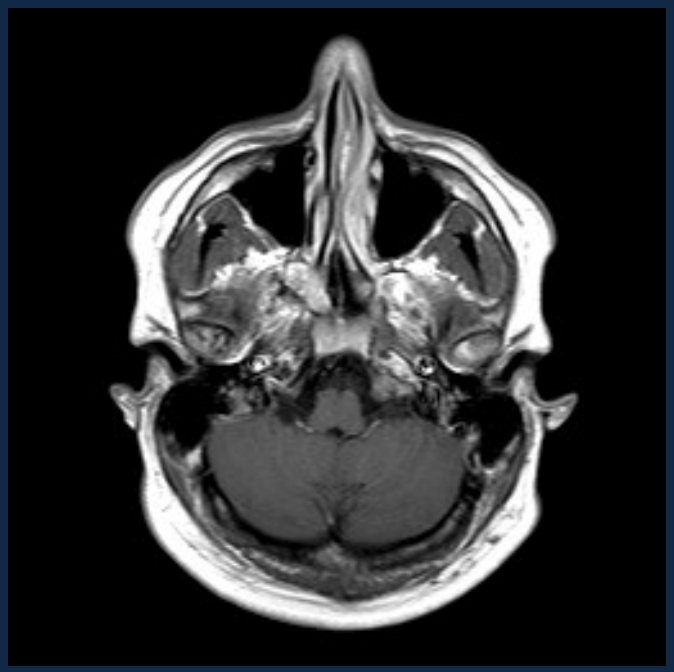


T1W + C, FS

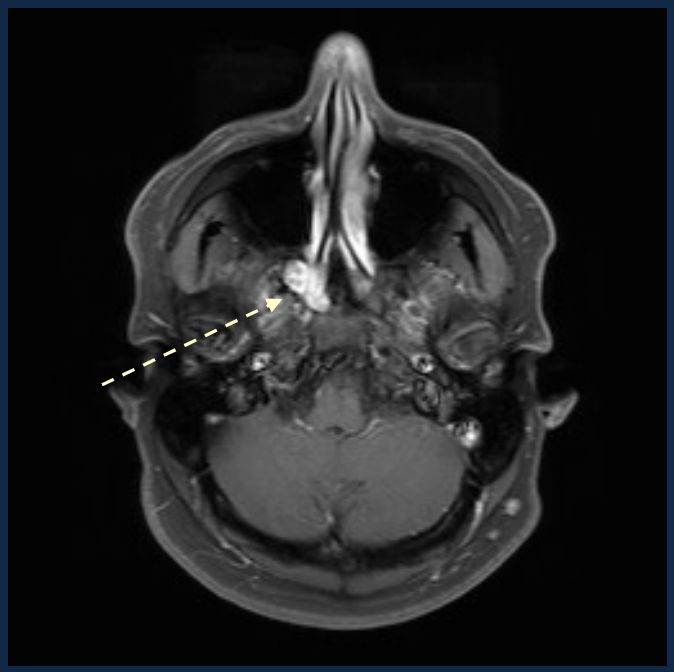
http://mriquestions.com/does-gd-affect-t2.html

T1+C with Fat Sat

- Fat has short T1 – bright on T1W
- Confused with contrast uptake
- Fat sat increases diagnostic accuracy and improves lesion delineation
- Fat suppression increases scan time, also depends on local field homogeneity



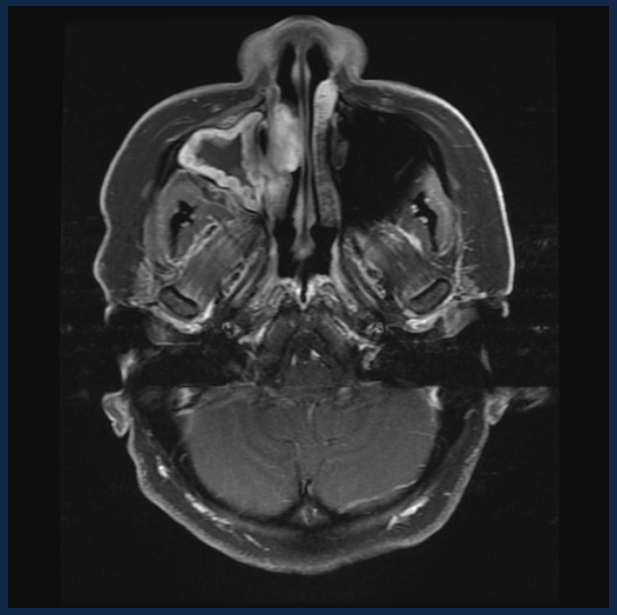
T1W + C



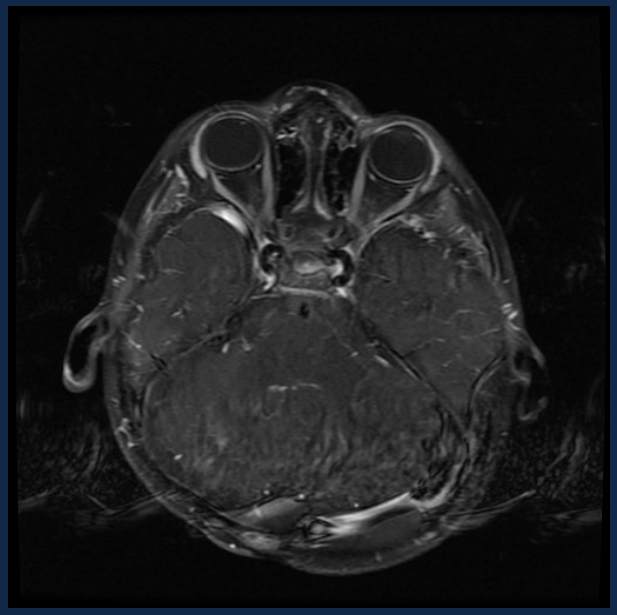
T1W +C, FS

Post Contrast T1W Artifacts

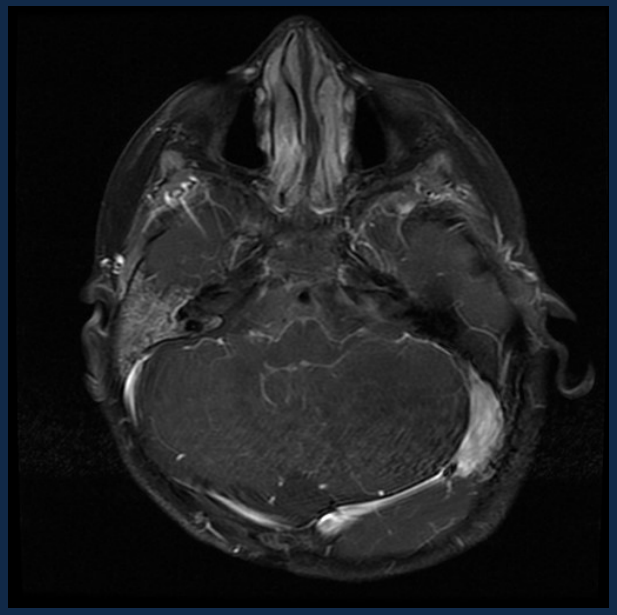
- Most post contrast T1W image artifacts are non-uniform fat suppression, flow artifacts in the posterior fossa, motion.



Fat Sat fail

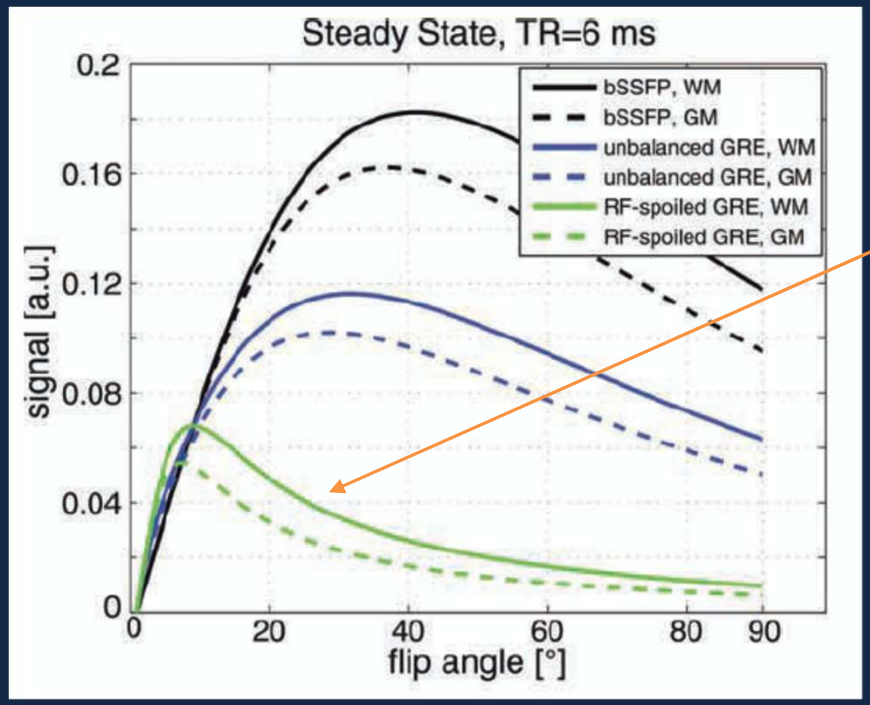


No Flow comp



Flow Comp

Post Contrast 3D T1W imaging



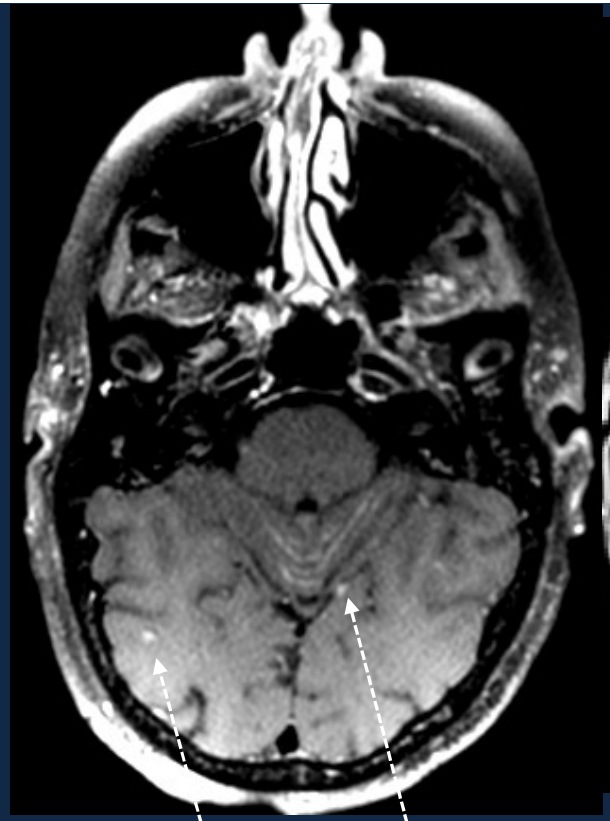
Maximum signal at Ernst angle

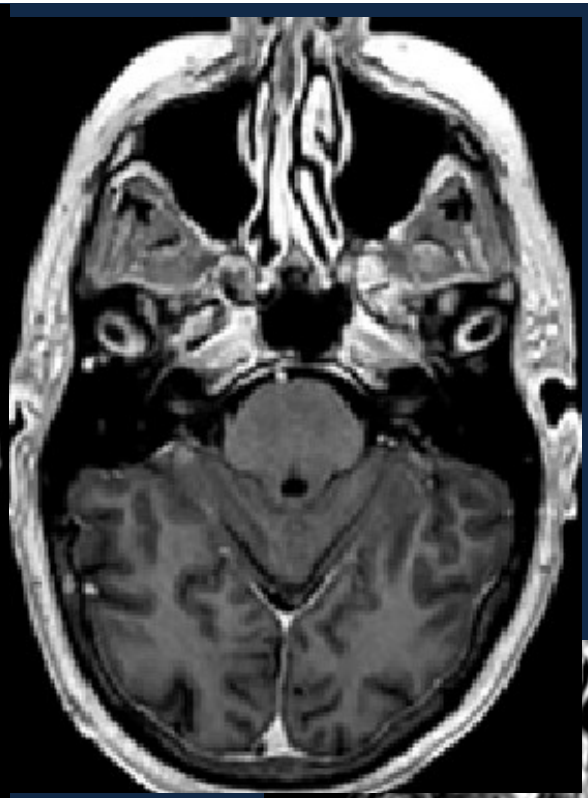
$\alpha_E = \cos^{-1}(e^{-TR/T1})$

Markl M, Leupold J, JMRI, 35:1274-1289 (2012).

- Fast GRE SNR is a function of flip angle (FA), TR, TE
  - Gradient spoiled, T2/T1-contrast
  - RF-spoiled, T1 contrast, low SNR/CNR clinical (FSPGR, FLASH).
  - Balanced SSFP, truly RF and gradient balanced, T2/T1 contrast, (FIESTA, true FISP).
- 3D FSPGR
  - Optimum T1W contrast happen at flip angle large than Ernst angle. For FSPGR, FA = 20 shown to have best tissue contrast.

AX, 3D FSPGR, FA = 20
TR = min (<10msec),TE = min (close to in-phase)
slice thickness = 1.4mm, gap = -0.7mm
FOV = 240 mm, matrix =256x256
Phase encoding dir = RL, 1NEX
BW = 20.83 (41.67 3T) kHz, scan time ~ 4min
Reformat to 1mm slice on AX, SAG, COR

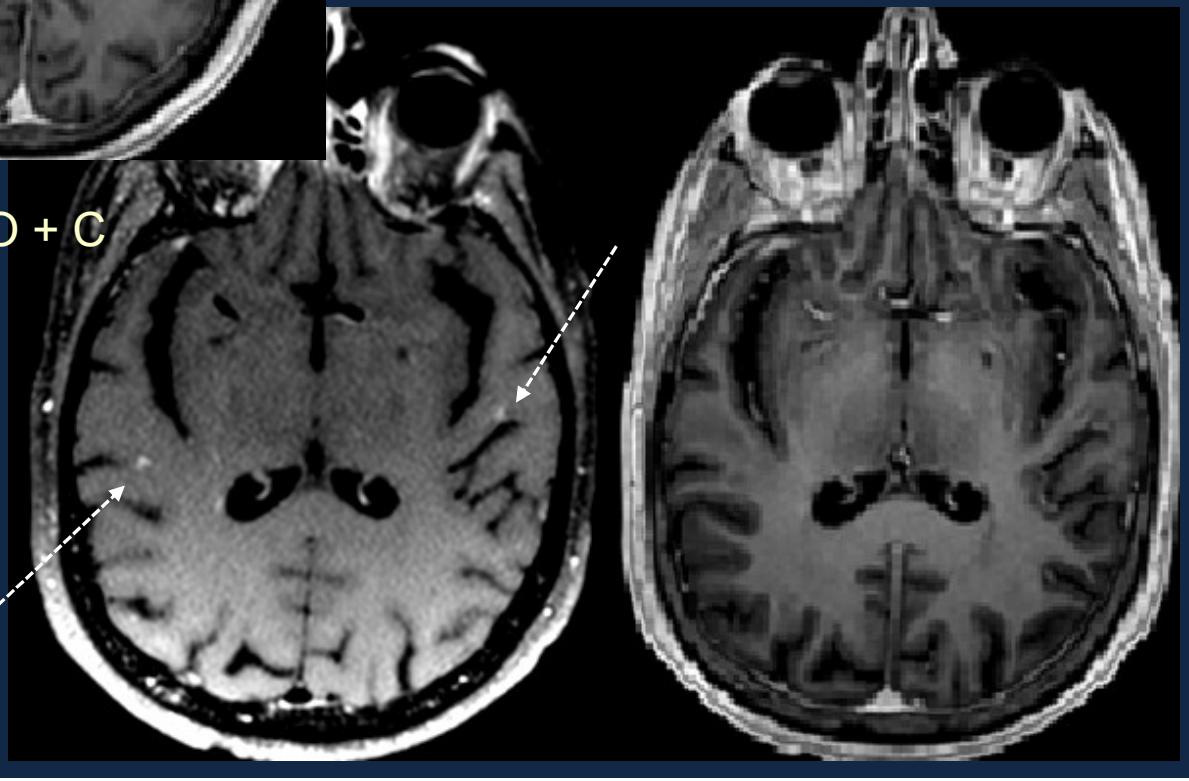


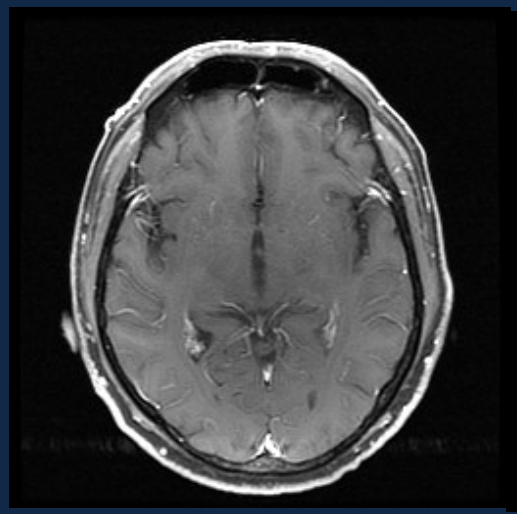


Reformatted T1Cube + C

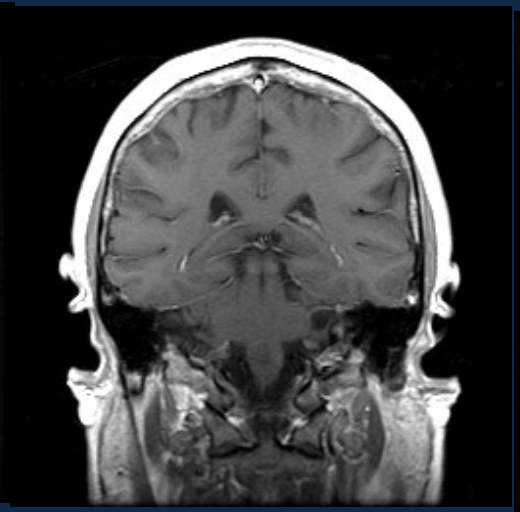
BRAVO + C

- IR based BRAVO/MPRAGE has excellent GM and WM contrast
- Use with caution for post contrast
- It could miss small metastases

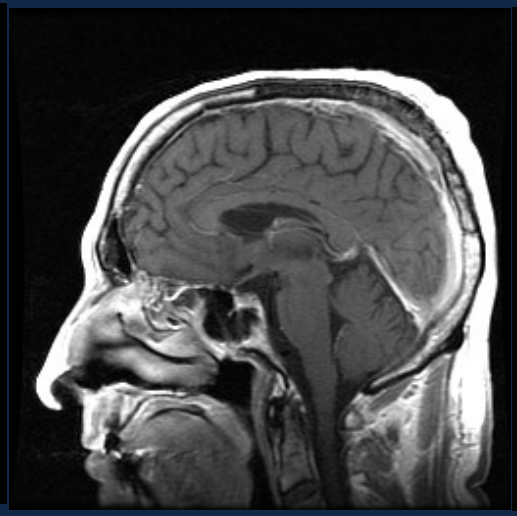




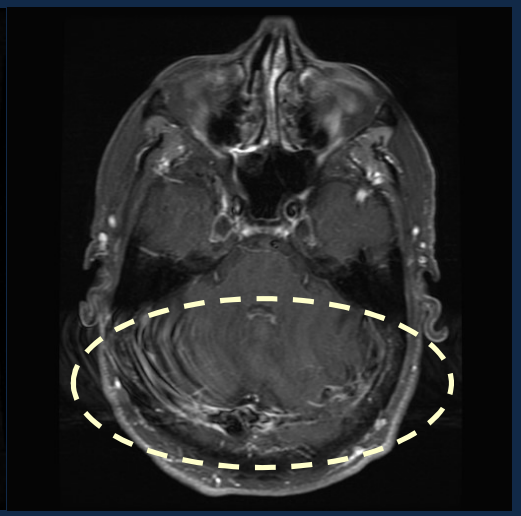
AX SE T1+C, FS, 6:32



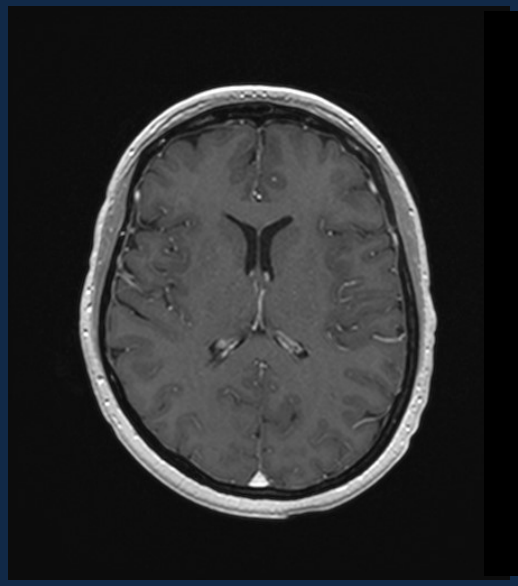
COR SE T1+C, 3:16



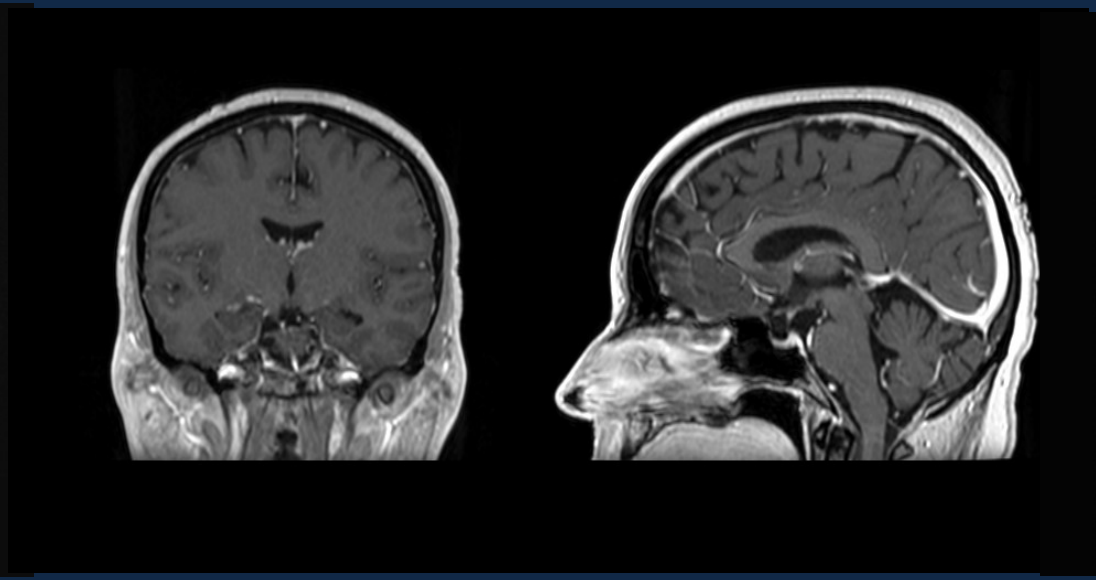
SAG SE T1+C, 2:15



AX SE, flow artifact

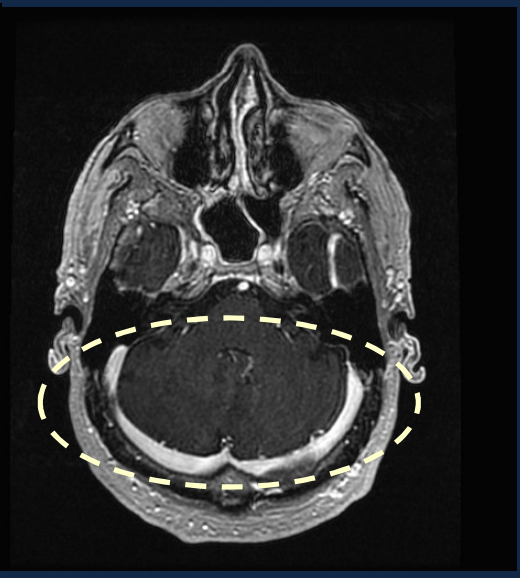


AX 3D T1+C, 3:44



Cor reformat

Sag reformat



3D FSPGR

Other Options

- GRE T1W –uncooperative patient
- DTI - fiber tracking
- ASL - Perfusion
- T2*W/SWI – calcification, hemorrhages
- DIXON – option for fatsat
- FLAIR+C – LMD

Advanced Techniques

- MR Spectroscopy (MRS)
- Dynamic Contrast Enhanced imaging (DCE)
- Dynamic Susceptibility Contrast (DSC) Imaging
- fMRI (EPI) BOLD Imaging

Summary

	TR (msec)	TE (msec)	TI (msec)
T1W	Short (500)	Short (Min, 10)	N/A
T2W	Long (>3500)	Long (>80)	N/A
FLAIR	Very Long (>8000)	Very Long (>100)	Very Long (>2200)
DWI	Long (>5000)	Min (~ 70)	N/A
T1W + C, FS	Short (500)	Short (10)	N/A