Iowa Neuroimaging Consortium: Summer Neuroimaging Bootcamp

Other MRI Methods

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Disclosures

- Medical Physicist (not a Neuroscientist)
- Research expertise in body and breast MRI

Outline

Structural Imaging

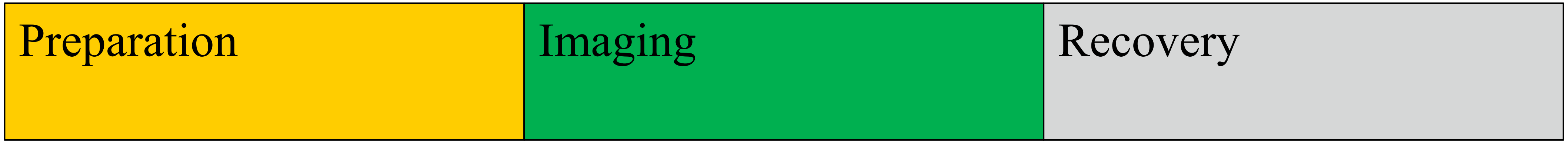
- Review of ‘standard contrasts’
  - T2w: T2 cube, flair, etc.
  - T1w: MP-RAGE, DIR and others. White vs grey matter nulled.
- Susceptibility
  - SWI
  - QSM

Functional Imaging

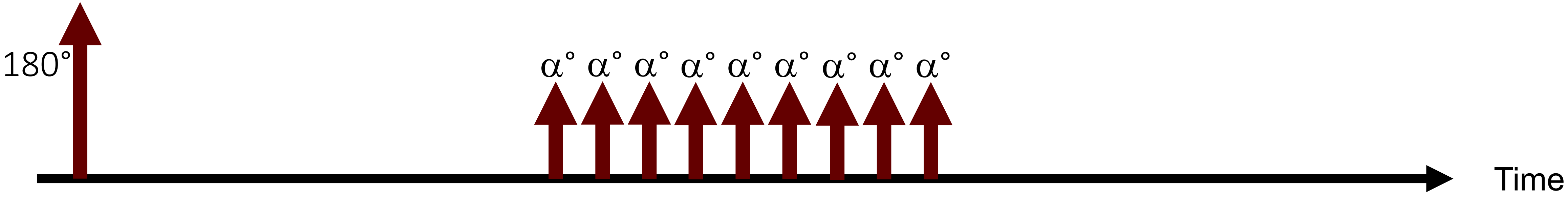
- Perfusion
  - Exogenous. DSC, DCE
  - ASL, pcASL, VSASL
- Exchange
  - T1 rho
  - MT
  - CEST
- Spectroscopy
- MNS imaging

Structural Imaging

Magnetization Preparation for Optimizing Tissue Contrast

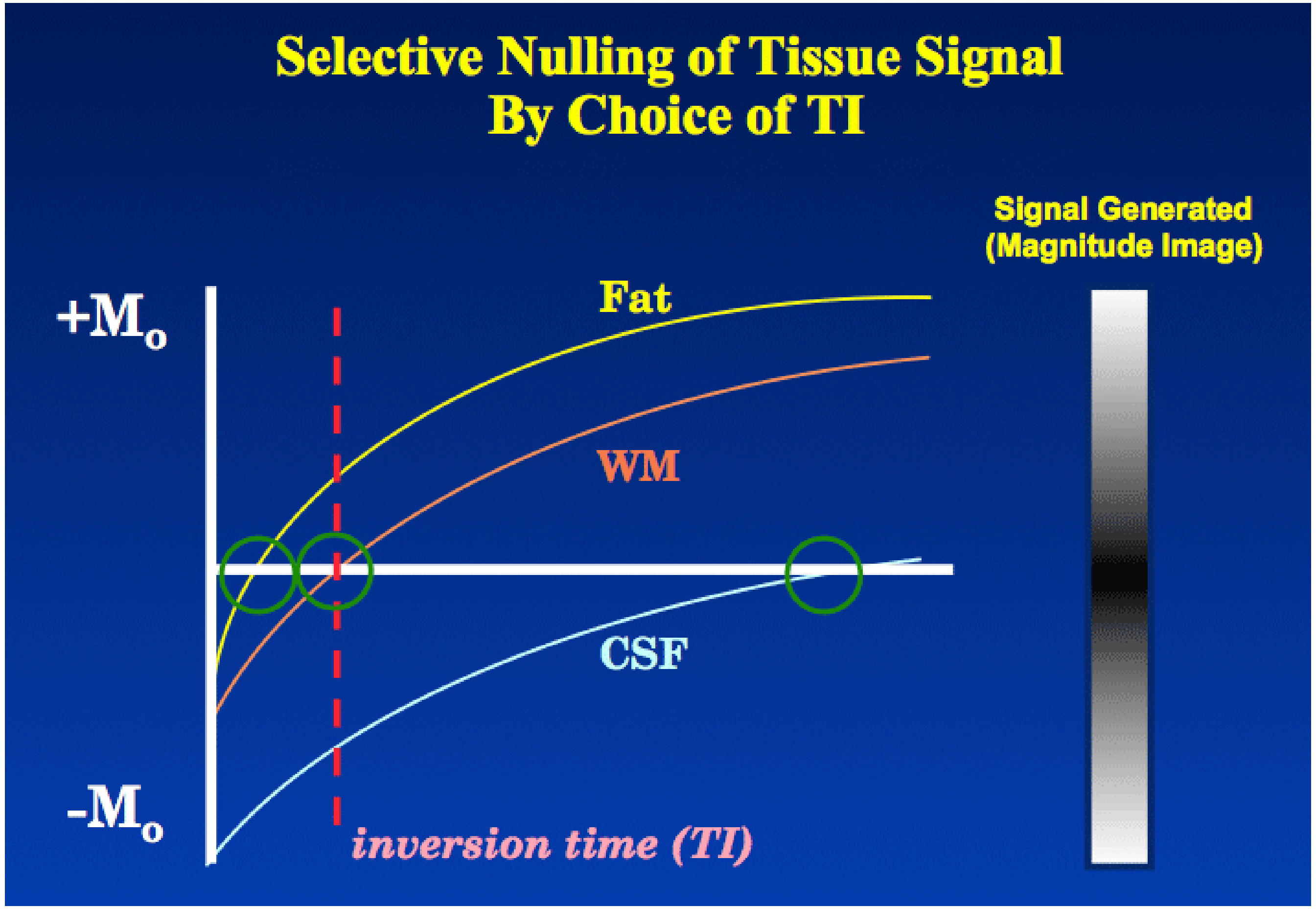


Example: Inversion Recovery

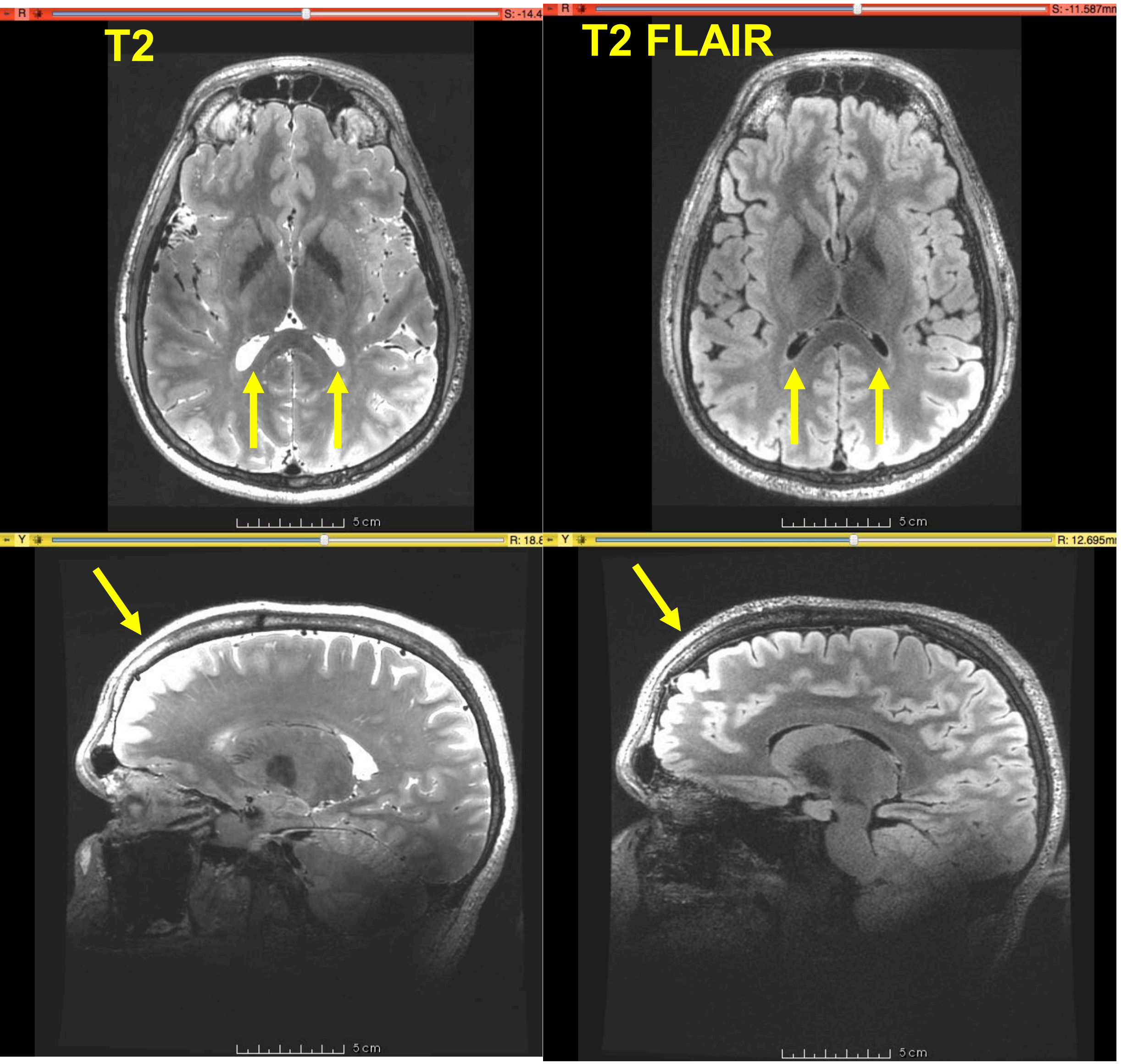


Inversion Recovery

- Choice of TI allows for nulling specific tissues
- Signal differences can be maximized between different tissues
- Multiple inversions can be combined



https://mriquestions.com/ti-to-null-a-tissue.html



T2 and FLAIR CUBE

T2-weighted-Fluid-Attenuated Inversion Recovery

Timings:

Preparation:
TI = long to null CSF

Imaging:
TE = long (~140 ms) to generate T2 contrast
Fast spin echo

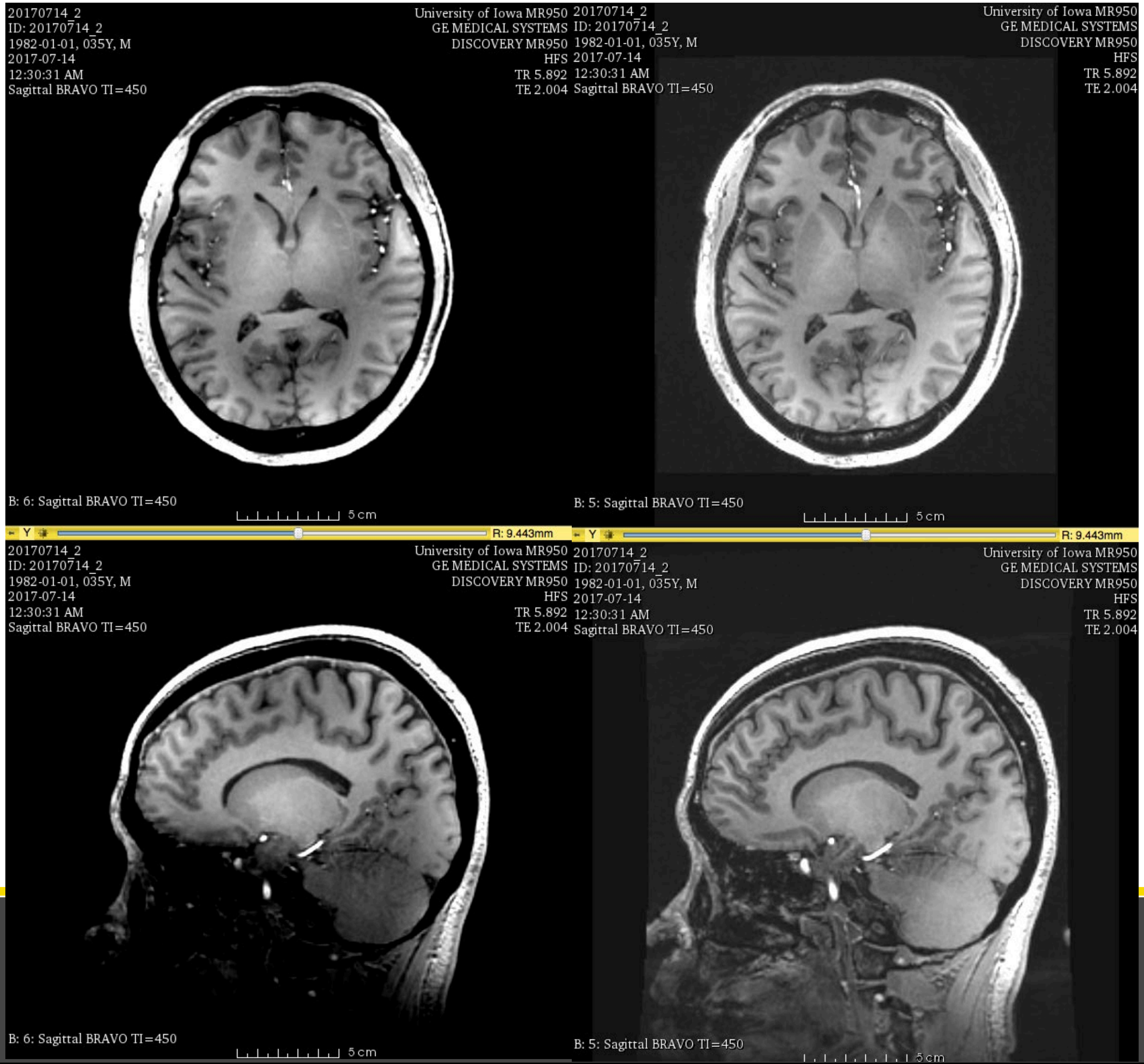
Recovery:
TR = long

Hajnal JV, et al. High signal regions in normal white matter shown by heavily T2-weighted CSF nulled IR sequences. J Comput Assist Tomogr 1992; 16:506-13.
Hajnal JV, et al. Use of Fluid Attenuated Inversion Recovery (FLAIR) pulse sequences in MRI of the brain. J Comput Assist Tomogr 1992; 16:841-844.

3D T1-Weighted BRAVO

TI = 450 ms

TI = 800 ms



Preparation:
TI=450 ms and 800 ms shown

Imaging:
TE=2 ms
Gradient echo

Recovery:
TR=5892 ms

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MP-RAGE

Magnetization Prepared - RApid Gradient Echo

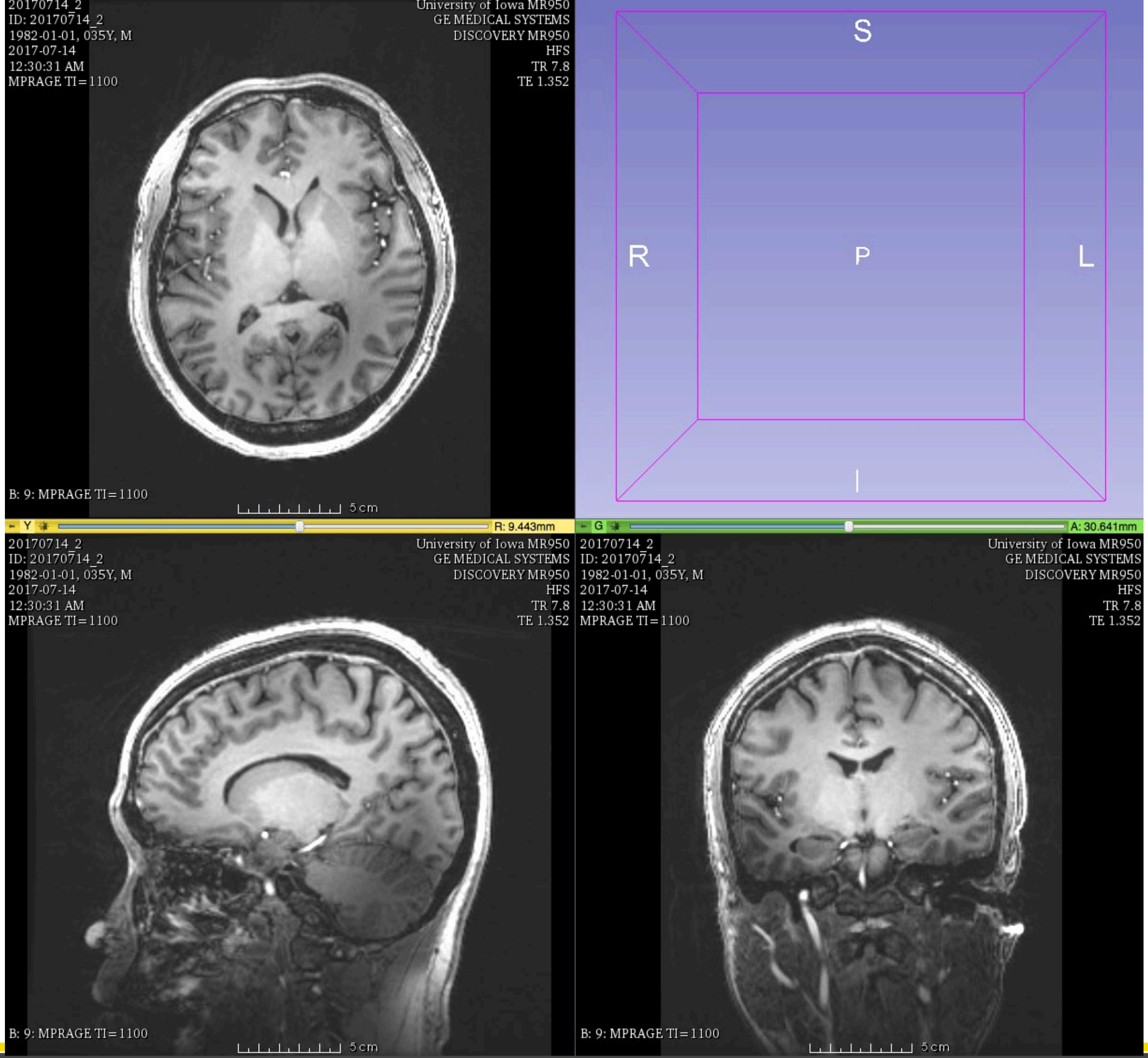
Collected at 7T
(Warning: T1 & T2 change with B0!)

Typical timing parameters

Preparation:
TI=1000 ms

Imaging:
TE=3 ms

Recovery:
TR=2200 ms



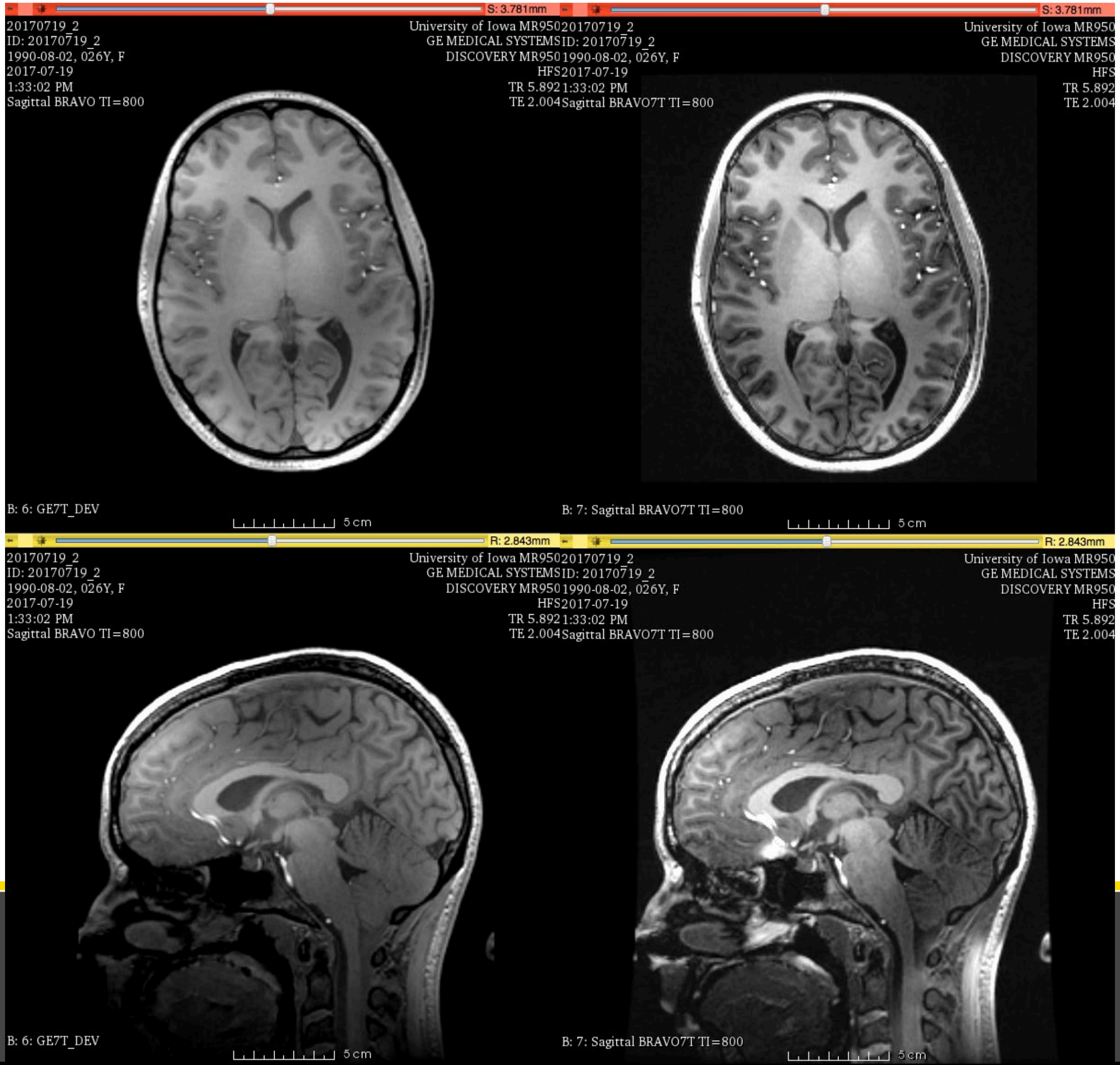
Mugler JP 3rd, Brookeman JR. Rapid three-dimensional T1-weighted MR imaging with the MP-RAGE sequence. J Magn Reson Imaging 1991; 1:561-7.

BRAVO

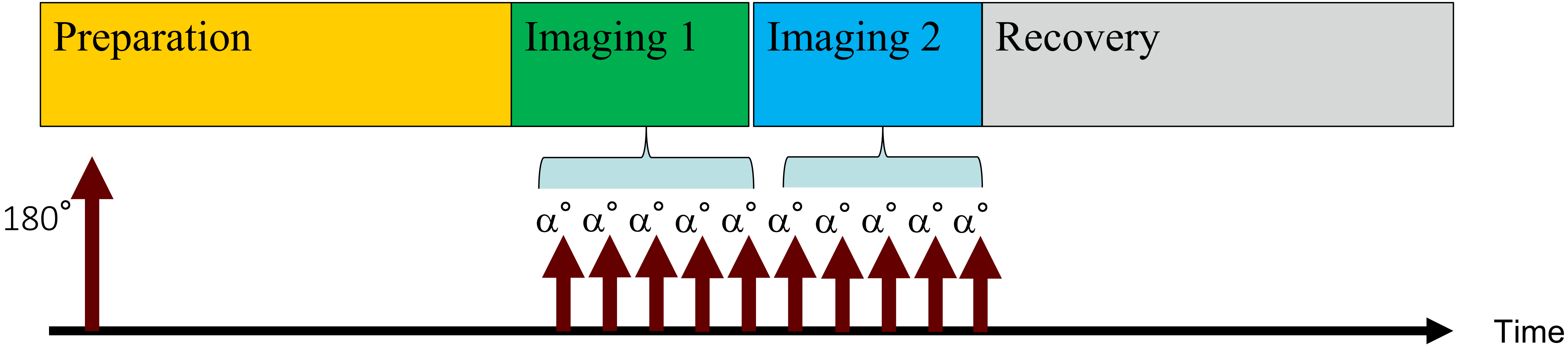
Impact of changing the RF inversion Pulse

Standard IR-Pulse

Hyperbolic Secant IR-Pulse



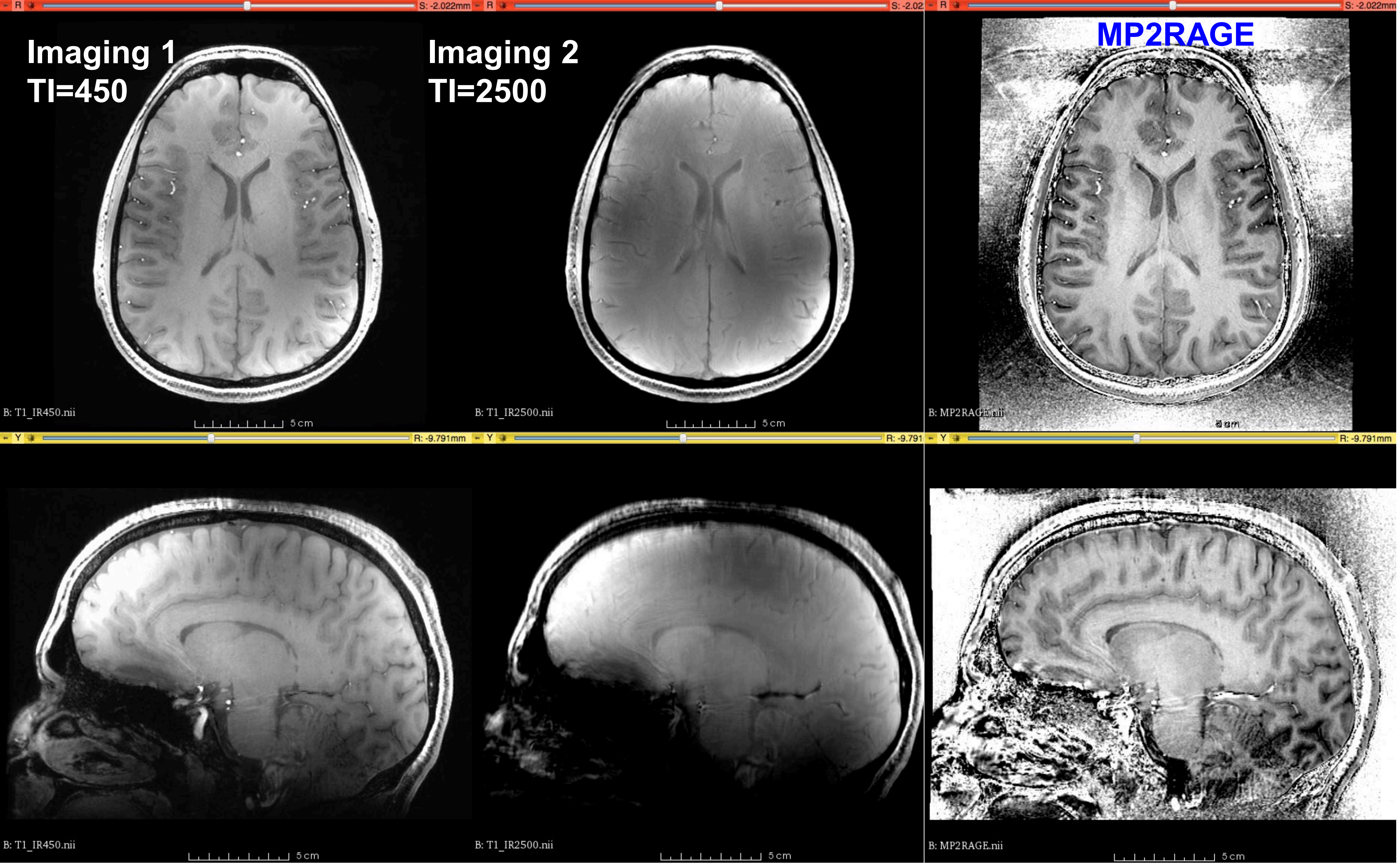
MP2RAGE



Imaging 1: T1w, gray matter nulled
Imaging 2: PDw

Processing of Imaging 1 and Imaging 2: T1w image with gray/white matter contrast, removing T2* and B1 effects

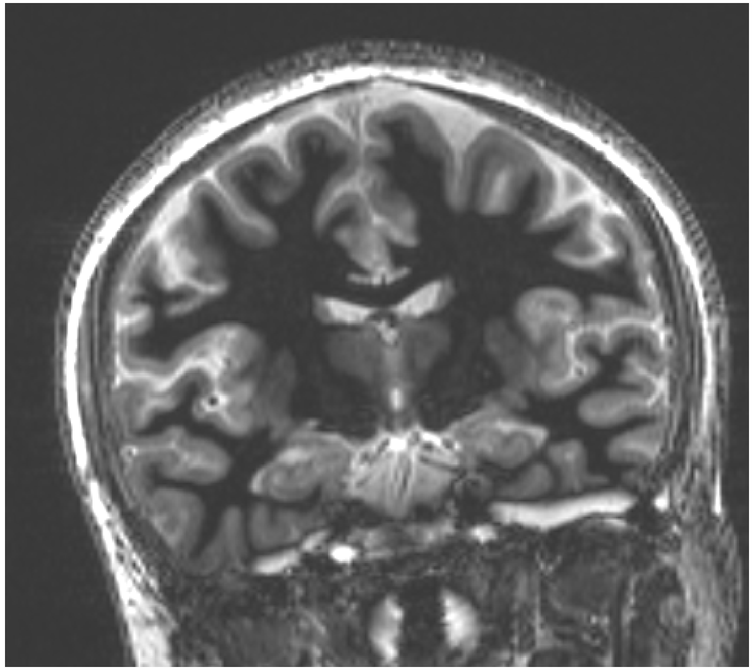
Marques JP, et al. MP2RAGE, a self bias-field corrected sequence for improved segmentation and T1-mapping at high field. NeuroImage 2010; 49:1271-1281.



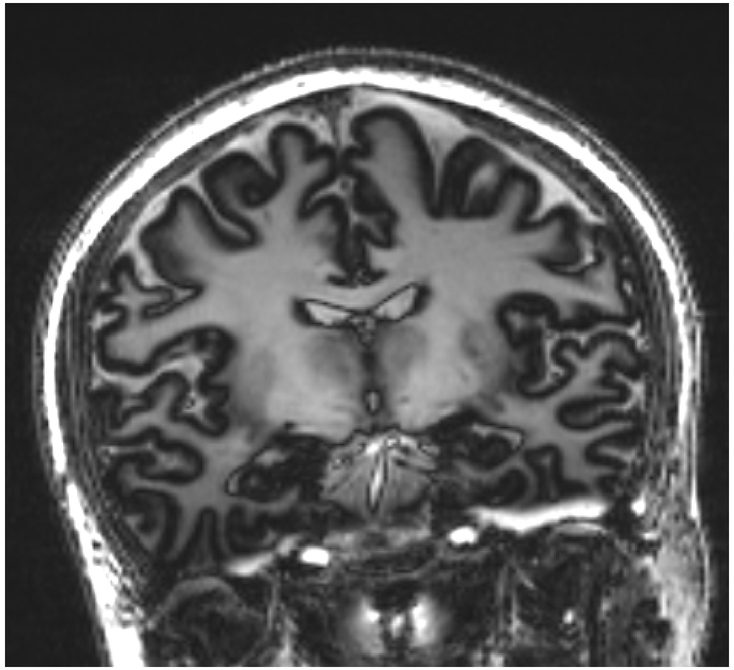
MP2RAGE

Marques JP, et al. MP2RAGE, a self bias-field corrected sequence for improved segmentation and T1-mapping at high field. NeuroImage 2010; 49:1271-1281.

More ways to optimize the timing of inversion pulses, imaging, and recovery

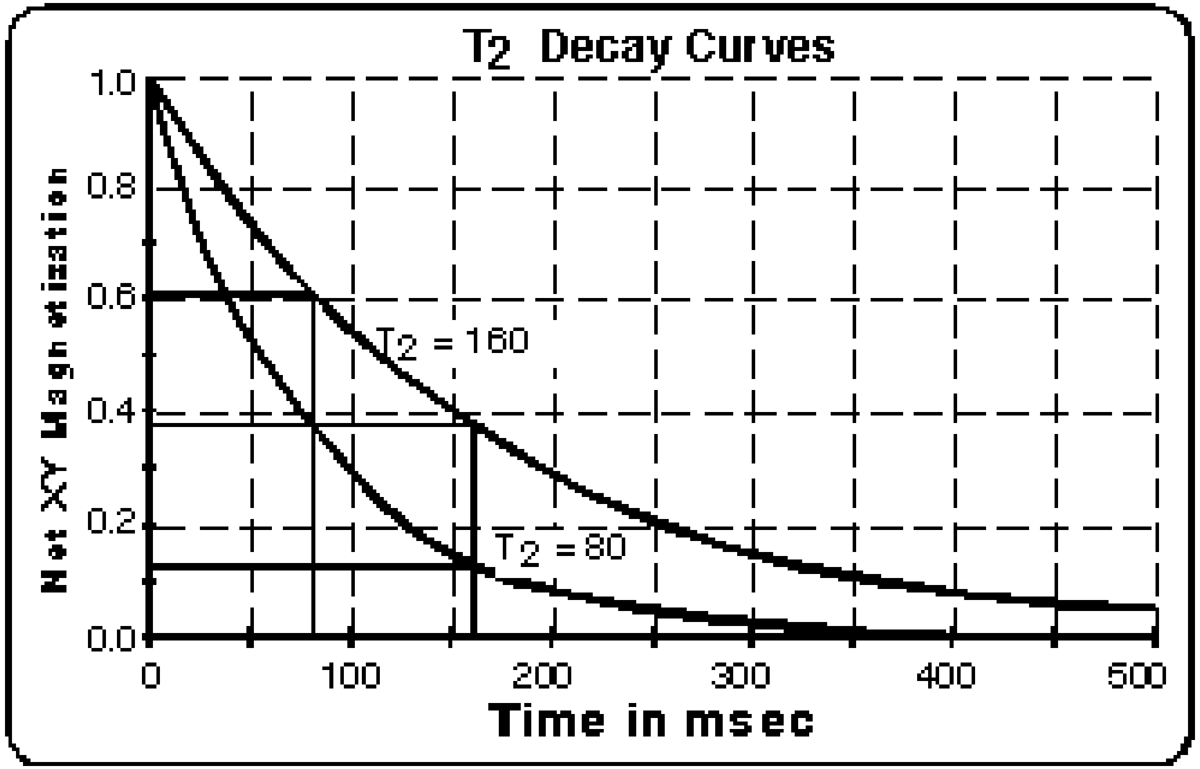


White Matter Nulled



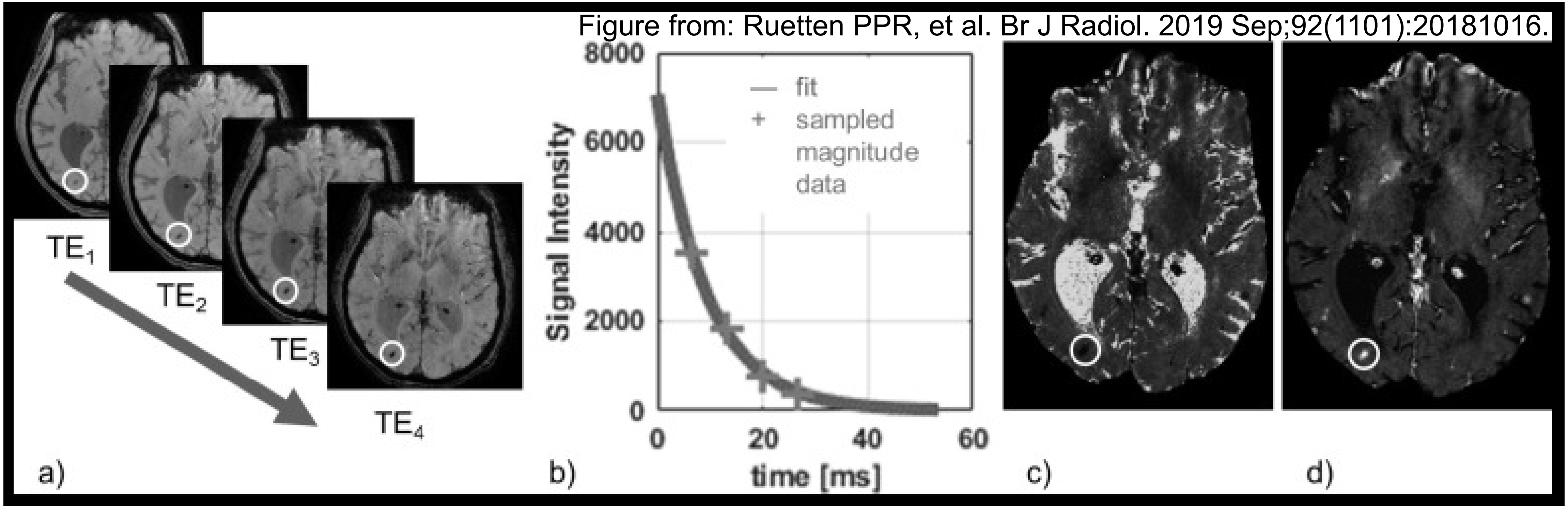
Gray Matter Nulled

T2 Decay


T2 Decay Curves
1.0
0.8
0.6
0.4
0.2
0.0
Net XY Magnetization
T2 = 160
T2 = 80
0
100
200
300
400
500
Time in msec

Approaches to Sensitize for Tissue Susceptibility

SWI (Susceptibility Weighted Imaging)
QSM (Quantitative Susceptibility Mapping)



a) Multiple images collected at different TE times

b) T2* decay can be modeled from signal changes between the images

c) T2* map and c) R2* map (1/T2*). Note how well we can visualize the hemorrhage in both maps (circles).

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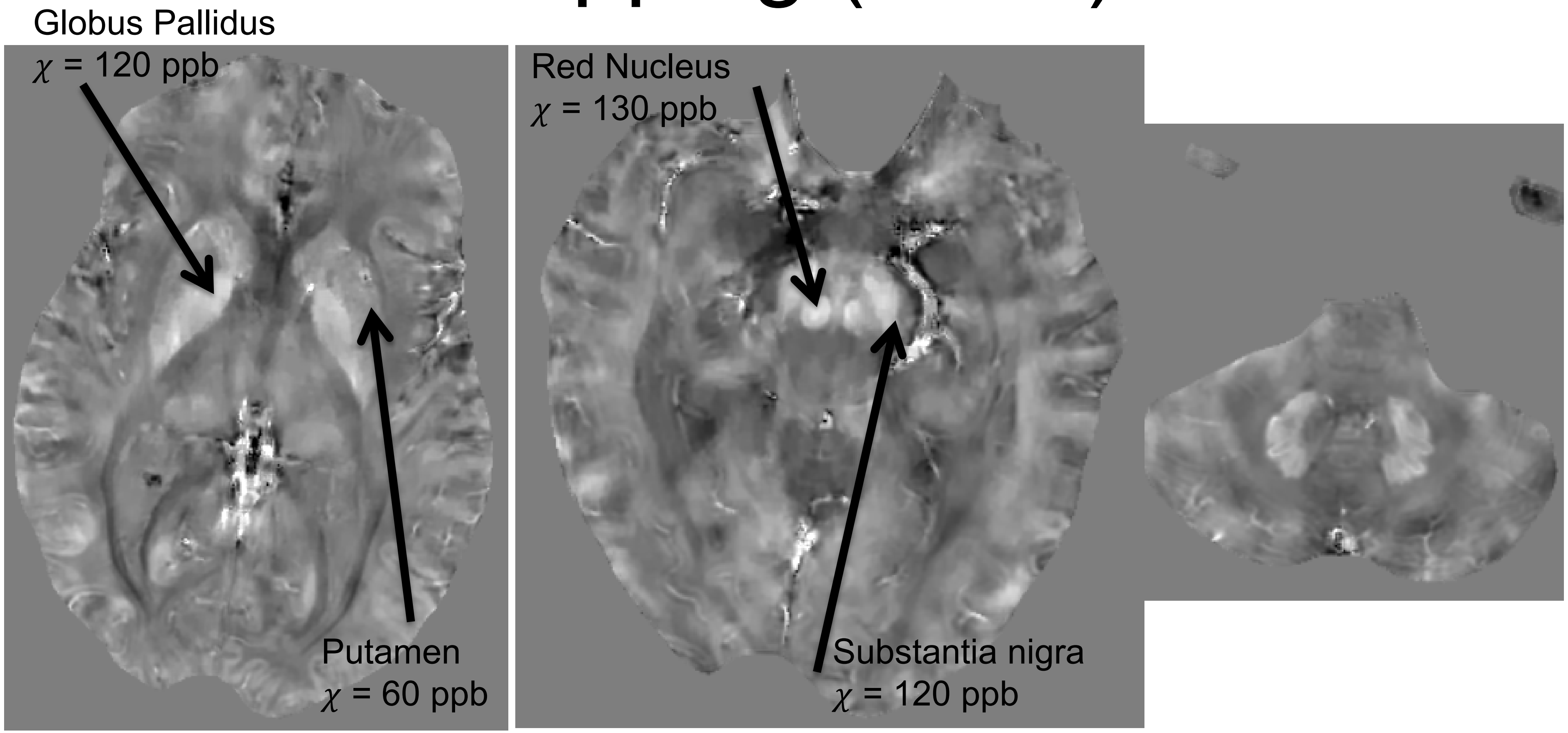
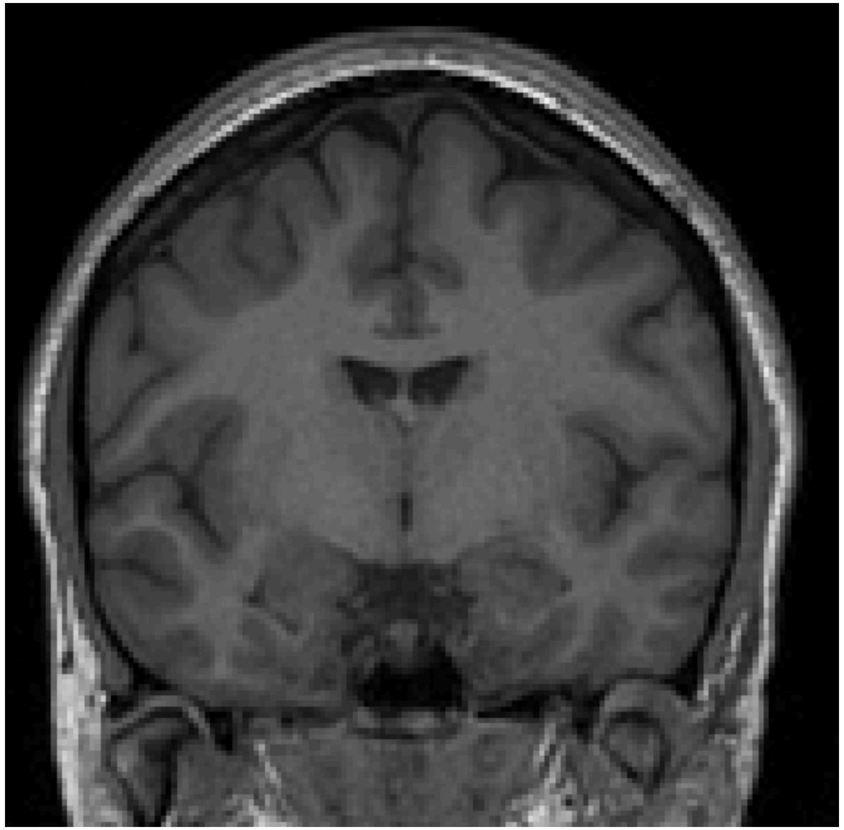
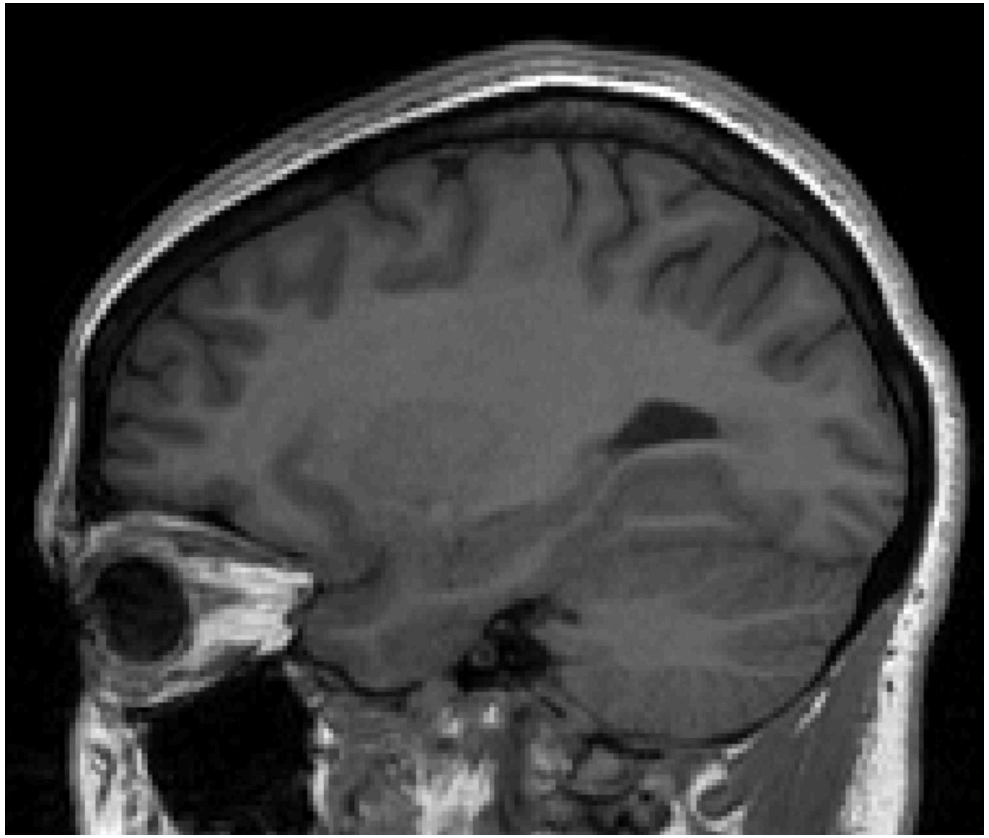
Quantitative Susceptibility Mapping (QSM)



Potential improvements with higher B0 field strength

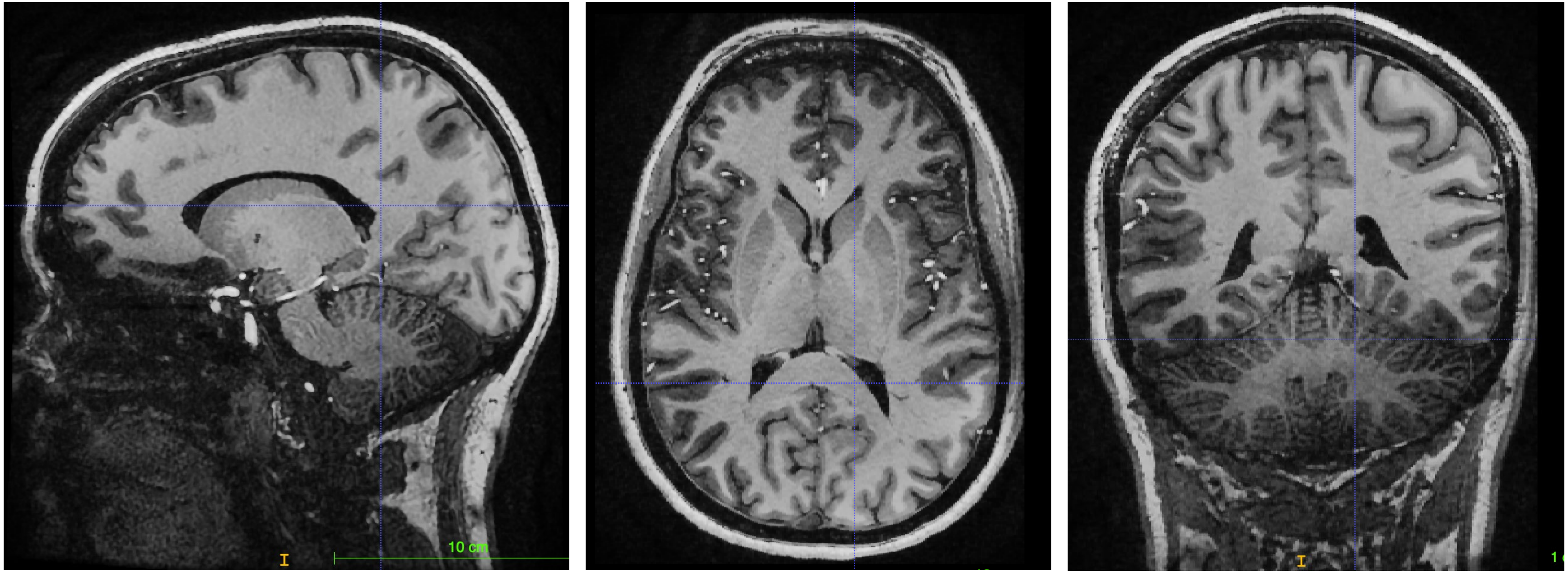
Typical Resolution at 3T





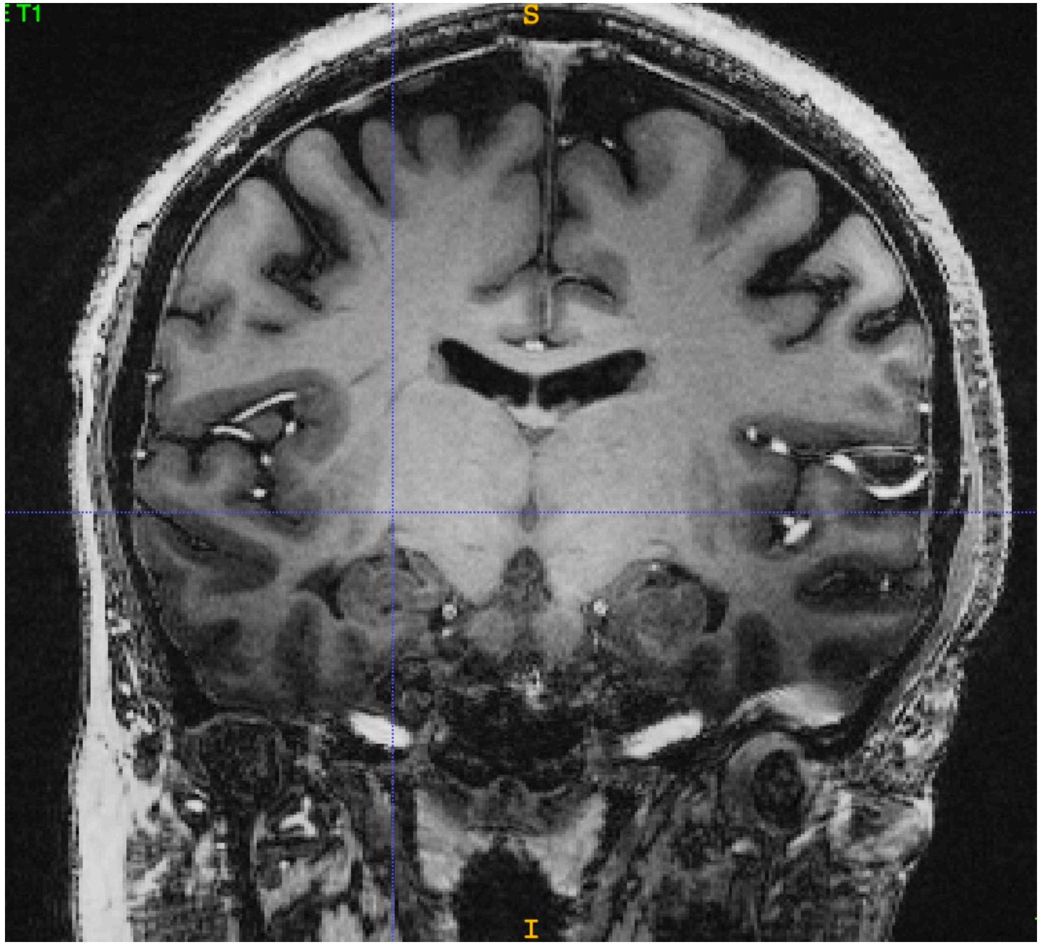
1mm Isotropic whole brain data from T1 and T2 weighted images

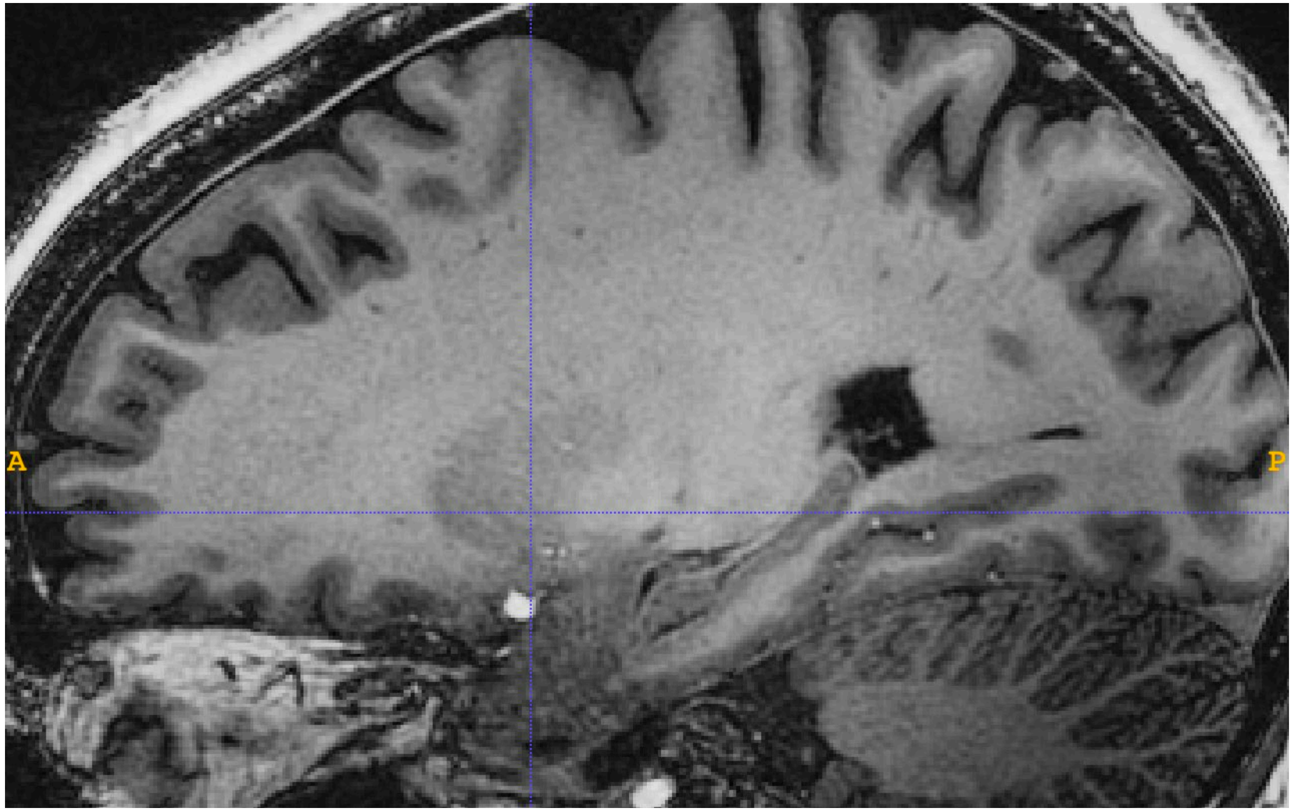
Signa 7T – MP-RAGE T1



0.7mm Isotropic Acquired Resolution – Signa 7T

Hippocampus at High Resolution



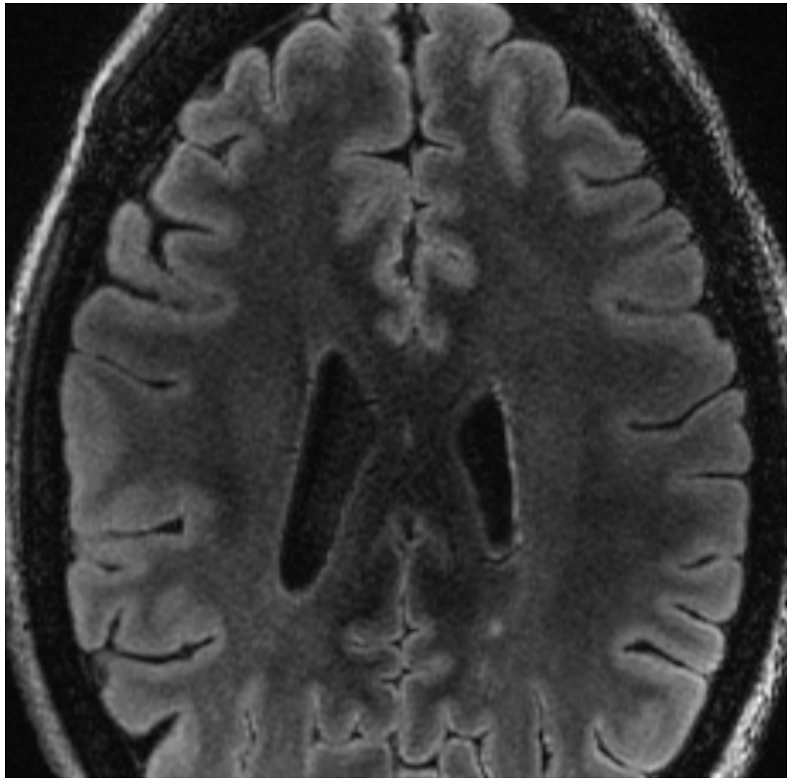


0.6mm isotropic resolution acquired at 7T

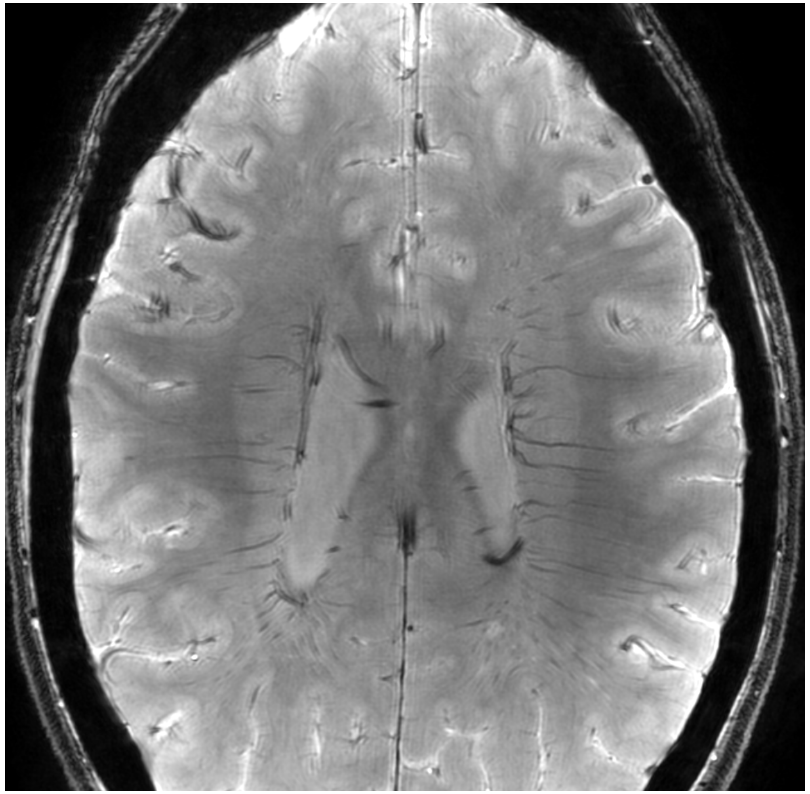
Examples of structural imaging in disease

Multiple Sclerosis Participant

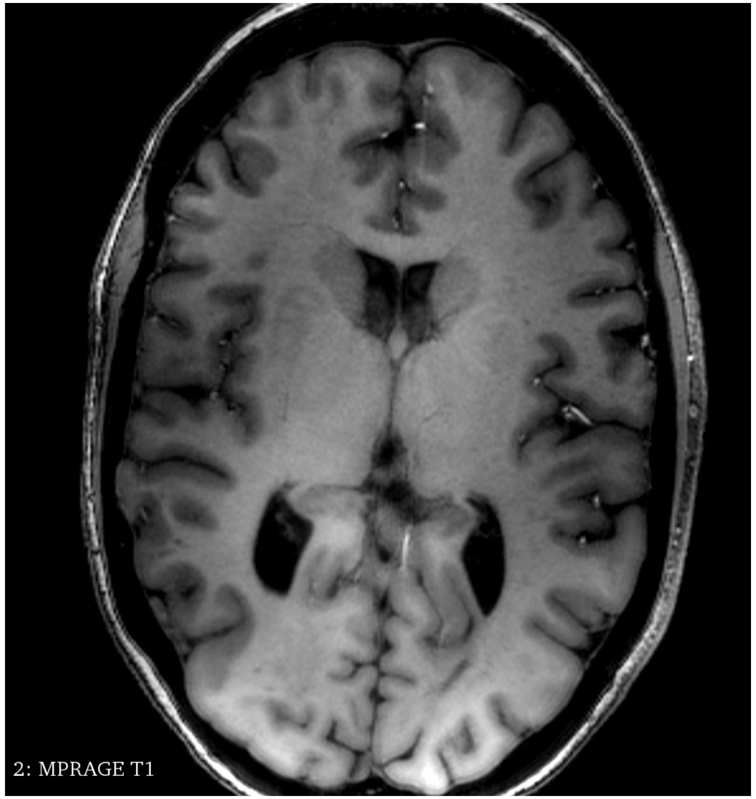
T2 FLAIR CUBE



Susceptibility Weighted



T1 MPRAGE



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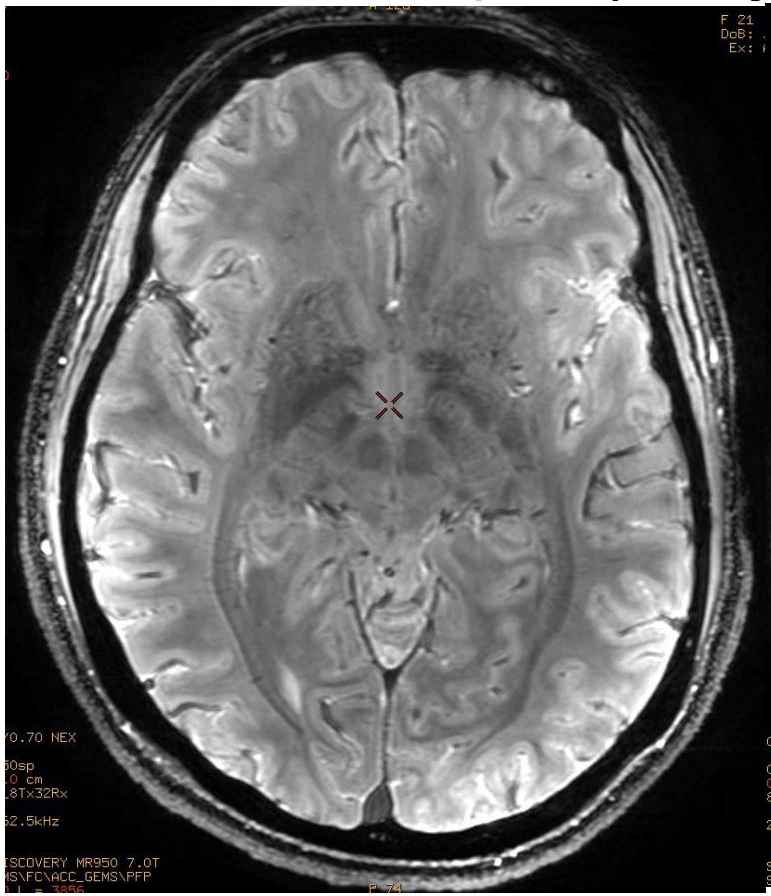
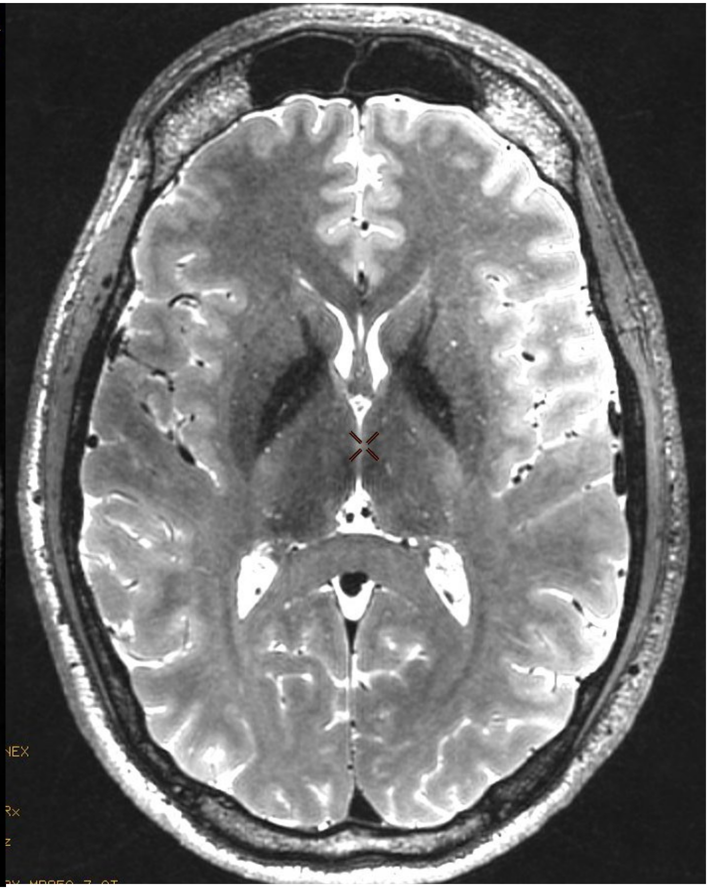
Huntington’s Disease Subject

Susceptibility Weighted Images



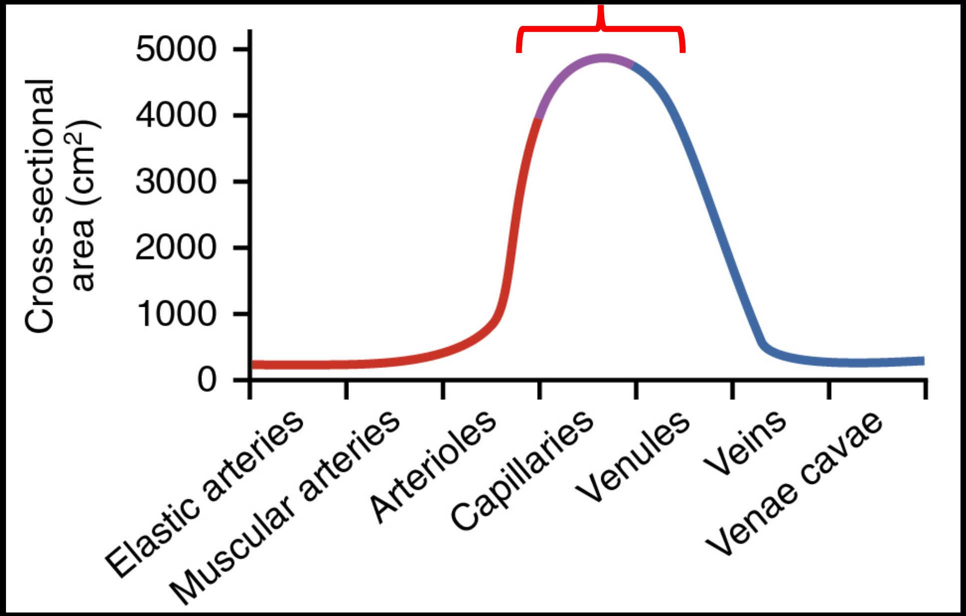
T2-weighted



Functional Imaging

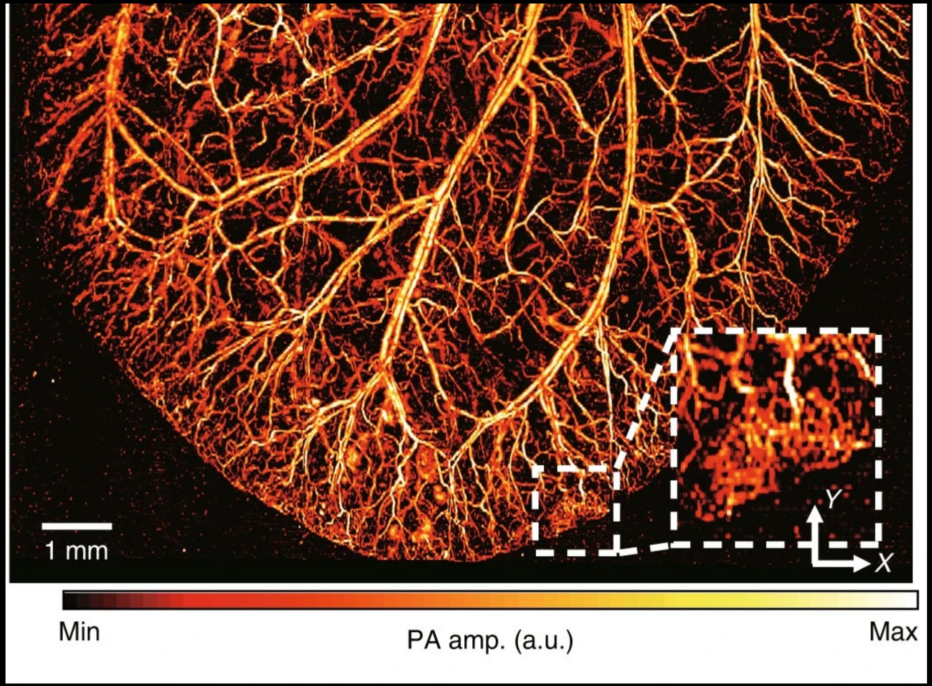
Perfusion and Capillary beds

Microcirculation system



Blood Flow, Blood Pressure and Resistance, Rice University, Open TextBook

Photoacoustic Microscopy in a Mouse Ear



Kim et al. Light: Science &Applications. (103) 2019

Example of a capillary bed.

Techniques to Analyze Perfusion

- Pre-imaging approaches.
  - Nitrous Oxide[1]
- Optical
- PET[2,3]
- CT[4]
- Ultrasound
  - Doppler[5,6,7]
  - Microbubbles[8,9]
- MRI
  - IVIM, ASL, DSC, DCE

[1] Kety SS, Schmidt CF. J Clin Invest 1948;27:476—83. [2] Kety SS. Semin NuclMed 1985;15:324—8. [3] Patlak CS, Blasberg RG, Fenstermacher JD. J Cereb Blood Flow Metab 1983;3:1—7. [4] Meier P, Zierler KL. J ApplPhysiol 1954;6:731—44. [5] Kedar RP, Cosgrove DO, Bamber JC, Bell DS. Radiology 1995;197(1):39–43. [6] Youssefzadeh S, Eibenberger K, Helbich T, Jakesz R, Wolf G. Clin Radiol 1996;51(6):418–20. [7] Leen E, Angerson WG, Cooke TG, McArdle CS. Ann Surg 1996;223(2):199–203. [8] Krix M. Eur Radiol 2005;15(Suppl 5):E104–8. [9] Meier P, Zierler KL. J Appl Physiol 1954;6:731–44.

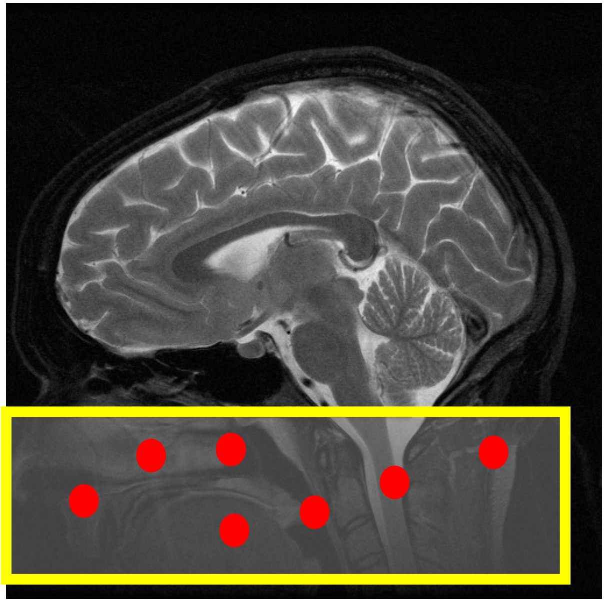
Common MRI-Based Perfusion Imaging Methods

	Tracer	Signal directly related to:	Common derived parameters
ASL	Mz of water	Blood flow	ATT
DSC	Gadolinium	Blood volume	Blood flow, MTT
DCE	Gadolinium	Vascular permeability	Transfer rate constant (K_{trans})

E.C. Wong , An Introduction to ASL Labeling Techniques. JMRI 2014. .Pg. 1-10.

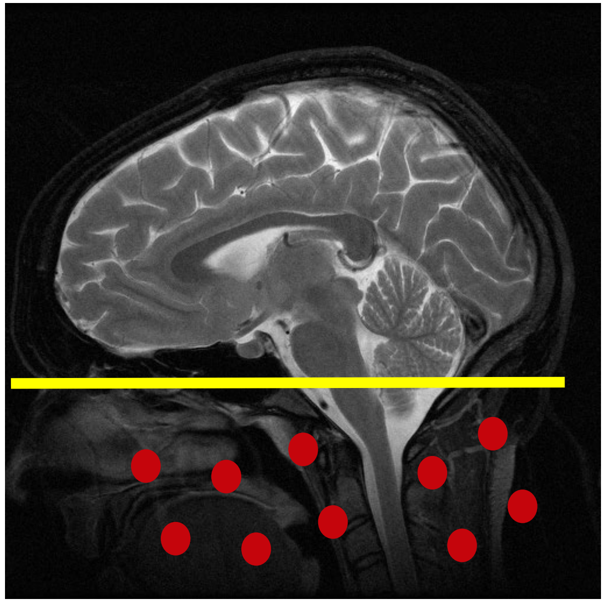
ASL and Virtual Magnetic Labeling of Spins

Selective Slab Based
(PASL, FAIR, STAR)



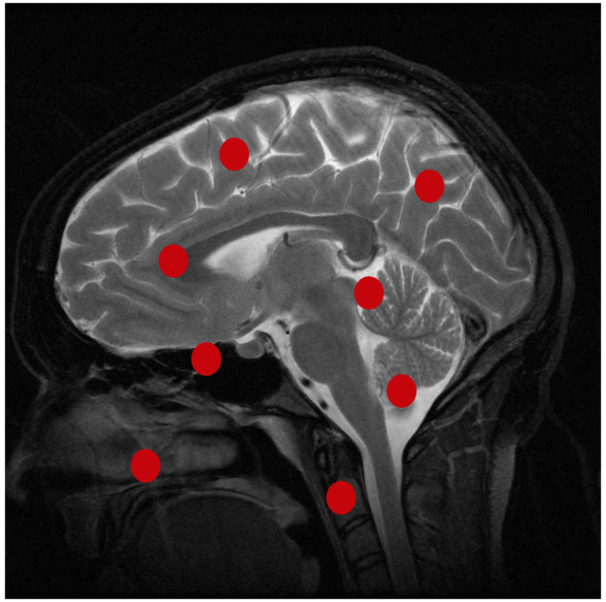
Blood in the slab tagged and moves into volume

Slice Based
(CASL, PCASL)



Blood that passes through plane is tagged

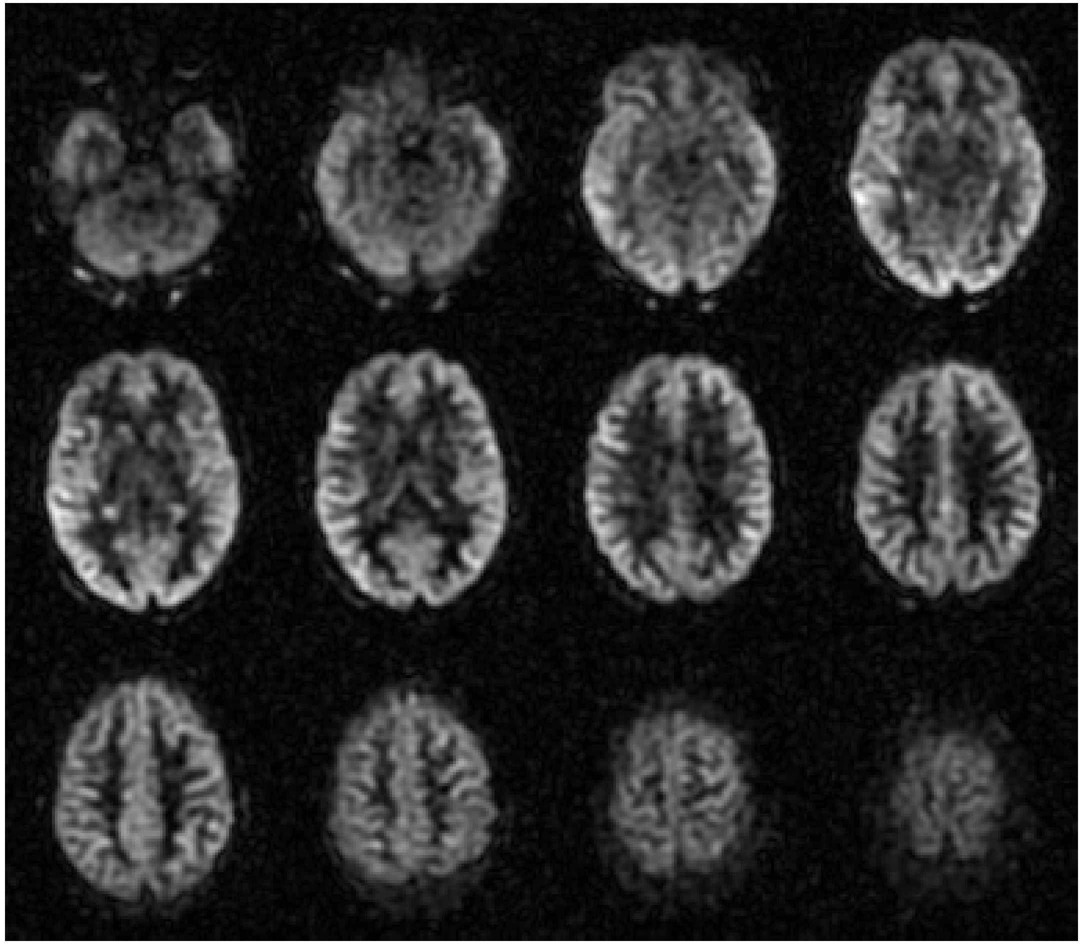
Motion Based
(VS-ASL)



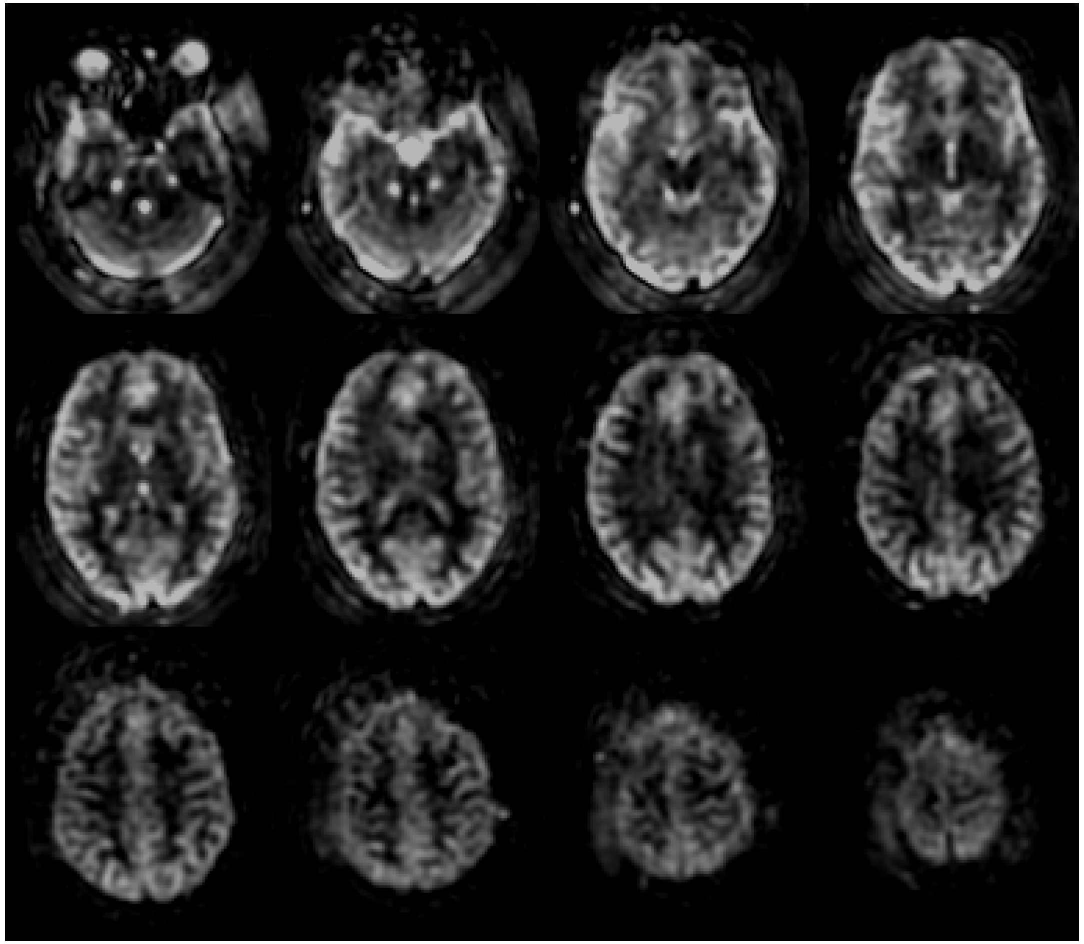
Blood that moves is tagged

Comparison (same normal volunteer)

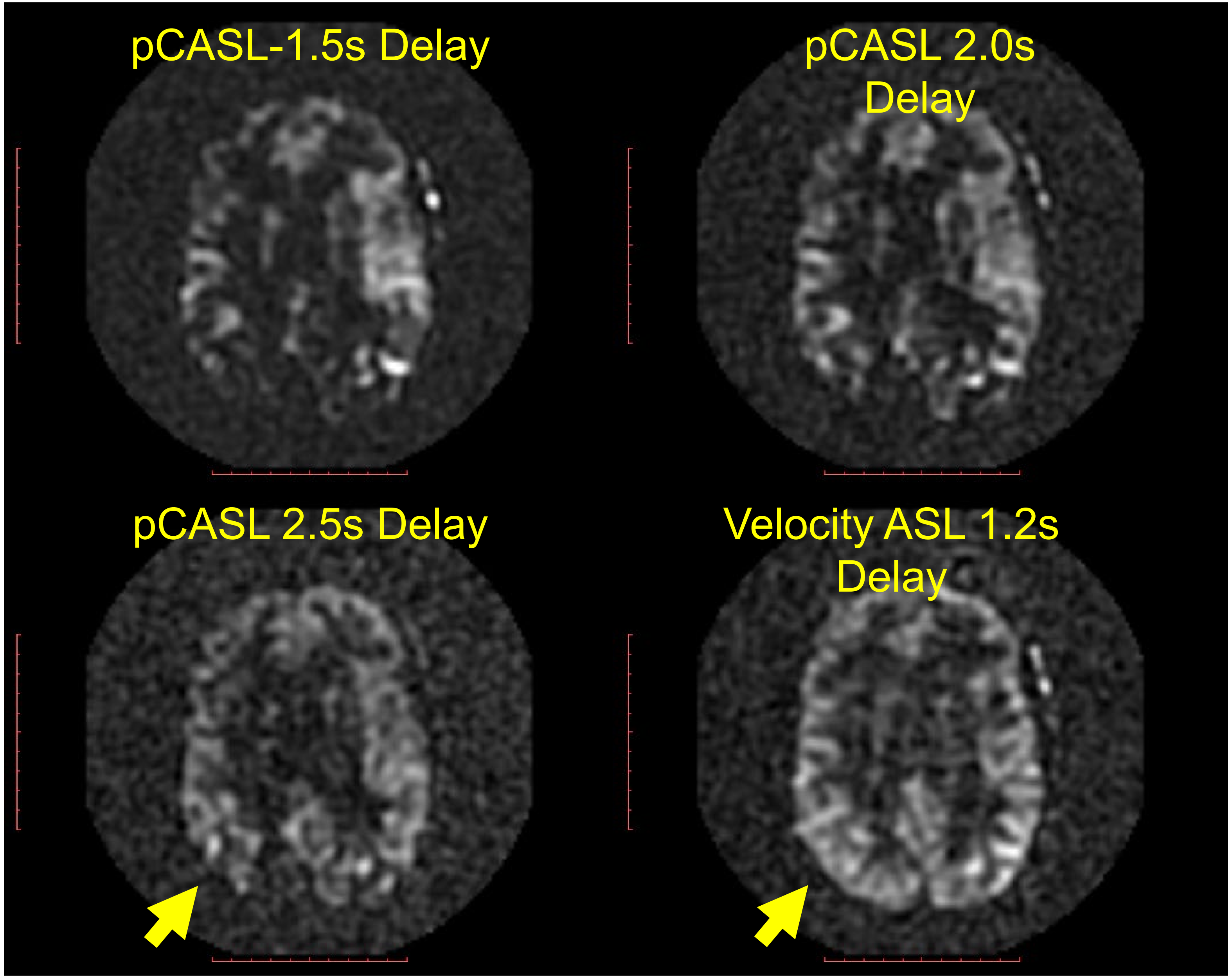
Spatial (PCASL)



Velocity (VSASL)



69y old subject with slow filling

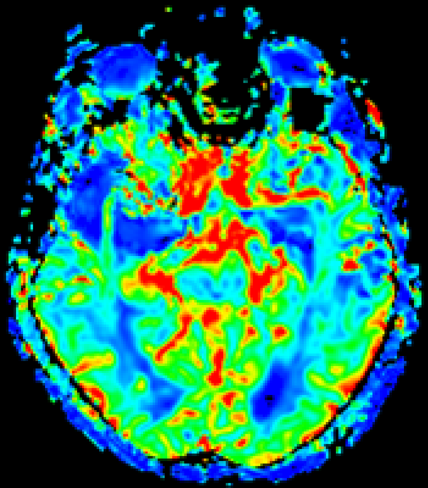


GBM : Progression vs Pseudoprogression vs Radiation Necrosis

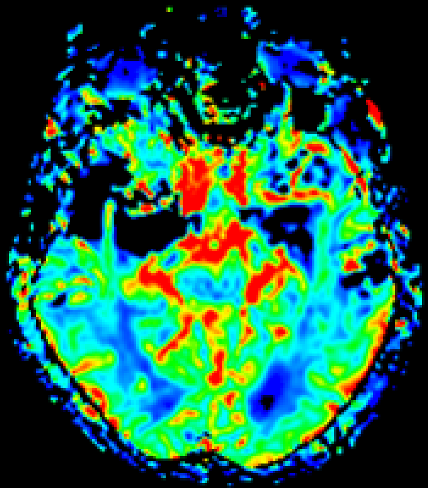
CE T1

DSC CE Perfusion

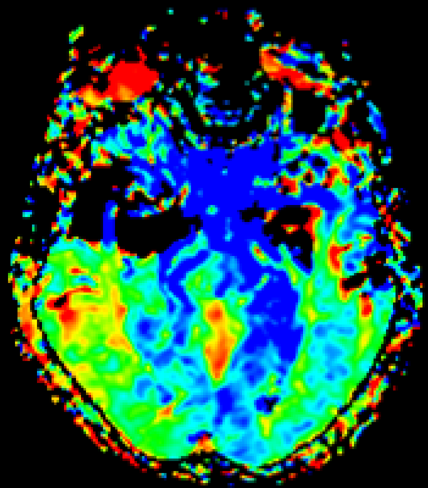
CBF



CBV

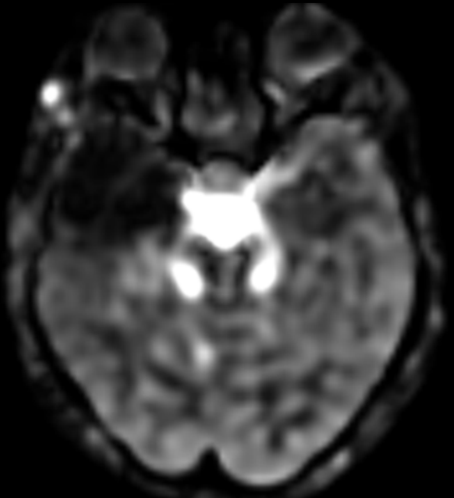


F MTT

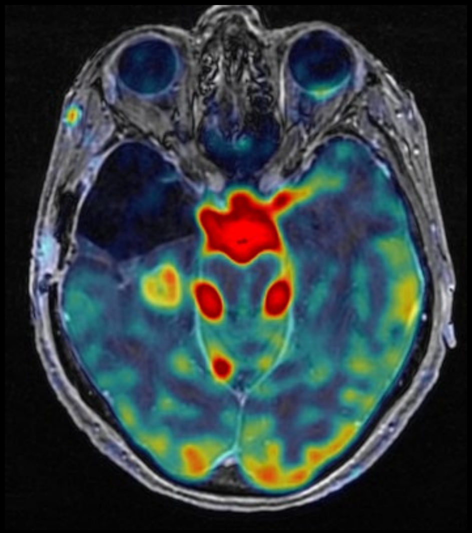


VS ASL MRA

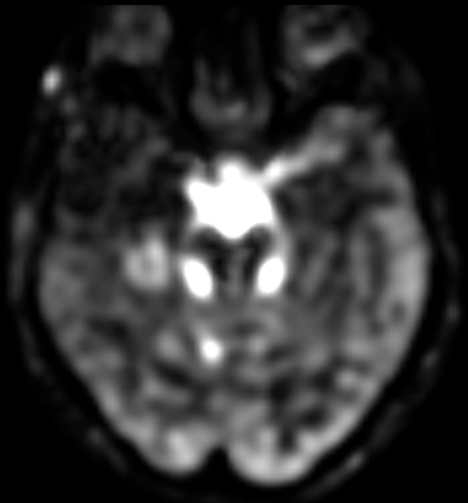
VSASL Perfusion



Quantitative CBF

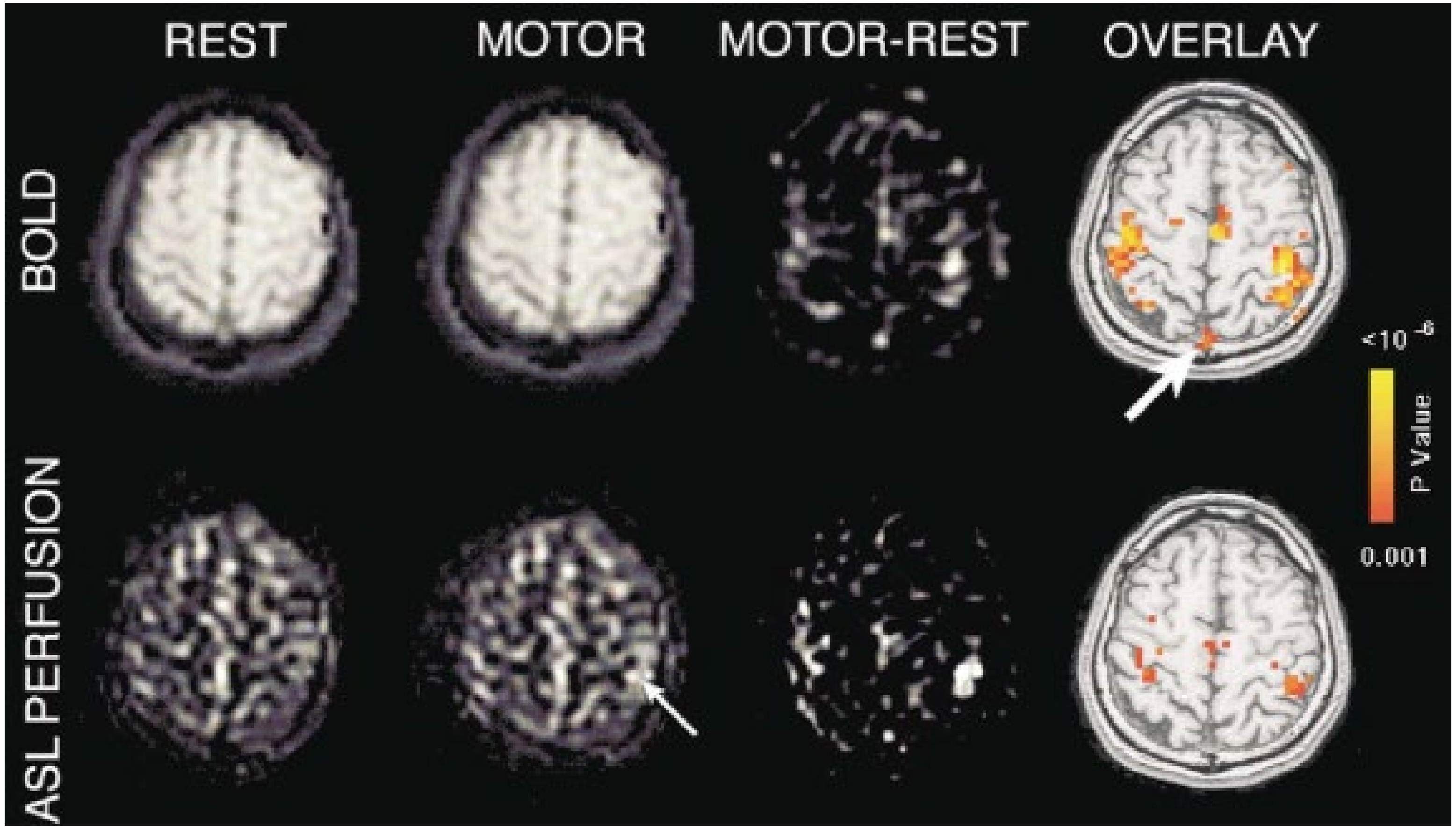


Perfusion



Qualitative Difference

Example: fMRI using ASL



Bi-lateral finger tapping

J.A. Detre, J. Wang. Clinical Neurophysiology 113 (2002) 621–634

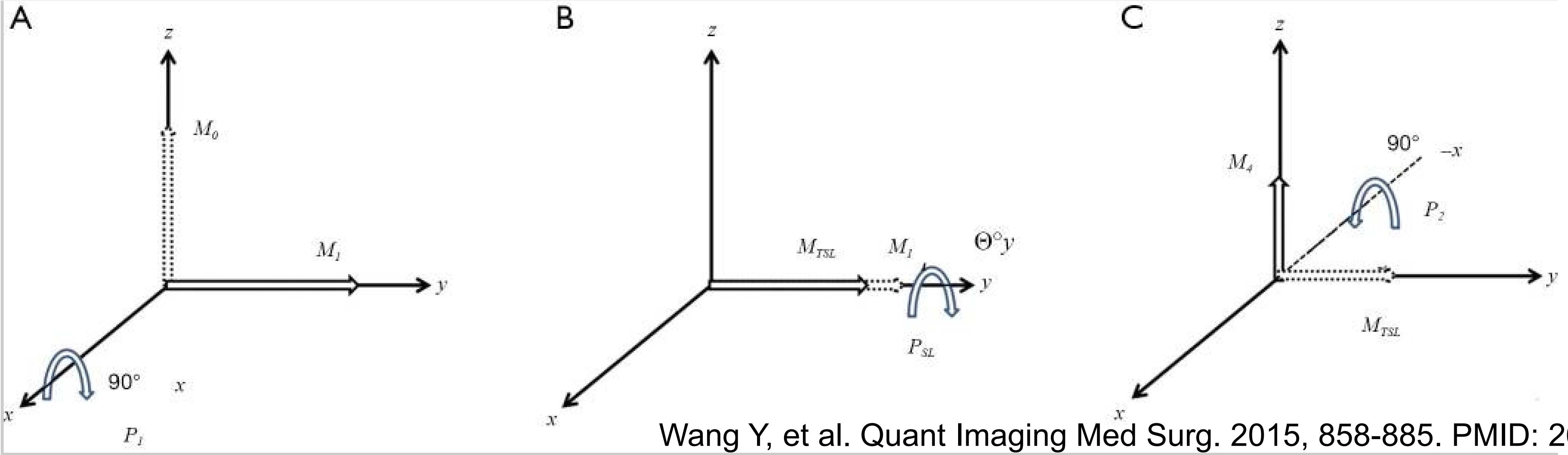
Metabolic Imaging

T1ρ, CEST, MRS

T1ρ (T1rho)

- Measures spin lattice relaxation time in rotating frame.
- Relaxation includes molecular interactions such as chemical exchange, dipolar interaction, and J-coupling

Preparation Overview

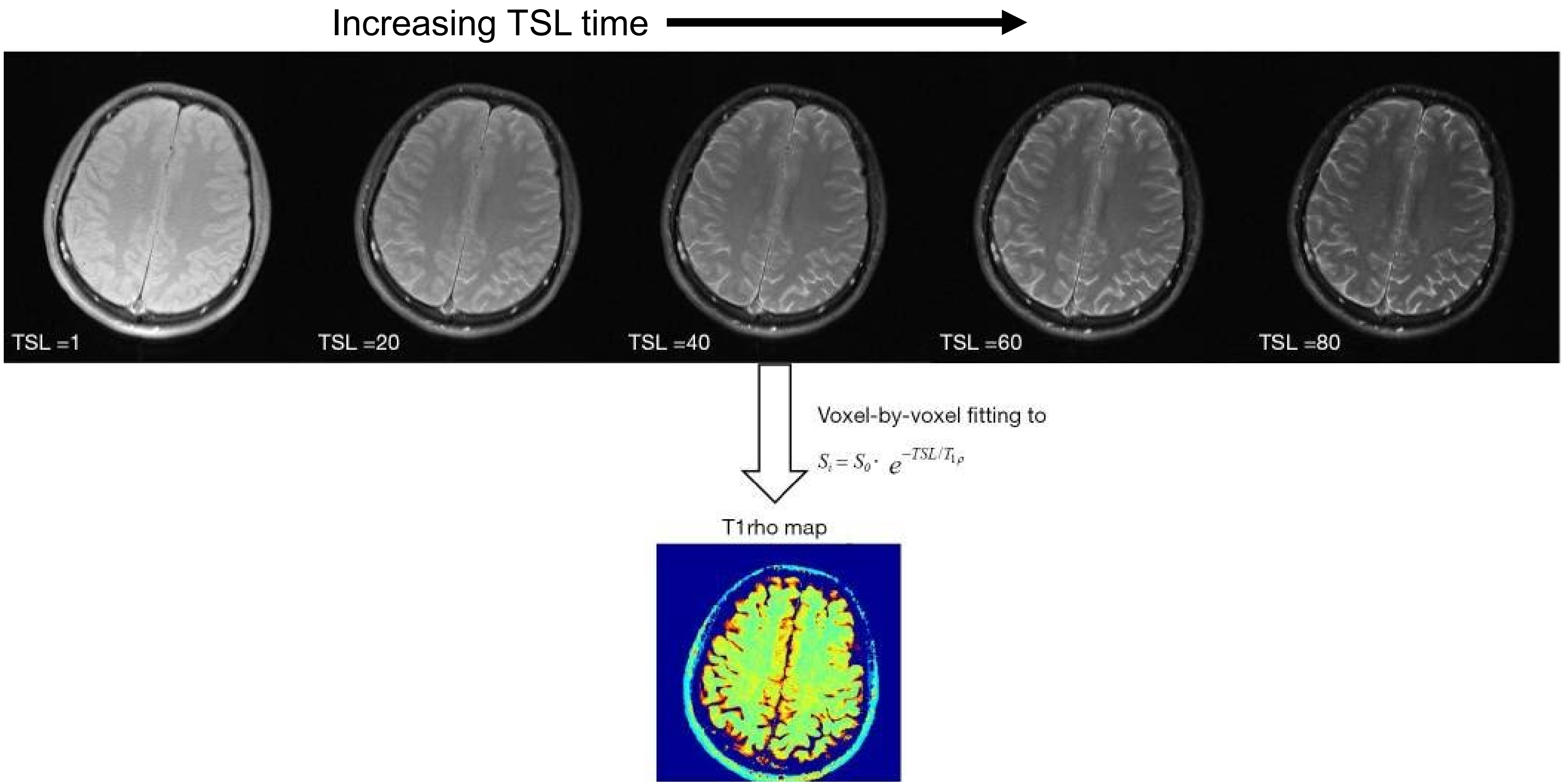


Wang Y, et al. Quant Imaging Med Surg. 2015, 858-885. PMID: 26807369

A) Tip-down 90 pulse
B) Spin-lock pulse in transverse plane for time TSL
C) Tip-up 90 pulse

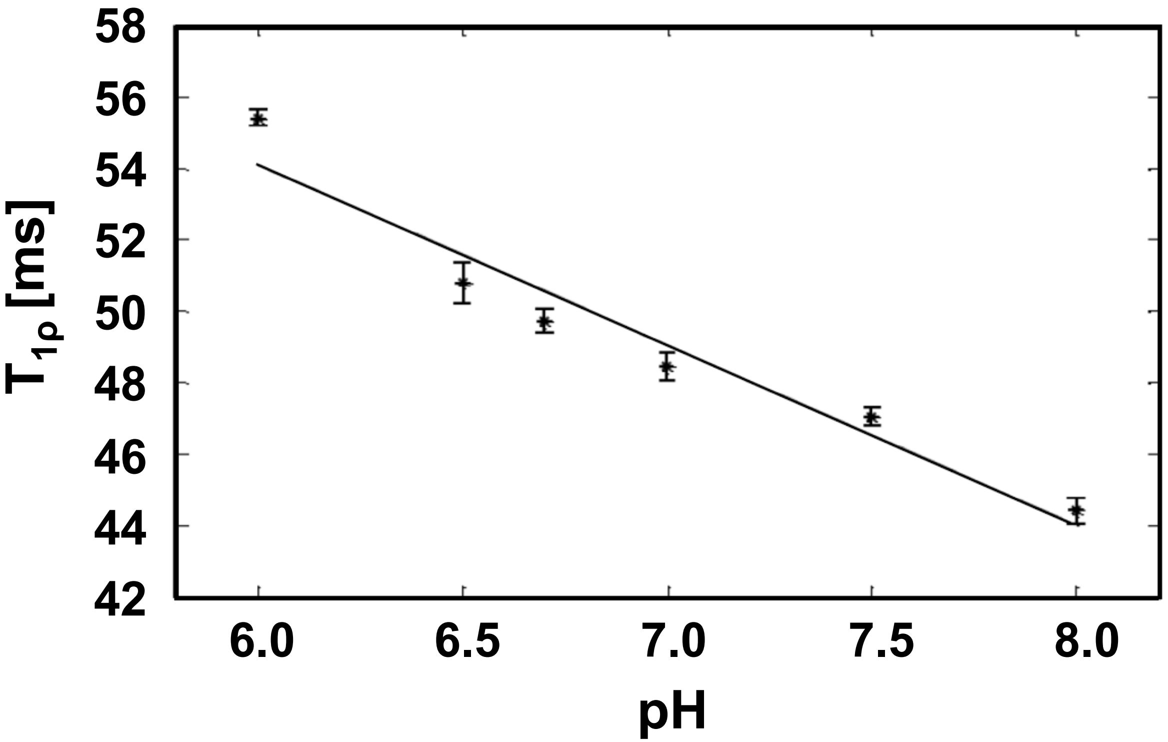
Redfield AG. Nuclear magnetic resonance saturation and rotary saturation in solids. Phys Rev 1955;98:1787.

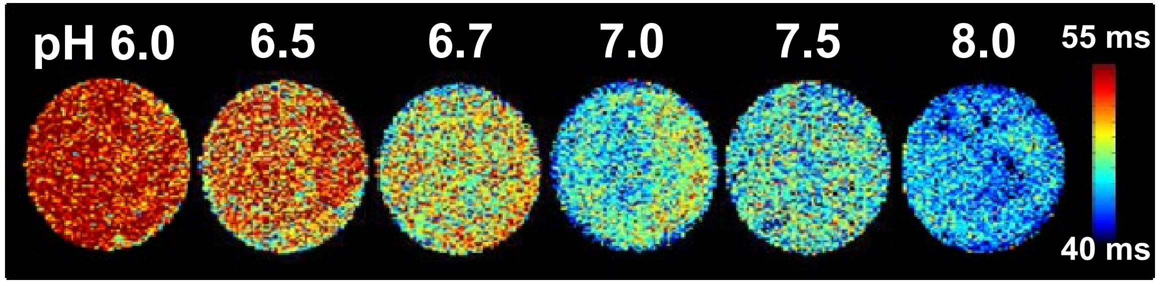
T1ρ



Wang Y, et al. Quant Imaging Med Surg. 2015, 858-885. PMID: 26807369

T1ρ Sensitivity to pH





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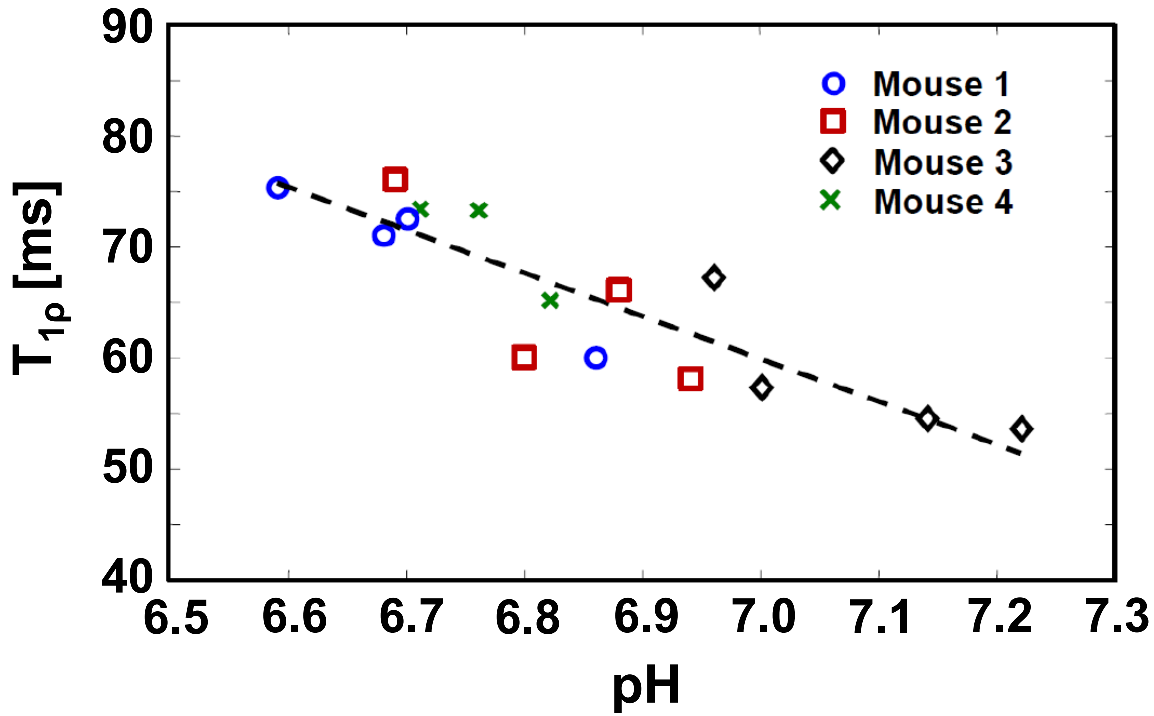
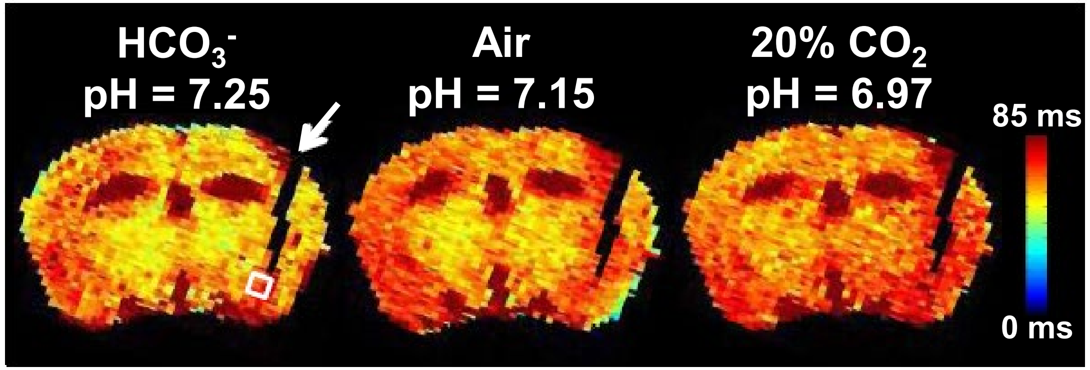
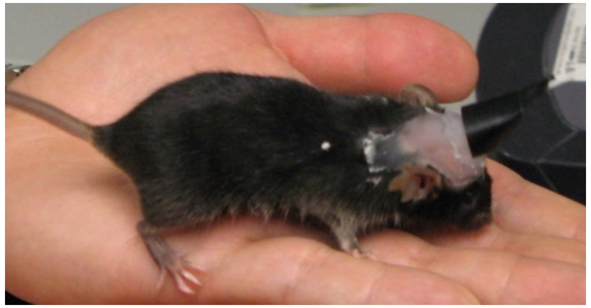
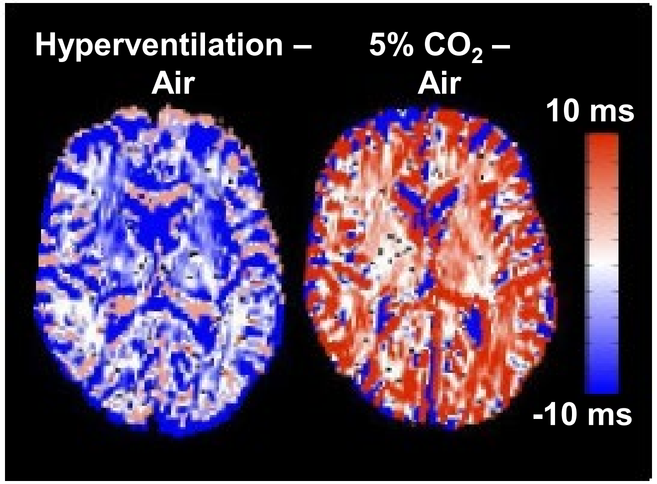
Animal Validation

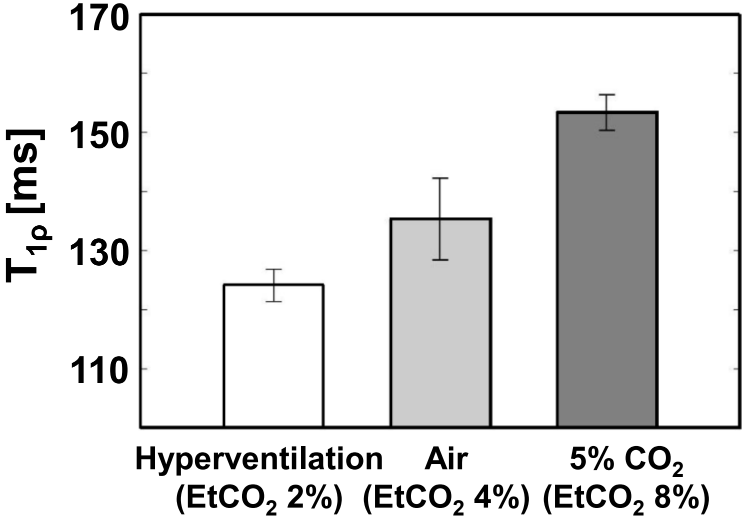


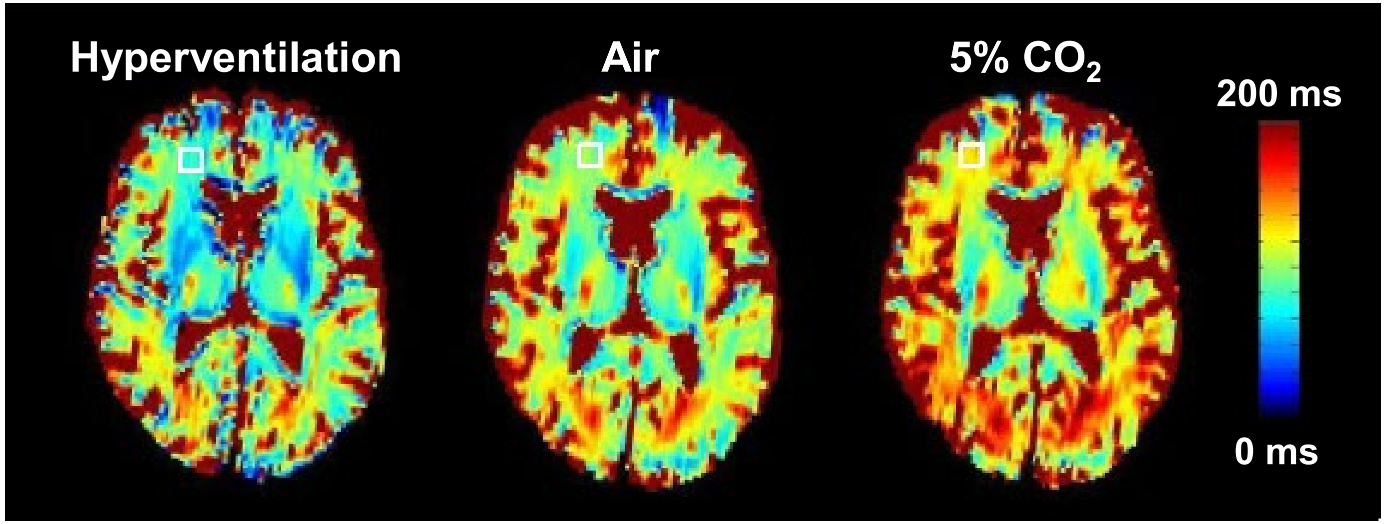




In vivo Evaluation







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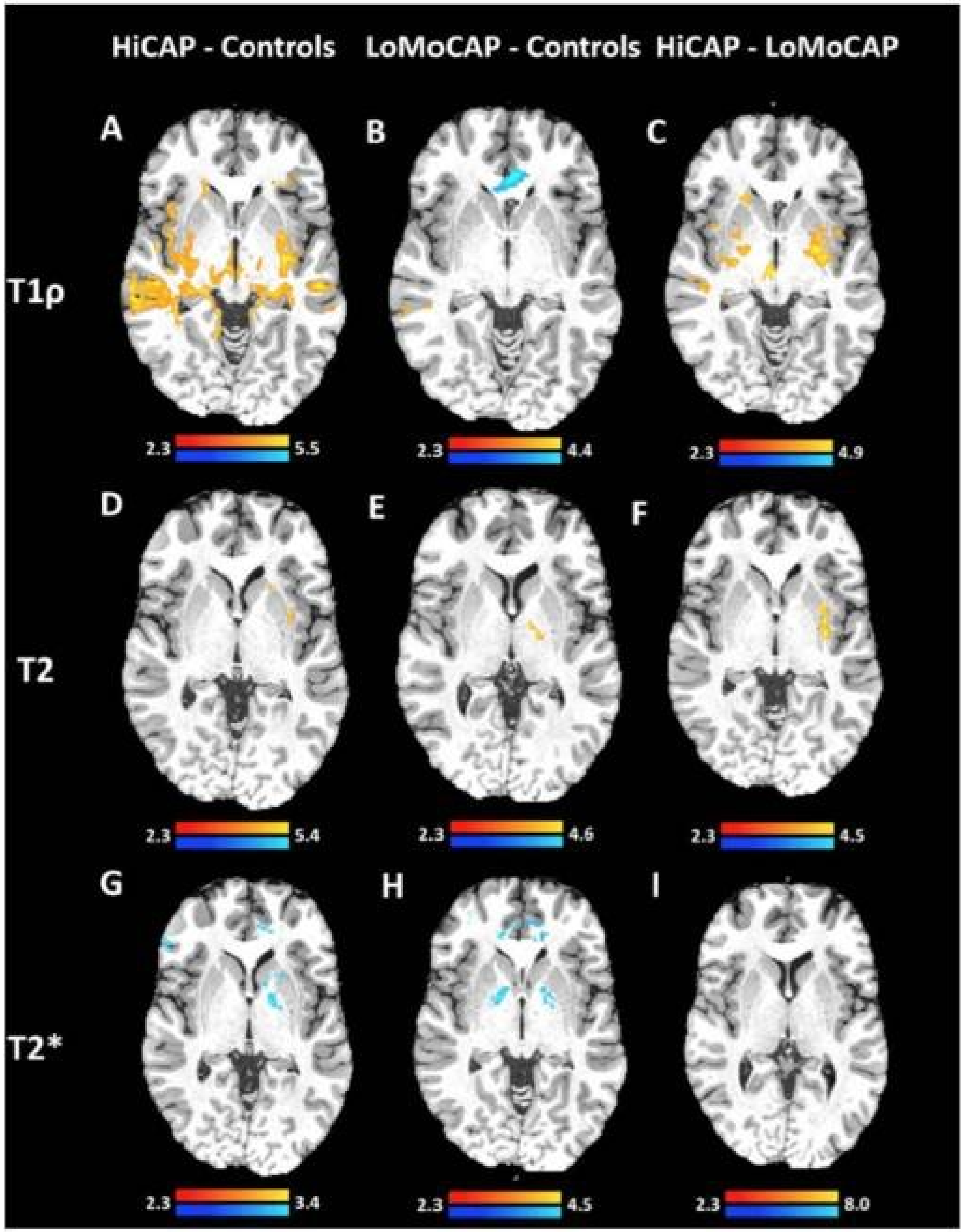
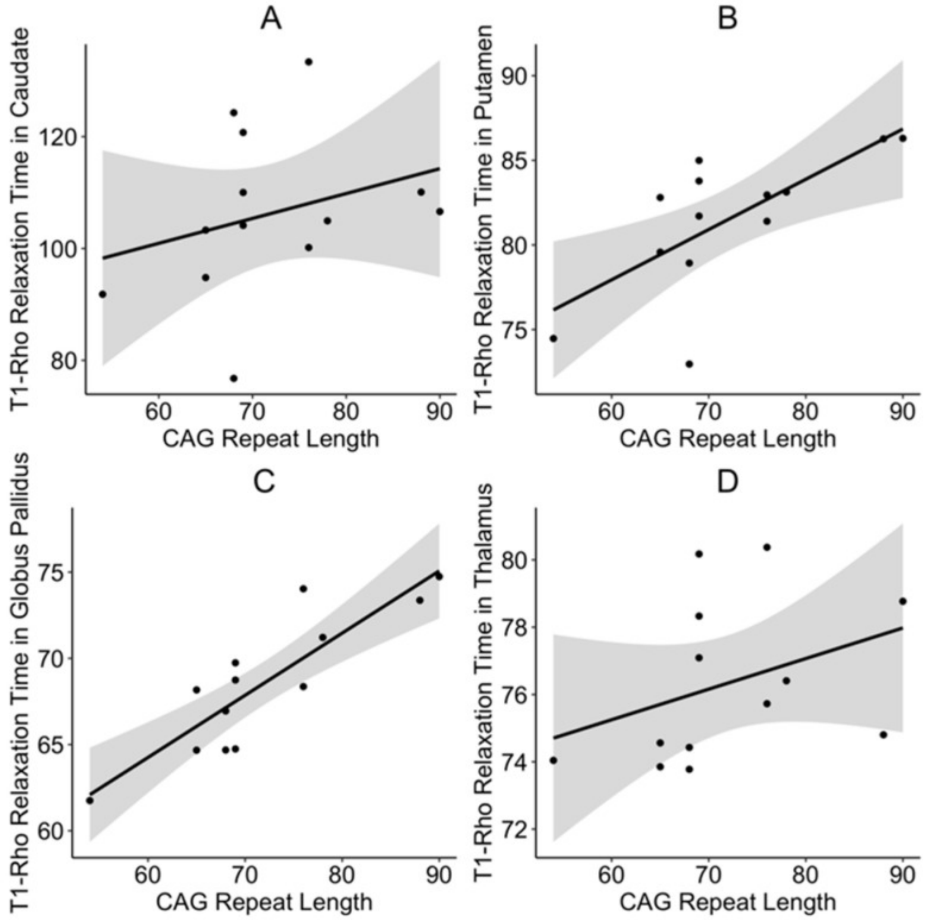
Multi-Parametric MR Imaging in HD

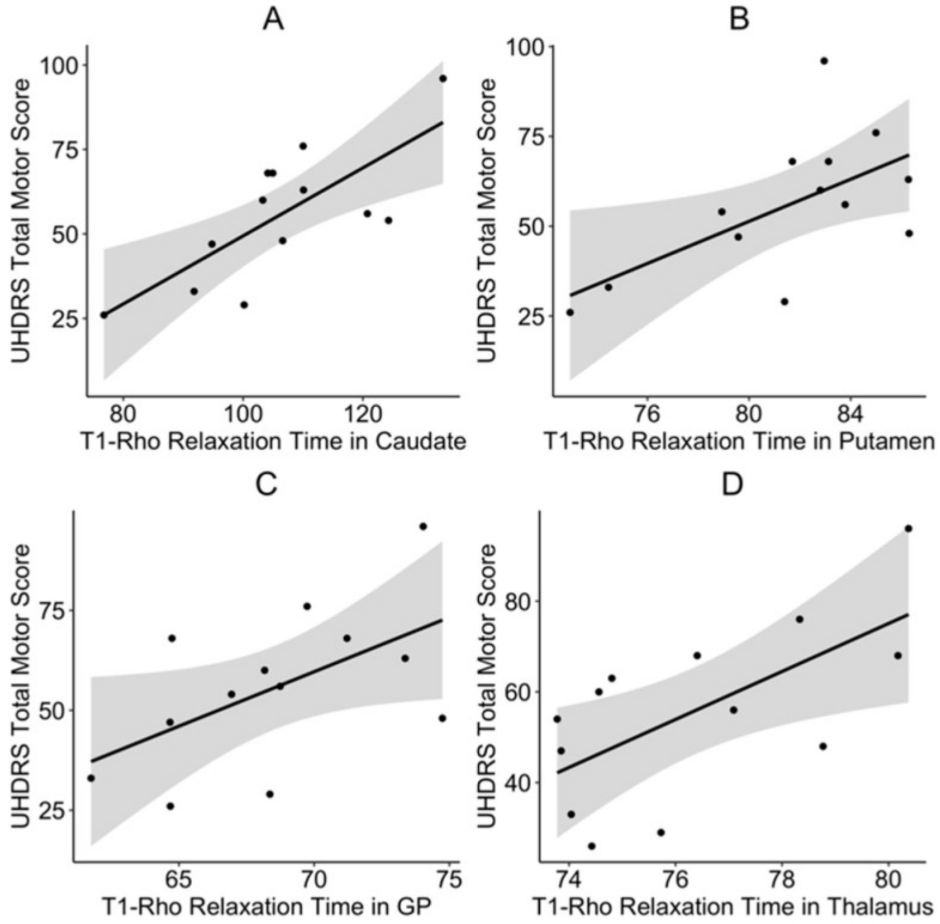
<u>Demographics</u>
Controls N=26
HiCAP: N=24 (CAG Age Product=430)
LoMo CAP: N=26 (CAG Age Product=295)

Data from Wassef et al. 2015



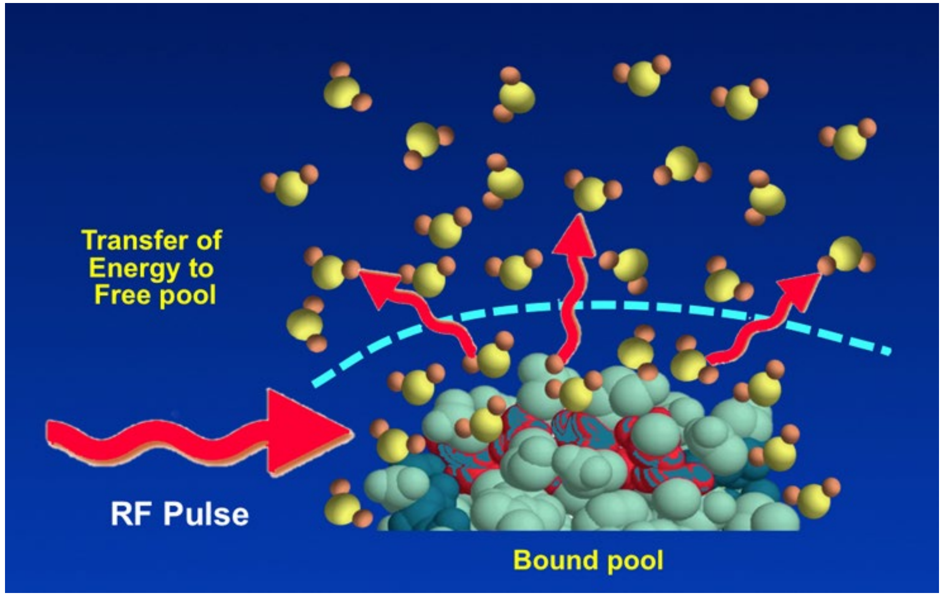
T1ρ in Juvenile Onset HD





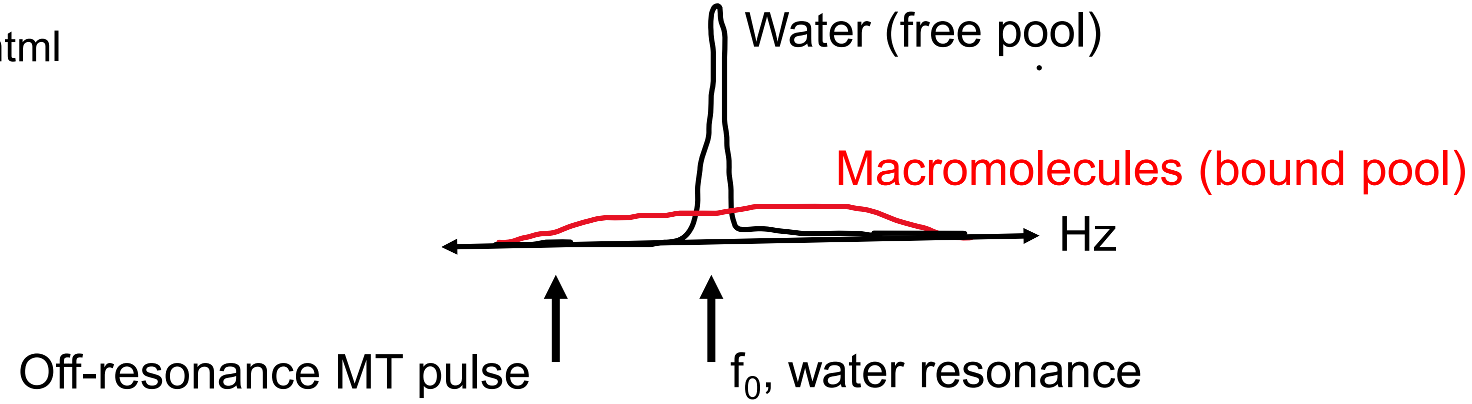
Data from Tereshchenko et al. 2020

Magnetization Transfer (MT) and Chemical Exchange Saturation Transfer (CEST)

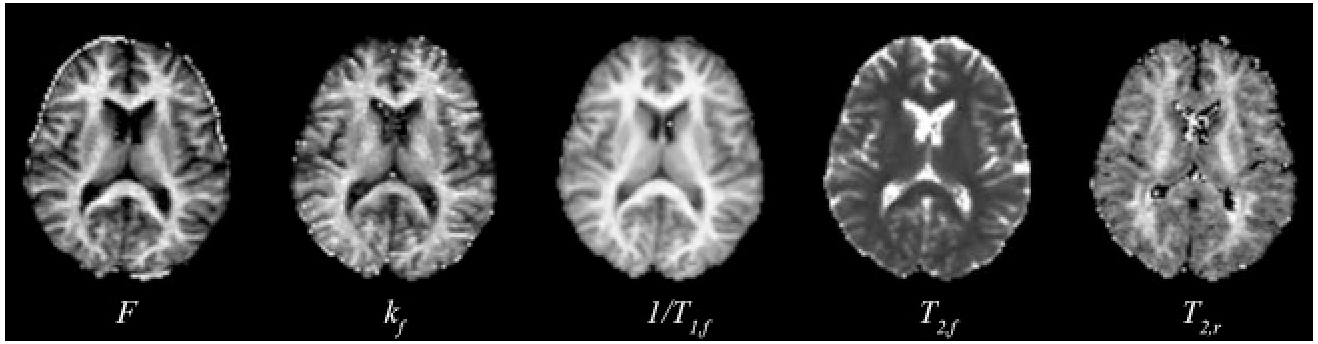


https://mriquestions.com/magnetization-transfer1.html

1) An off-resonance RF pulse excites the protons in the bound pool
2) Energy is transferred from the protons in the bound pool to those in the free pool
3) The change in signal is measured by imaging protons in the free pool on-resonance



Magnetization Transfer

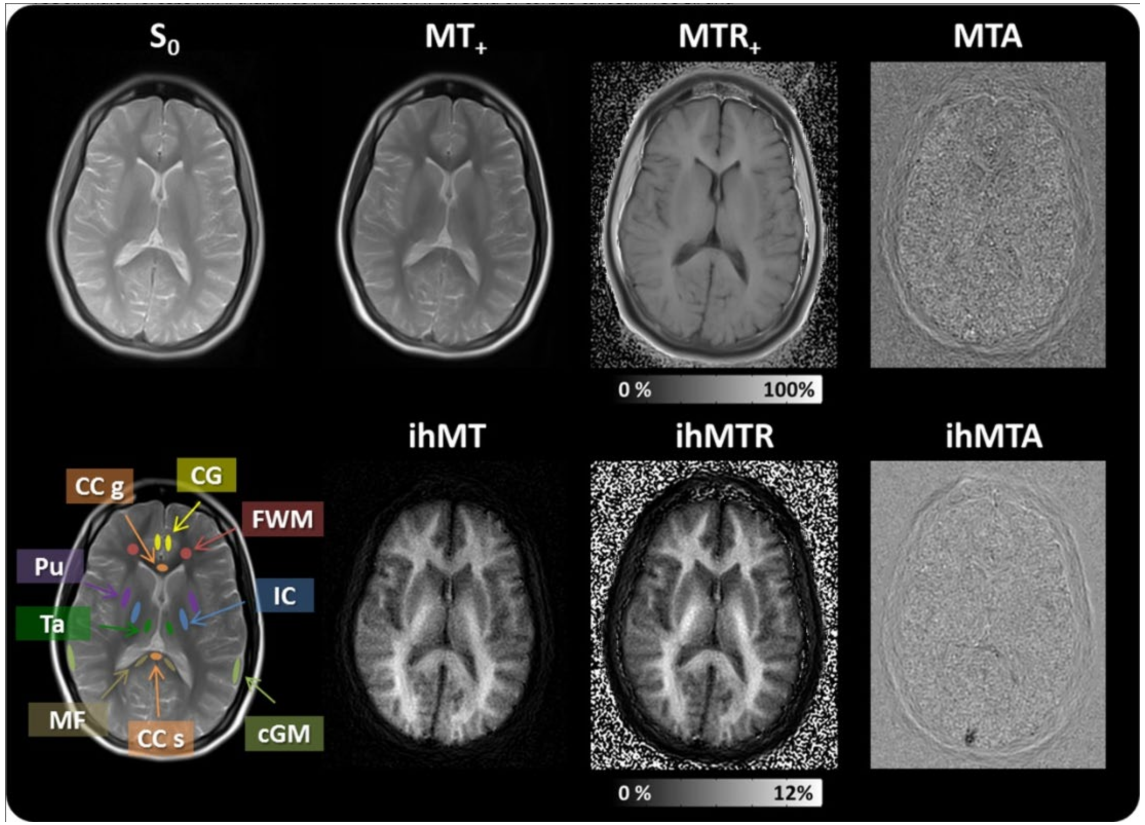


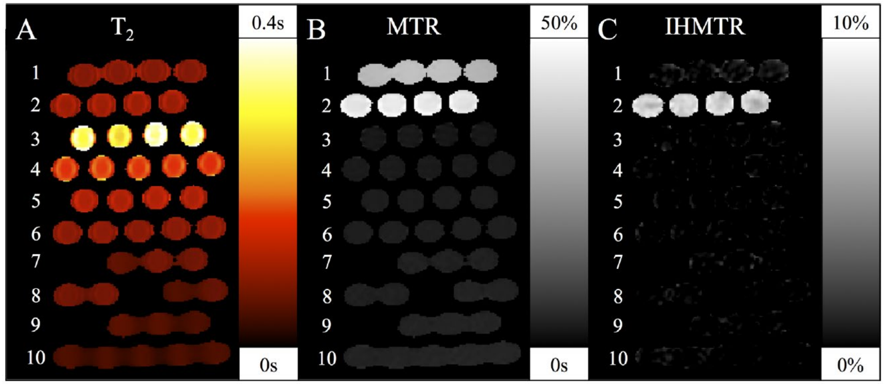
Quantitative MT images of the adult human brain.

Parameters include:
Pool size ratio *F*
Forward exchange rate k_f
Spin-lattice relaxation rate of the free pool $1/T_{1,f}$
Spin-spin relaxation rate of the free pool $T_{2,f}$
Spin-spin relaxation rate of the restricted motion pool $T_{2,r}$

Sled et al. MRM. 2001;46:923-931

Magnetization Transfer



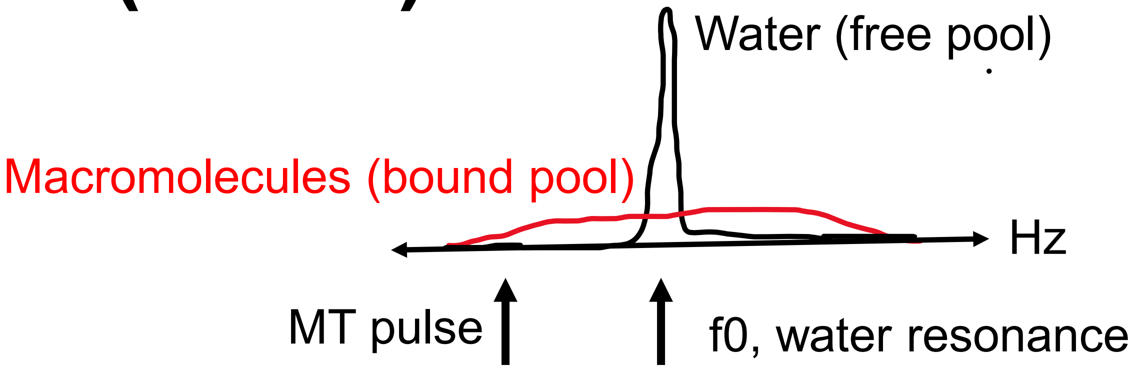


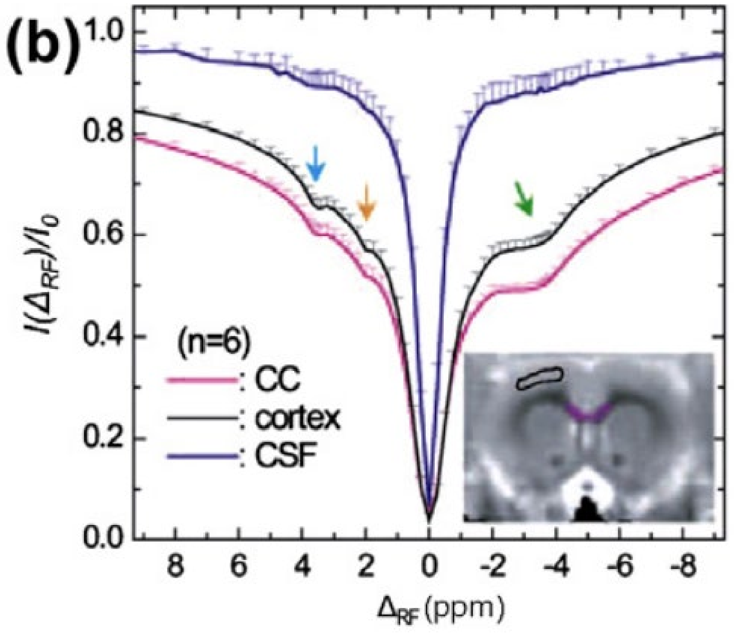
Exploits asymmetry of the MT spectrum. Provides sensitivity to myelin.

Varma et al. MRM 2015
Girard et al. MRM 2015;73:2111-2121

Magnetization Transfer (MT) and Chemical Exchange Saturation Transfer (CEST)

Extending to Z-spectrum and CEST
1) An off-resonance RF pulse excites the protons in the bound pool (fn)
2) Energy is transferred from the protons in the bound pool to those in the free pool
3) The change in signal is measured by imaging on-resonance protons in the free pool
4) Increment the off-resonance RF pulse and repeat steps 1-2.



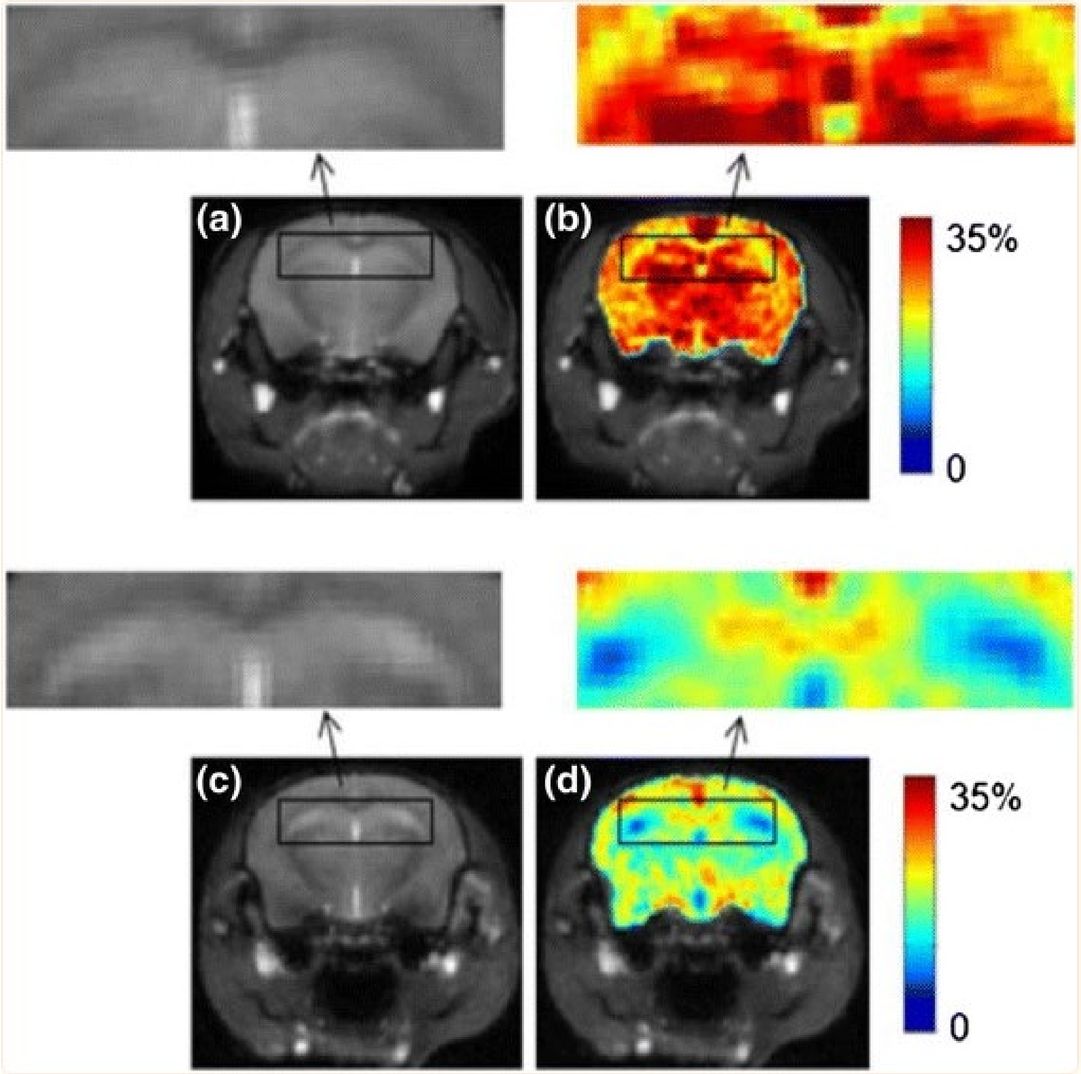


T. Jin et al. Magn. Reson. Med. (2012).

Example: Glu-CEST in AD

Mapping neurotransmitter Glutamate

- Mouse model of AD at U. Penn.
- Anatomical images (a, c)
- Glu-CEST (b, d)
- wild-type control (top)
- Alzheimer's disease (bottom)

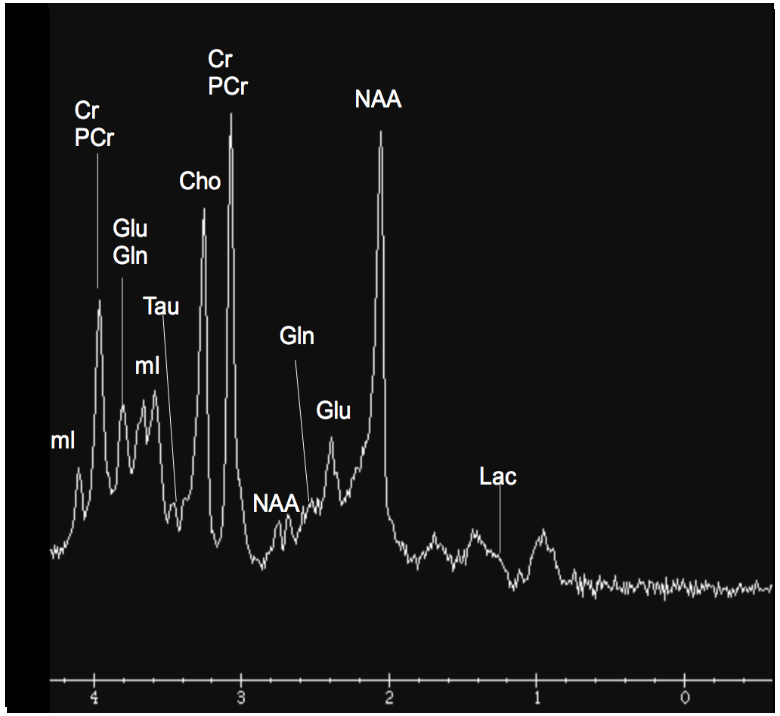


Haris M, et al. NMR Biomed. 2013;26:386–91. doi: 10.1002/nbm.2875.

CEST Used in Neurological Disorders

- Overview by Shaffer et al. Front Psychiatry. 2020
- APT CEST
  - Stroke: Harston et al. Brain (2015), Tietze et al. NMR Biomed (2014), González et al. J Magn Reson Imaging (2012)
  - AD: Wang et al. Chin Med J (Engl) (2015)
  - PD: Li et al. Eur Radiol (2014)
- GluCEST
  - Mouse models of HD, AD, and PD
- MICEST
  - Mouse models of AD

Single Voxel MRS - semiLASER

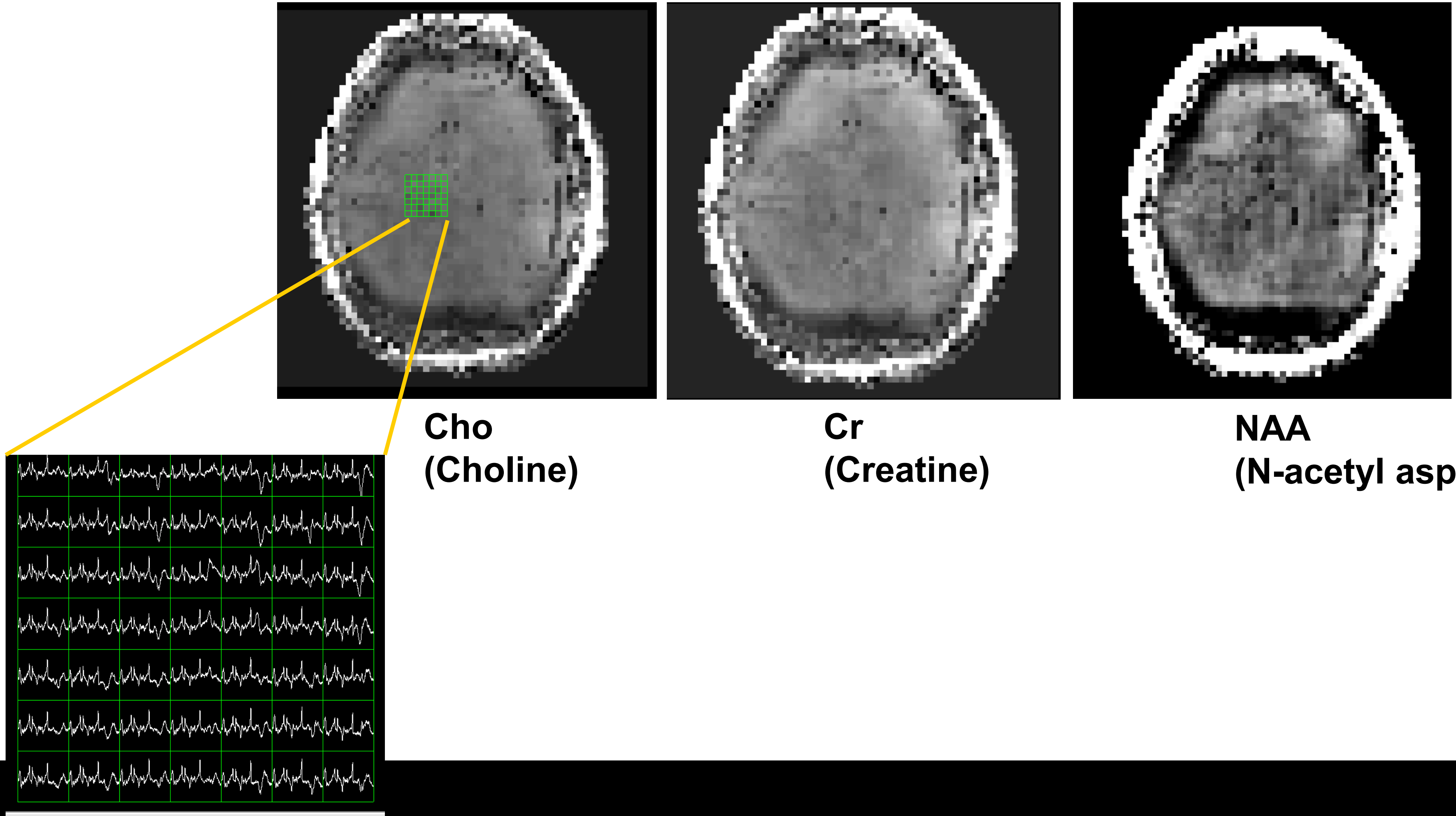


Data from Cerebellar Vermis
2x2x2cm voxel – MR950 (7T)

Metabolite	Coefficient of Variation (CV)
Cho	1.03
Cr+PCr	2.77
NAA	1.65
Glx	1.31
Gsh	0.79
ml	1.18
Asp	1.41
Tau	3.27

Localizer + Cal + MRS = 8 minutes

FID Acquisition - Volunteer



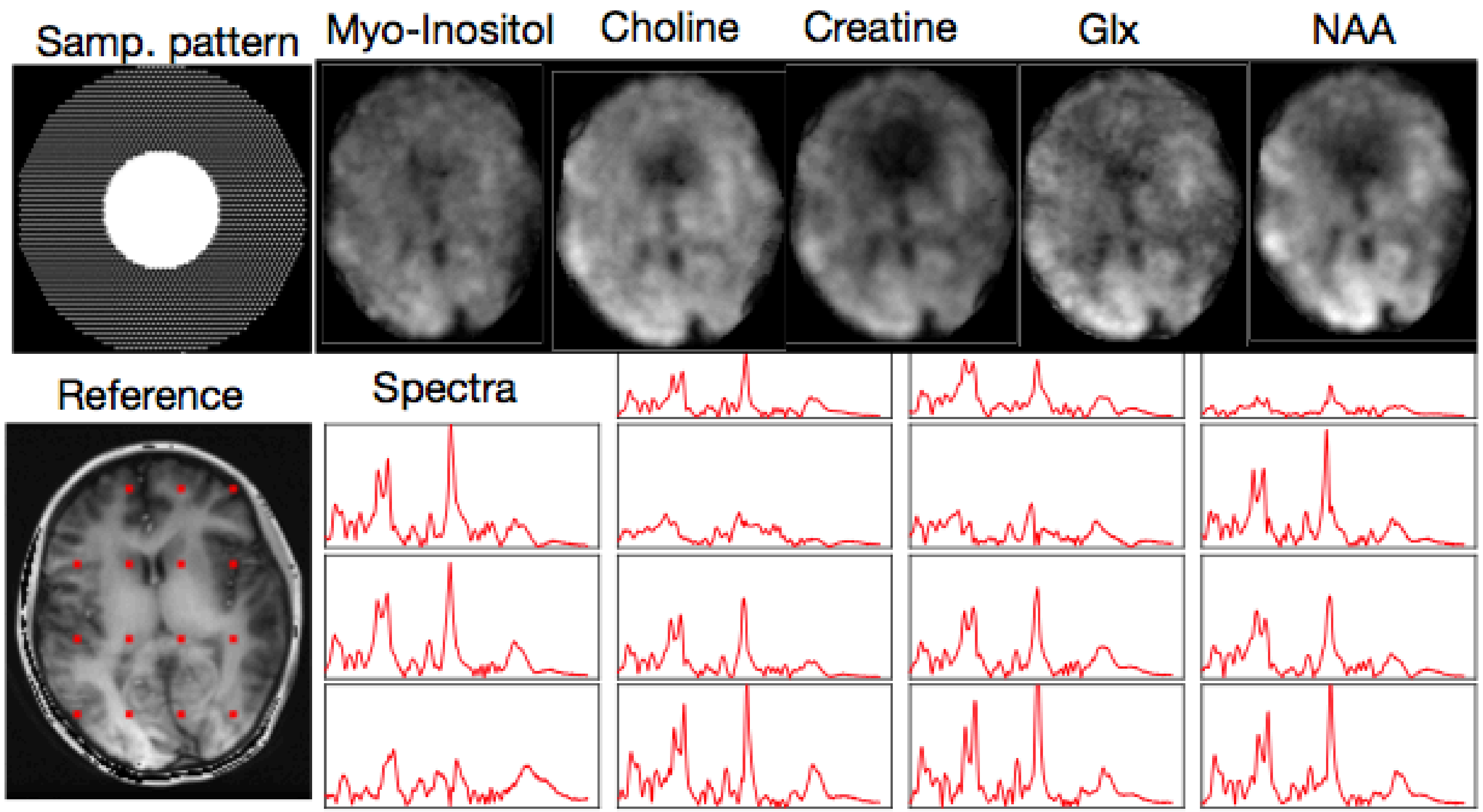
Cho
(Choline)

Cr
(Creatine)

NAA
(N-acetyl aspartate)

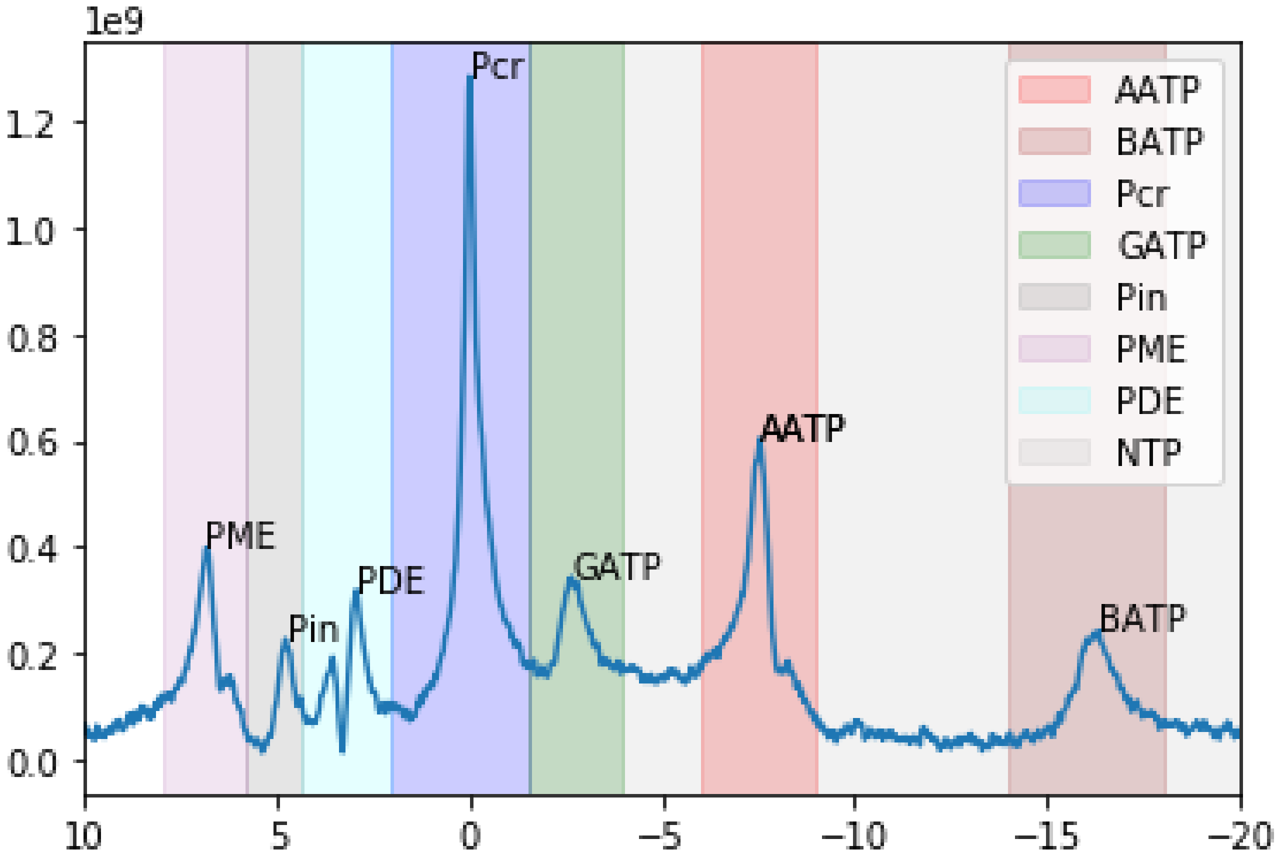
Scan Parameters
Matrix=64x64
FOV=20x20cm
Slice=10mm
WET WS
Acq Time:
WS=12 min
NWS=4min

7T CSI Acquisition



Data from Mathews Jacob

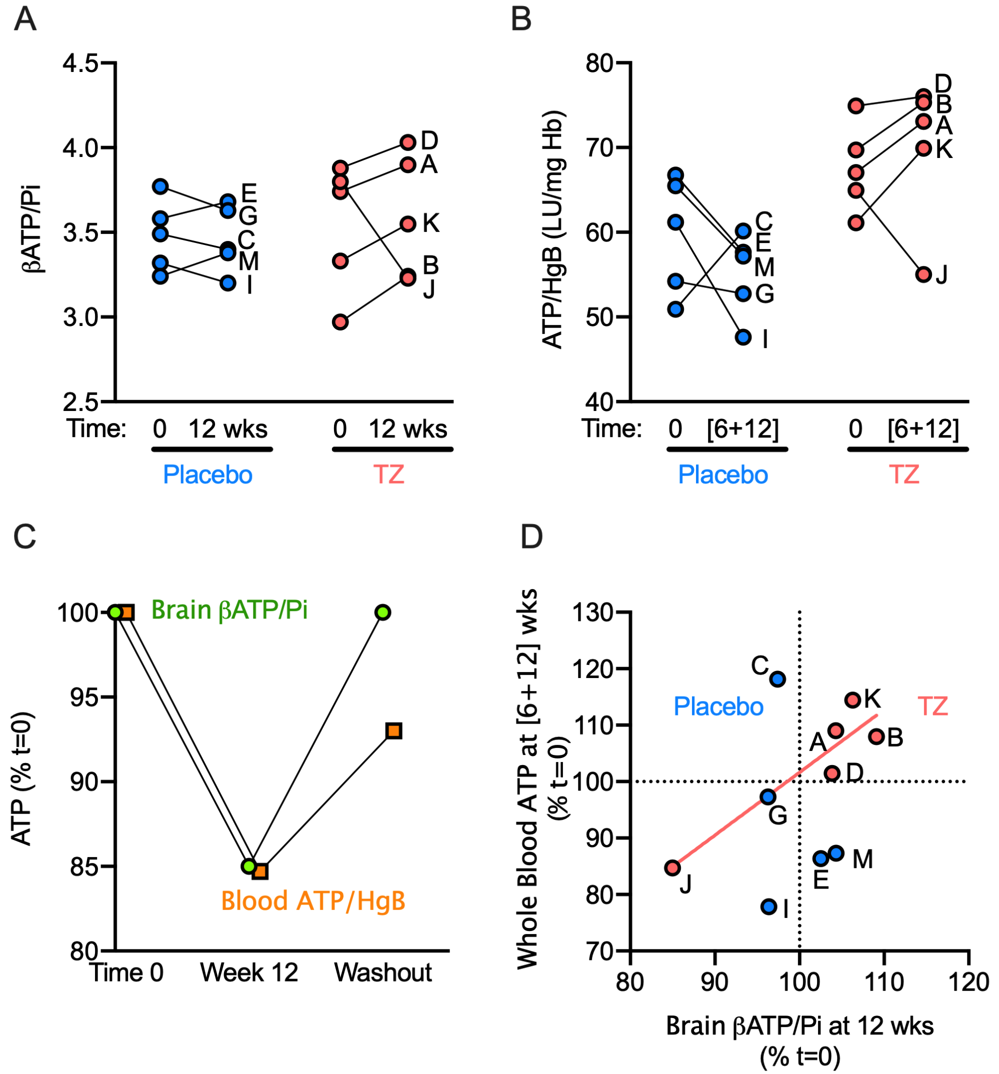
^{31}P MRS



- Provides insight on energy processes
- Pcr (phosphocreatine) dominant signal
- ATP composed of 3 phosphate groups
- PME (phosphomonoesters)
- PDE (phosphordiesters)
- Pin (inorganic Phosphorus) shift is pH dependent.

Data from Jia Xu - MR950

^{31}P MRS: Terazosin Trial in PD



TZ Study
Kumar Narayanan
Jordan Schultz
Mike Welsh

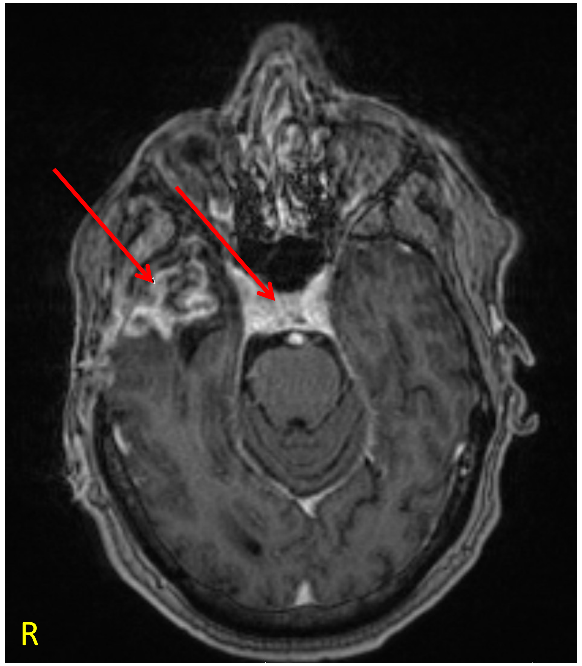
IOWA

Analysis by Jia Xu

Neuro Applications of ^{31}P Imaging

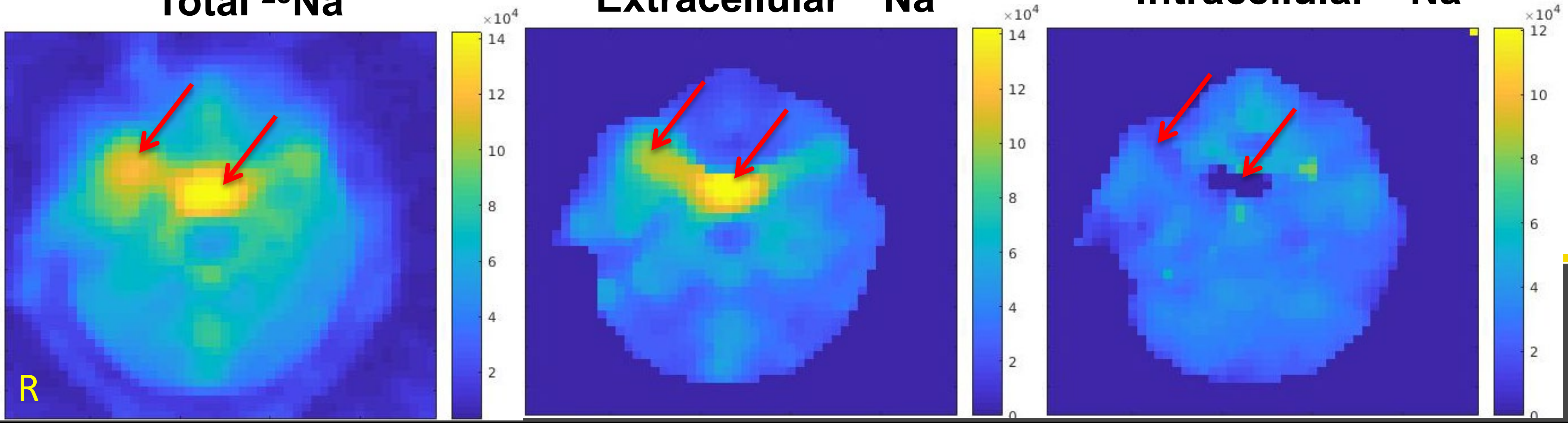
- Review Article:
  - Santos-Diaz A, et al. Biomed Signal Process Cont. 2022;60:101967
- Stroke
  - Bottomley PA, et al. Radiology 1986;160:763-6.
  - Levine SR, et al.. Radiology 1992;185:537-44.
- Brain tumors
  - Aisen AM, et al. Radiology. 1989;173:593–599.
- Alzheimer’s disease
  - Rijpma A, et al. Neuroimage Clin., 2018;18:254-261
- Multiple Sclerosis
  - Husted CA, et al. Ann. Neurol. 1994;36:239-241.
- Bipolar Disorder
  - Lee JH, et al. Ann. Reports of NMR Spectro. 2012;75:115-160.

T1 Post Contrast



^{23}Na Imaging in Subject with GBM

Total ^{23}Na | Extracellular ^{23}Na | Intracellular ^{23}Na



Neuro Applications of ^{23}Na Imaging

- Stroke (Thulborn KR, et al. Radiology (1999) 213:156–66.)
- Brain tumors (Ouwerkerk R, et al. Radiology (2003) 227:529–37.)
- Huntington's disease (Reetz K, et al. Neuroimage (2012) 63:517–24.)
- Alzheimer’s disease (Mellon EA, et al. AJNR Am J Neuroradiol. (2009) 30:978–84.)
- Normal aging (Thulborn K, et al. NMR Biomed. (2016) 29:137–43.)
- Multiple Sclerosis (Inglese M, et al. Brain (2010) 133:847–57.)

Summary

→ MRI provides great flexibility
  - Approaches to sensitize for various structural differences
  - Variety of methods to look at physiologic processes

→ Small changes to how we image can have large changes to image appearance and what the data mean.

→ The fields of MRI acquisition and reconstruction continue to evolve.
  - What new contrast mechanisms will be coming in the future?
  - Are they relevant for your application?

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