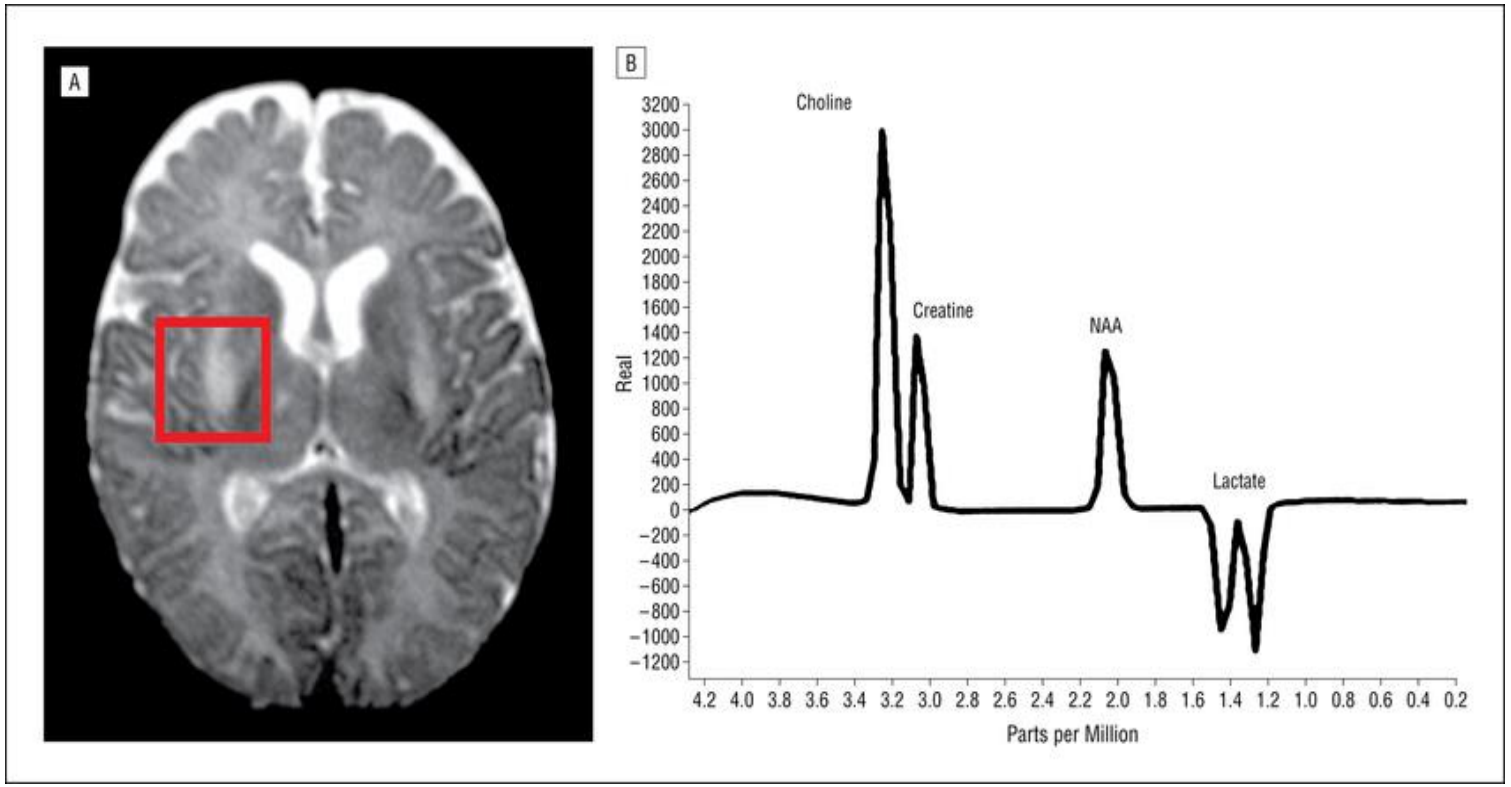
Principles of Magnetic Resonance Spectroscopy and its Applications in Neuroimaging



By: Hossein Mohammadi
Phd Student of Neuroimaging
Isfahan University of Medical Sciences

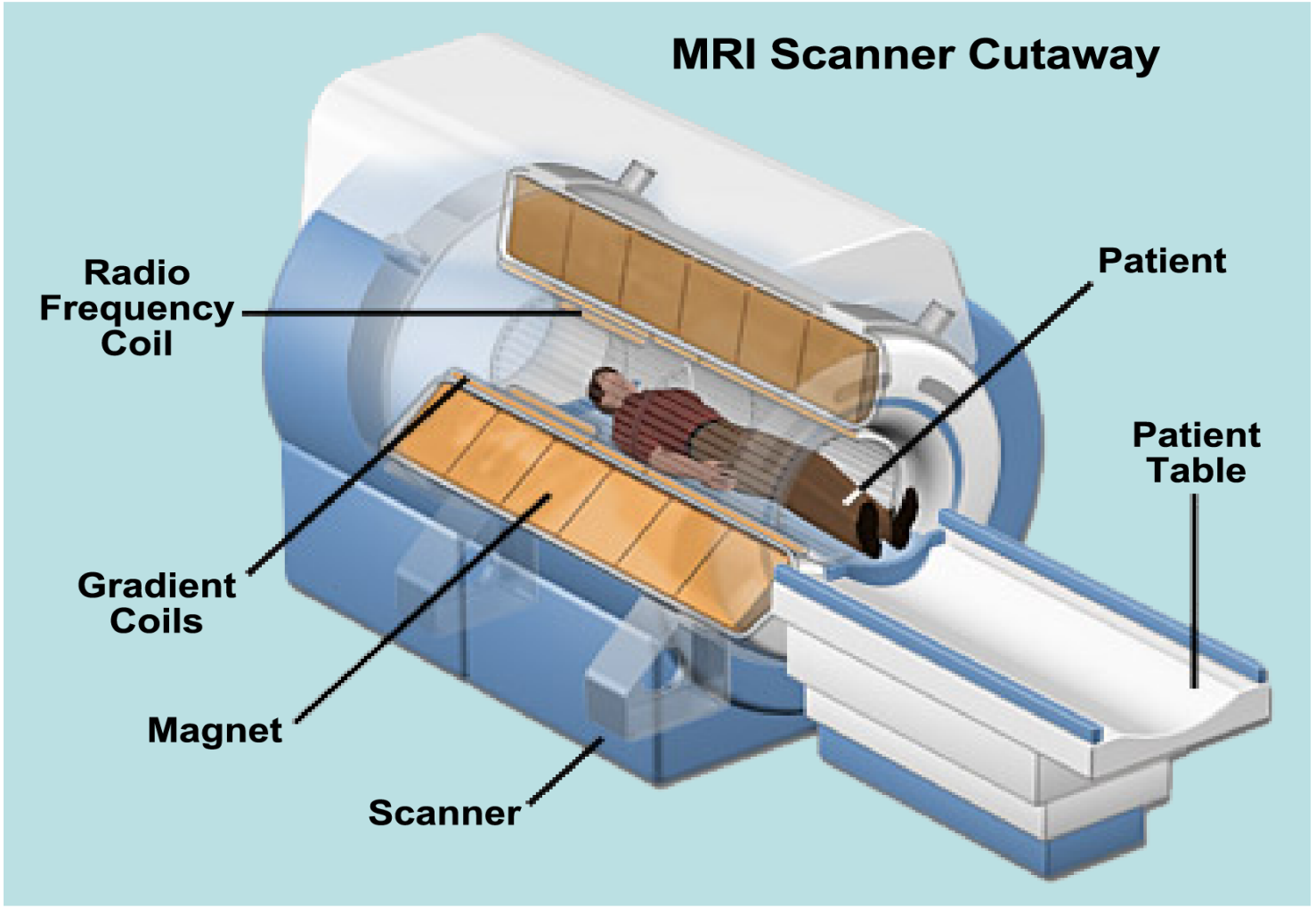
What you need for learning MRS

- MRI and MRS basic physics
- Chemistry
- Anatomy and physiology
- Pathology
- Image and signal processing and Analysis

Overview

- **Basics of MRI physics**
- **Principles of Magnetic Resonance Spectroscopy**
- **Different MRS methods**
- **MRS Applications in Neuroimaging**
- **New methods of MRS for Neuroimaging**

Basics of MRI physics



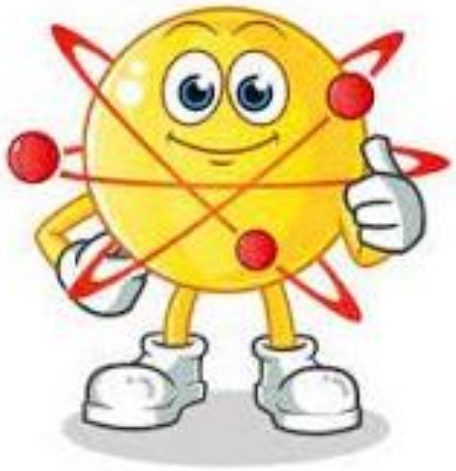
Basics of MRI physics

What is Magnetic Resonance Imaging (MRI)?

- Magnet
- Radio Frequency = Resonance
- Imaging

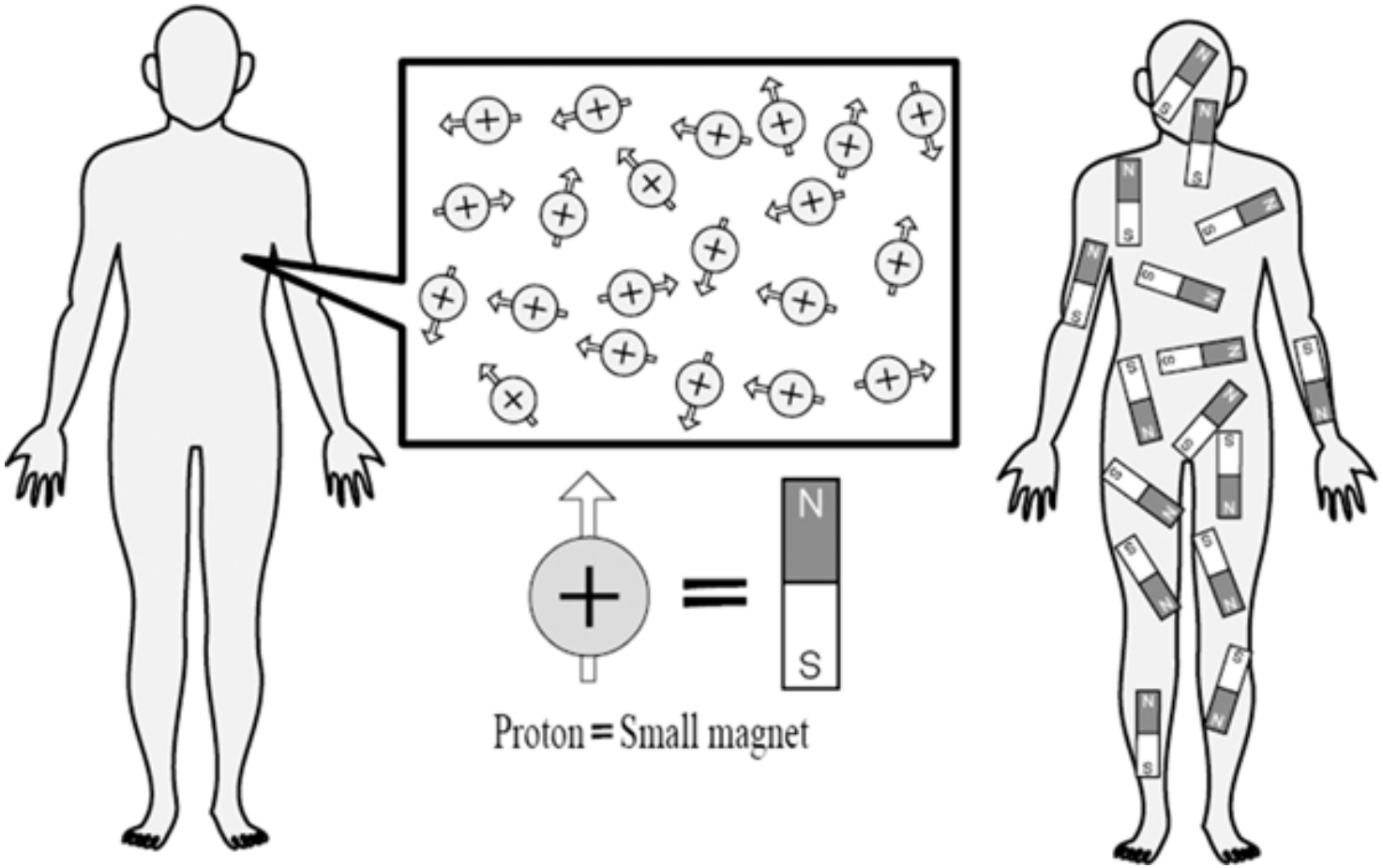
MRI Active Nuclei

- H1
- C13
- N15
- O17
- P31

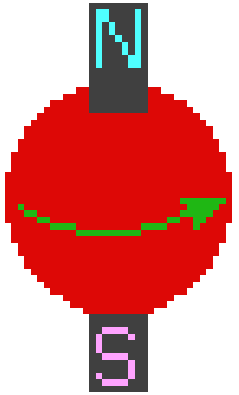


➢ Due to unpaired protons acts as tiny magnets

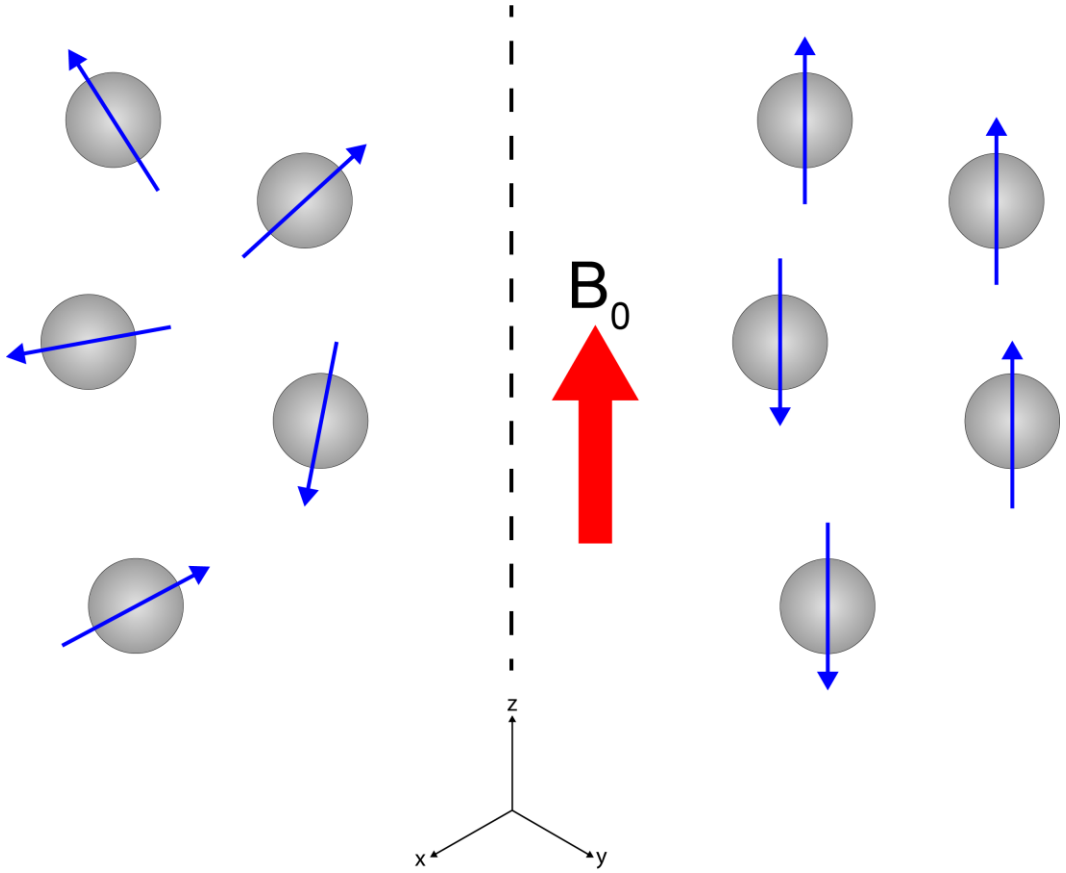
Nuclei direction in body



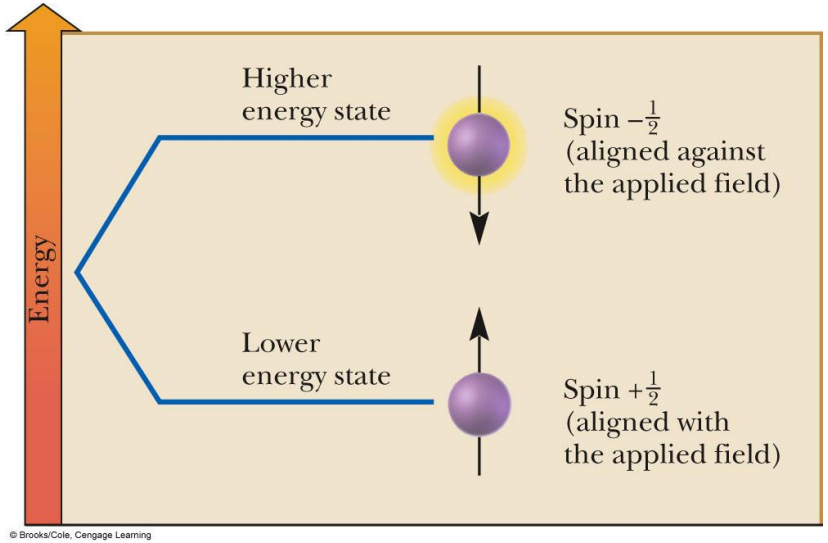
Gyromagnetic ratio

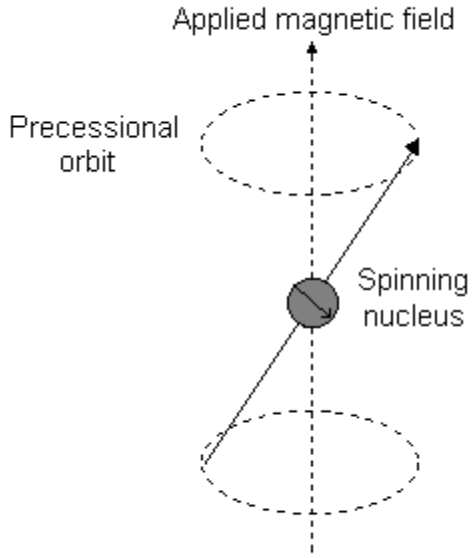


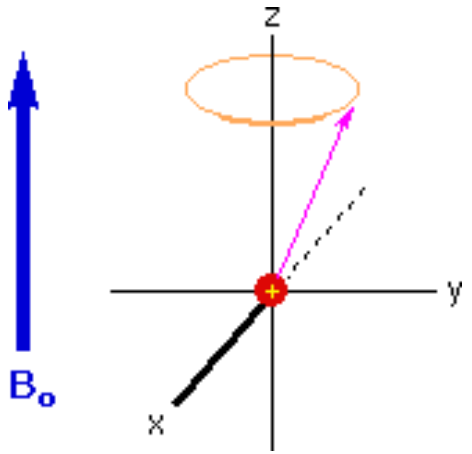
$$\gamma = Q/2m$$



Pression



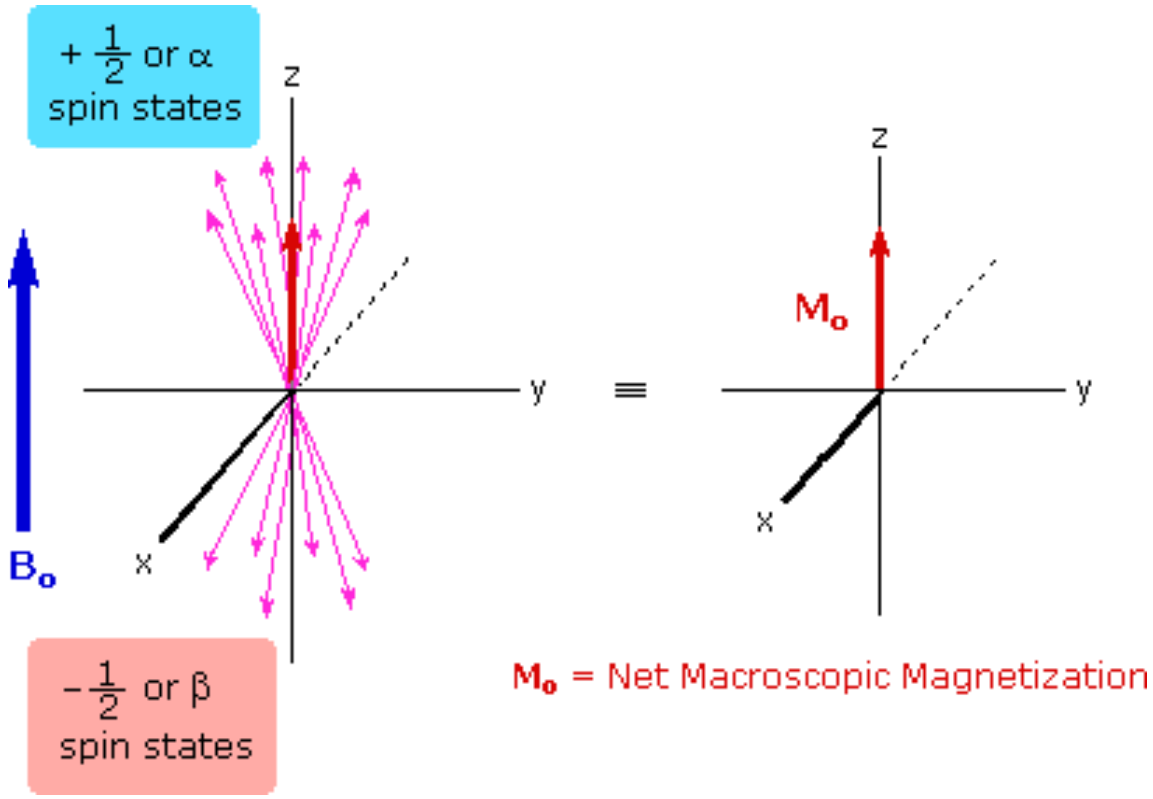


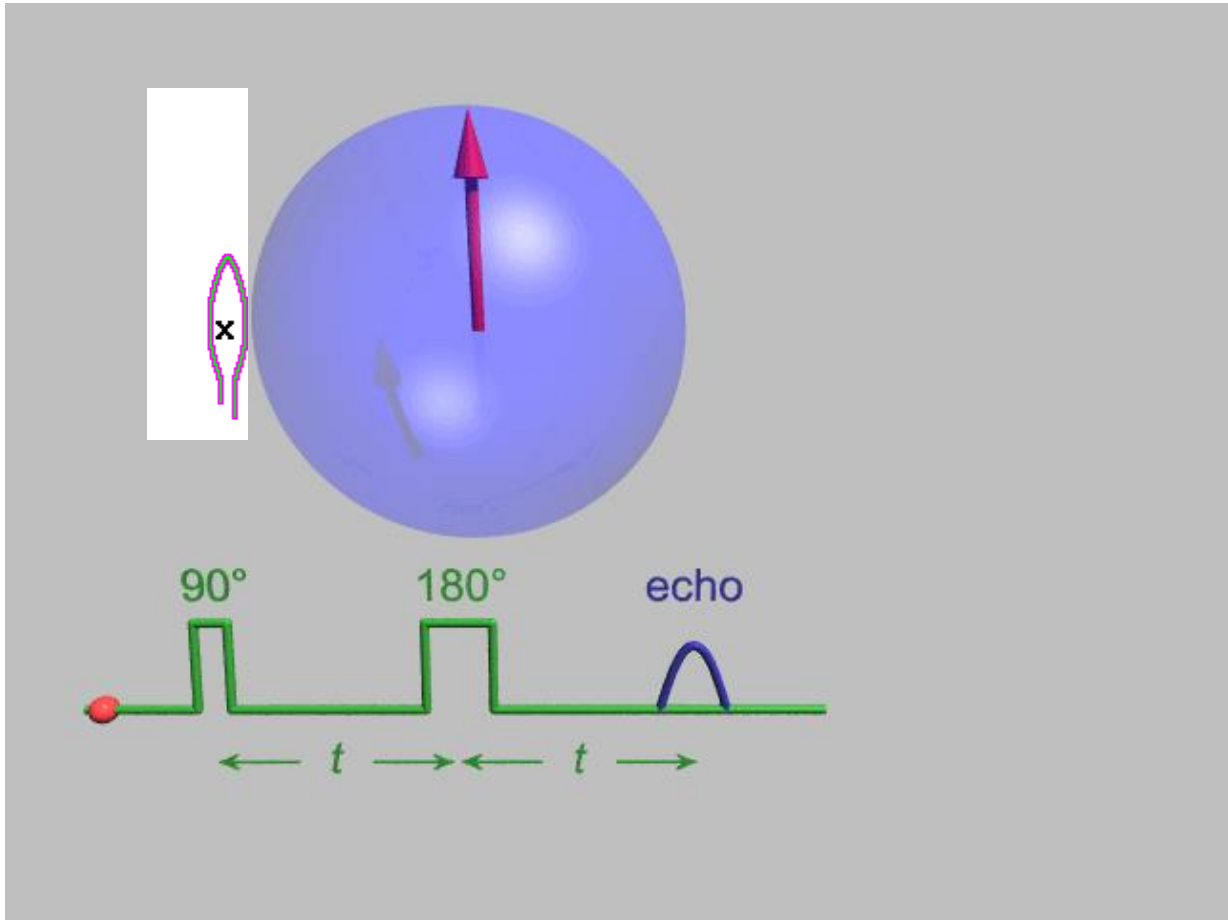


$$\gamma = Q/2m$$

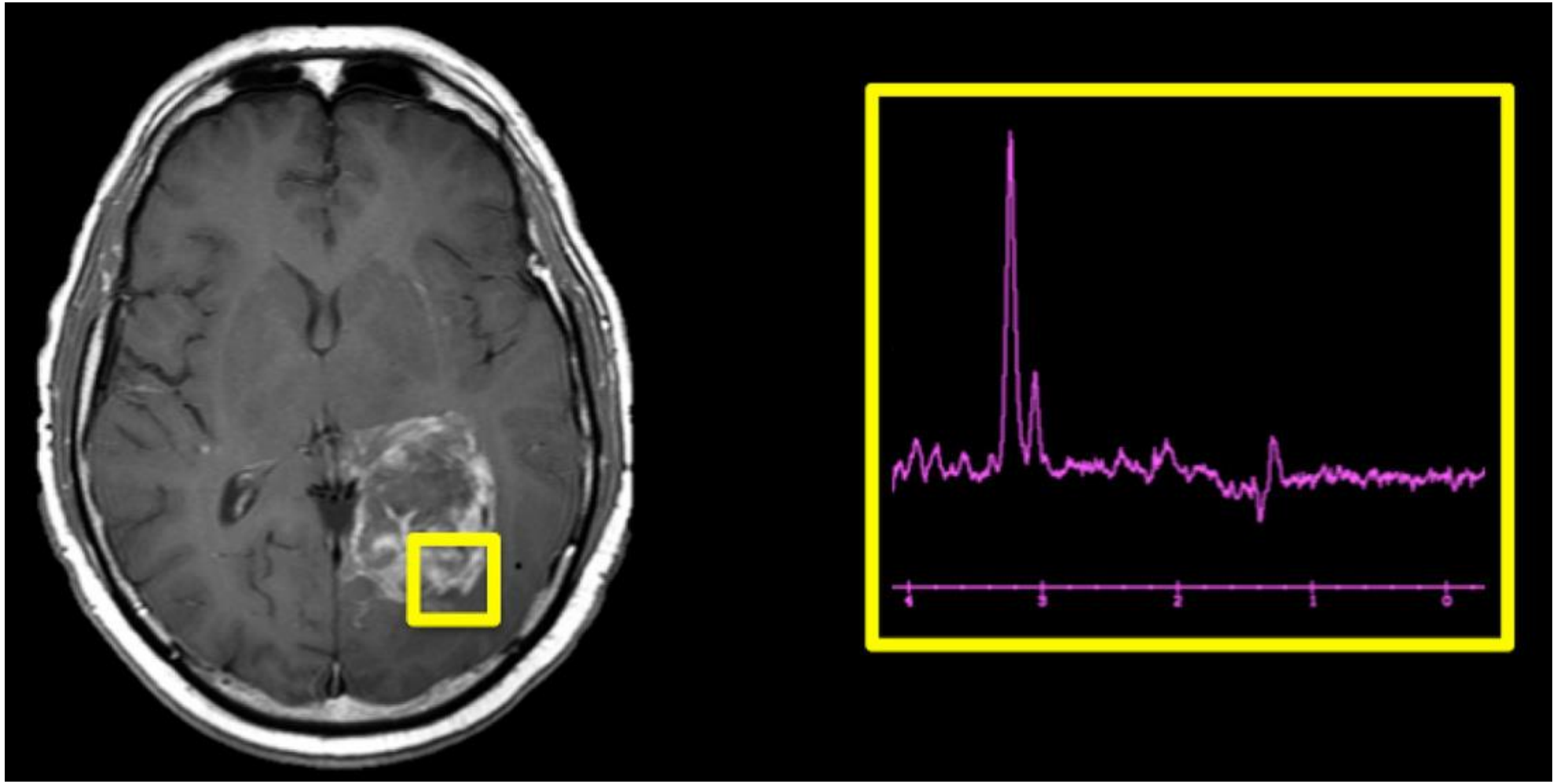
$$\omega = \gamma B_0$$

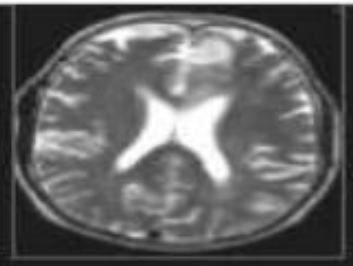
Basics of MRI physics



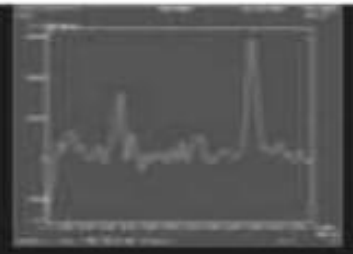


MRI Vs MRS





MRI Vs MRS



- Digitizes signal & generates images.
- Frequencies used to encode space.
- H2O & Fat predominates
- All field strengths

- Digitizes signal & generates a spectrum
- Frequencies used to encode chemistry
- Metabolites predominate
- Field strength equal or greater than 1.5 T

Larmor equation

$$\omega_0 = |\gamma| * B_0 \quad \text{or} \quad \nu_0 = \frac{|\gamma|}{2\pi} * B_0$$

	γ [$*10^7$ rad $s^{-1}T^{-1}$]	1T [MHz]	1.5T [MHz]	3T [MHz]	7T [MHz]
^{1}H	26.75	42.6	63.9	127.7	298.0
^{31}P	10.84	17.3	25.9	51.8	120.8
^{13}C	6.73	10.7	16.1	32.1	75.0

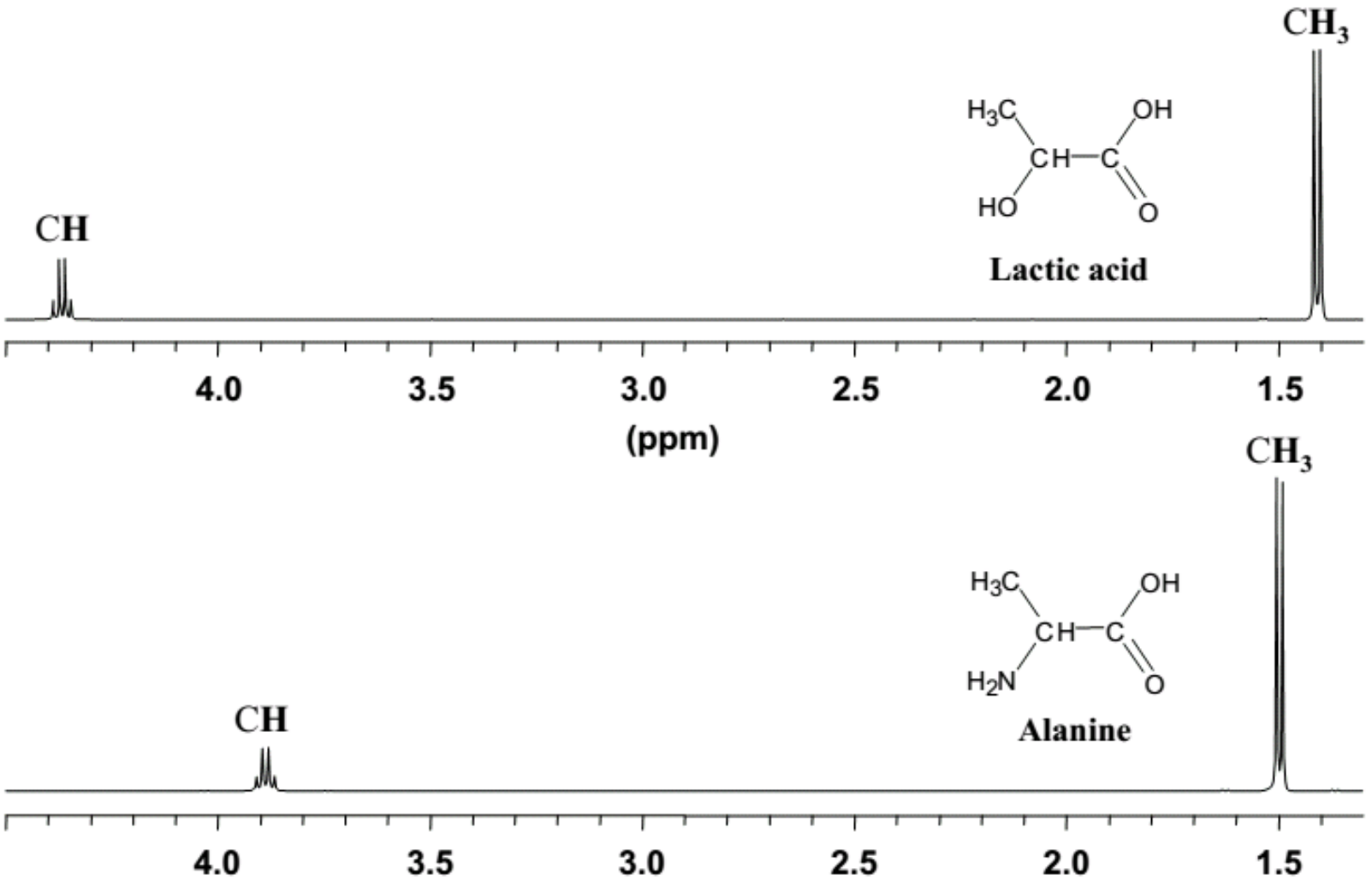
Chemical shift / Frequency

absolute -in Hz (field dependent)
relative -in ppm or [δ]

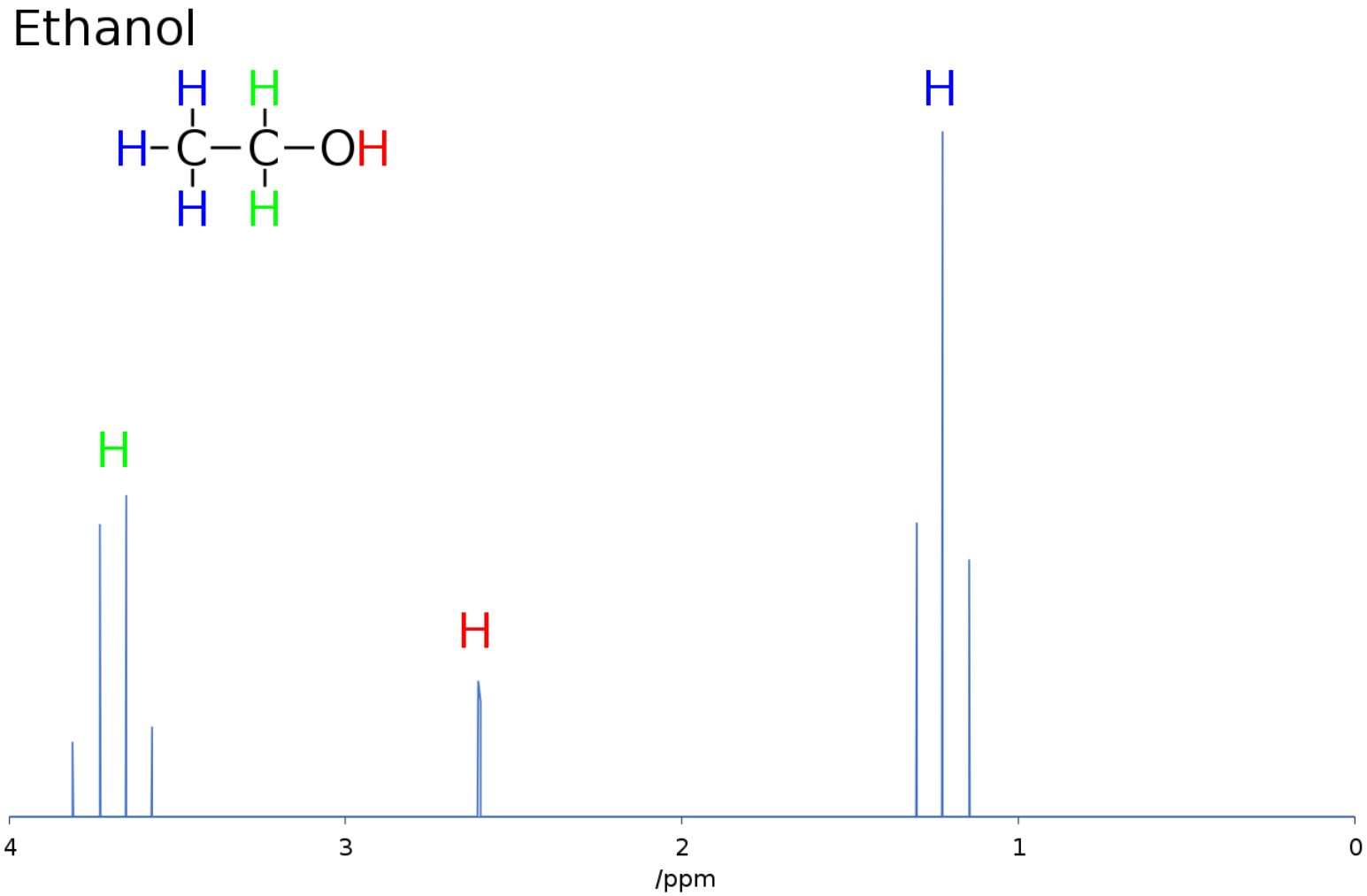
$$d_m = \frac{(\omega_m - \omega_{ref})}{\omega_{ref}} \cdot 10^6$$

Reference mulecules:
In vitro: tetramethylsilane (CH3) …….. 0 ppm
In vivo: N-acetylaspartate (CH3)…….. 2.01

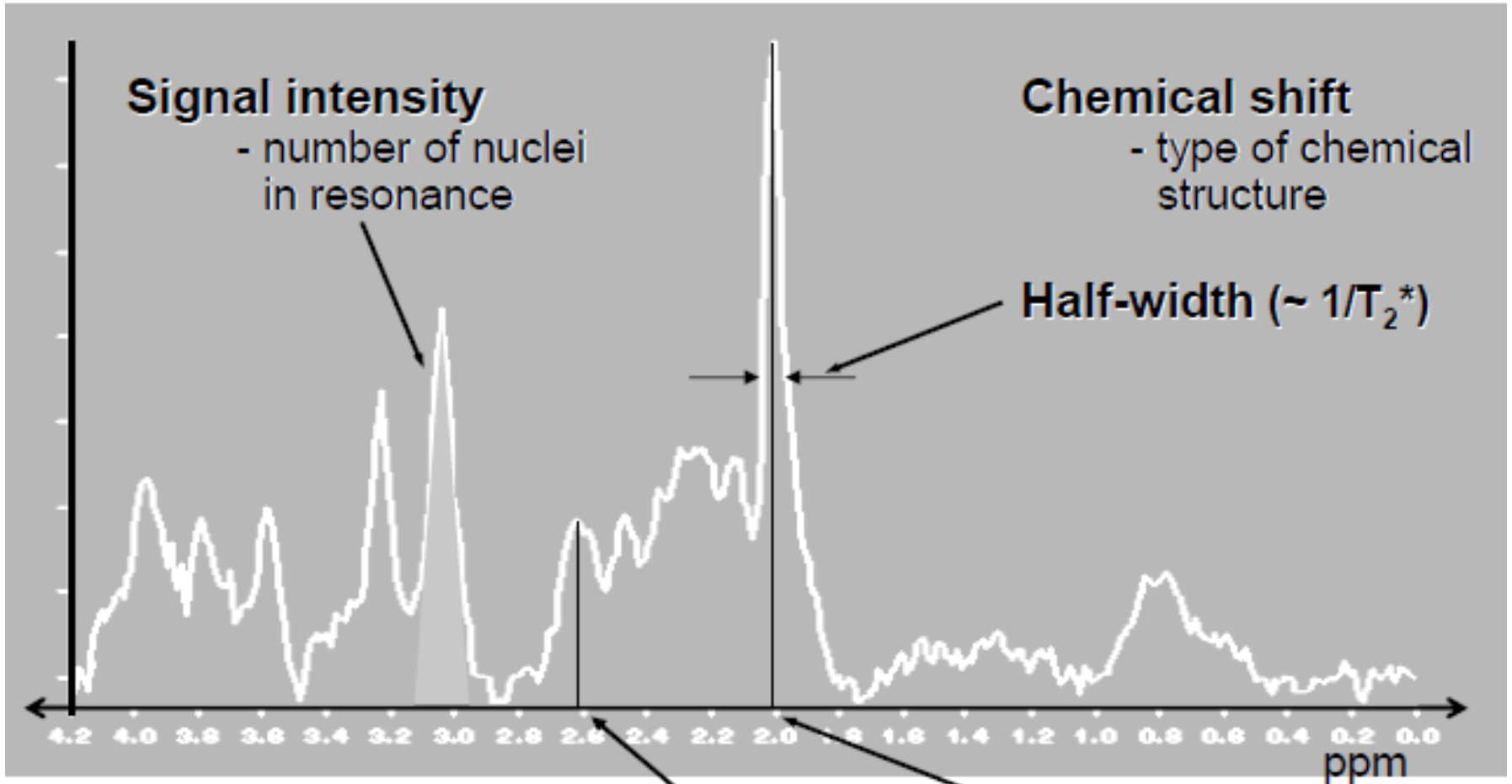
Chemical shift / Frequency



Spin-spin coupling



MR Spectrum



N-Acetylaspartate: $HO_2C\text{-}CH_2\text{-}CH\text{-}[(NH)\text{-}COCH_3]\text{-}CO_2H$

Different MRS methods

➢Single voxel Spectroscopy (SVS)

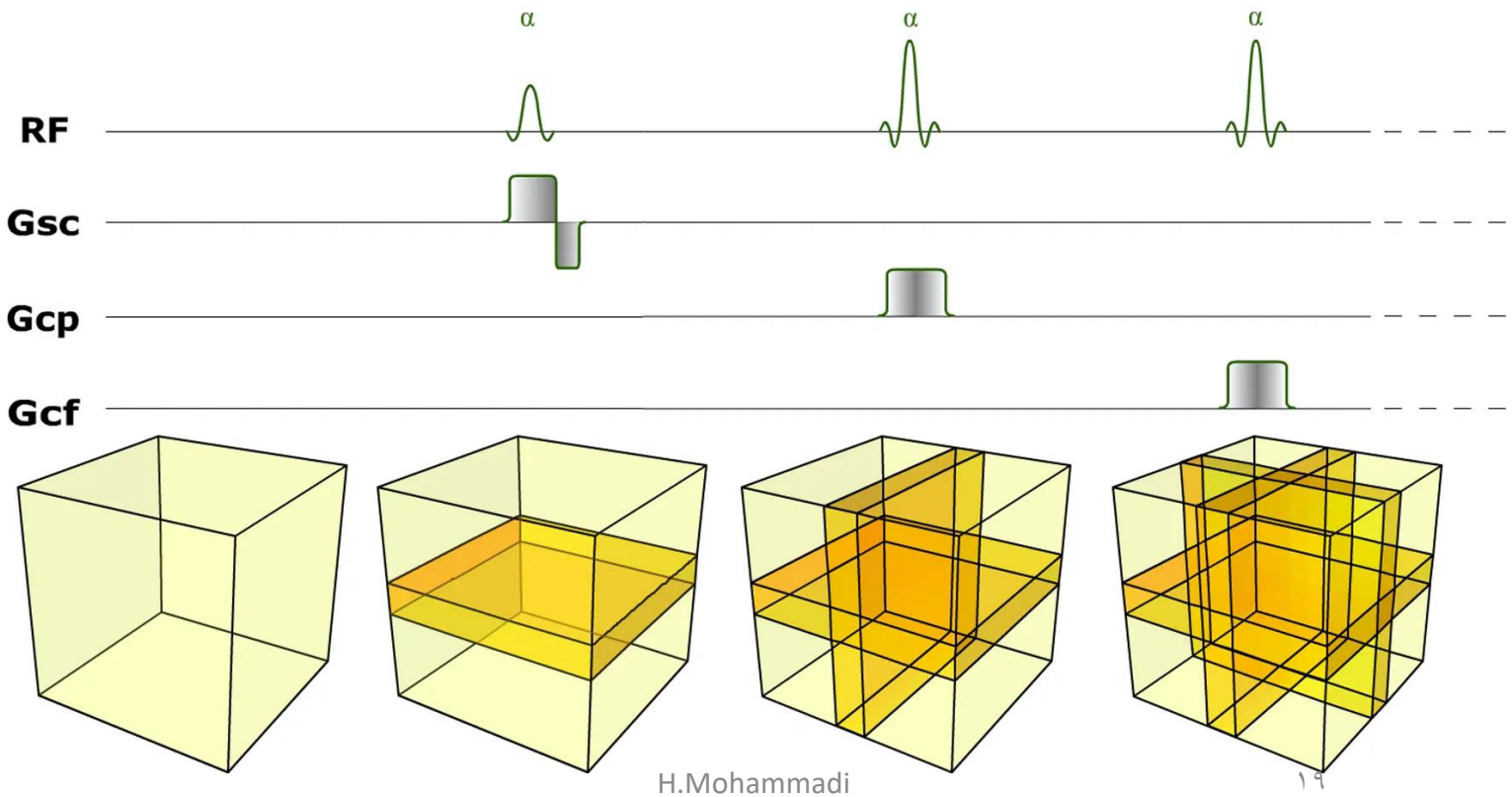
- **STEAM (Stimulated Echo Acquisition Mode)**
- **PRESS (Point RESolved Spectroscopy)**

➢Multivoxel Spectroscopy

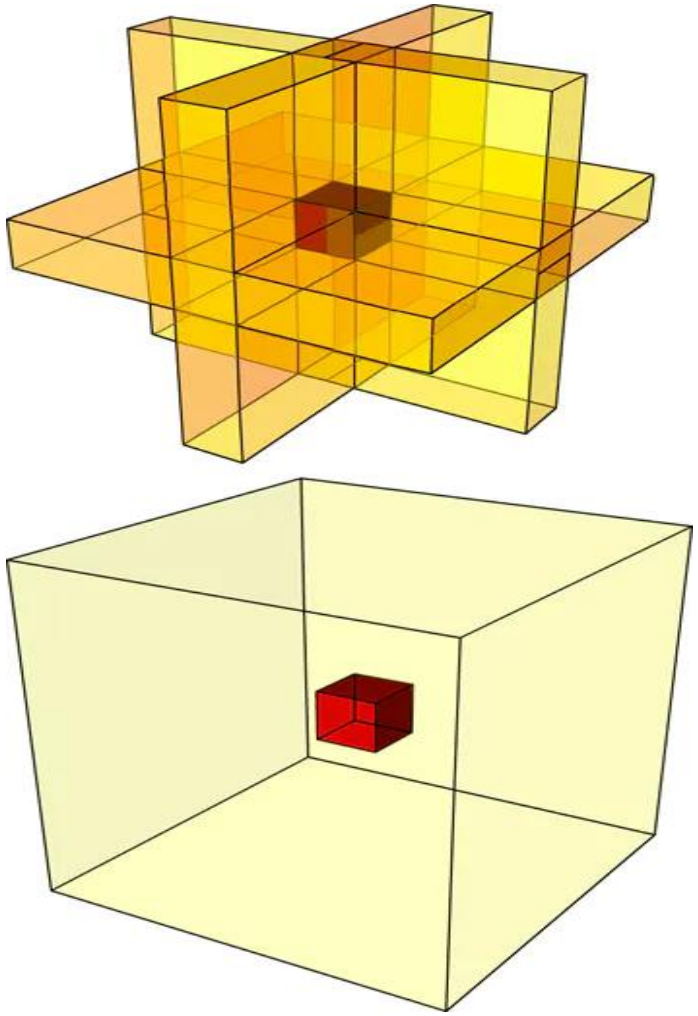
- **Chemical Shift Imaging (CSI)**

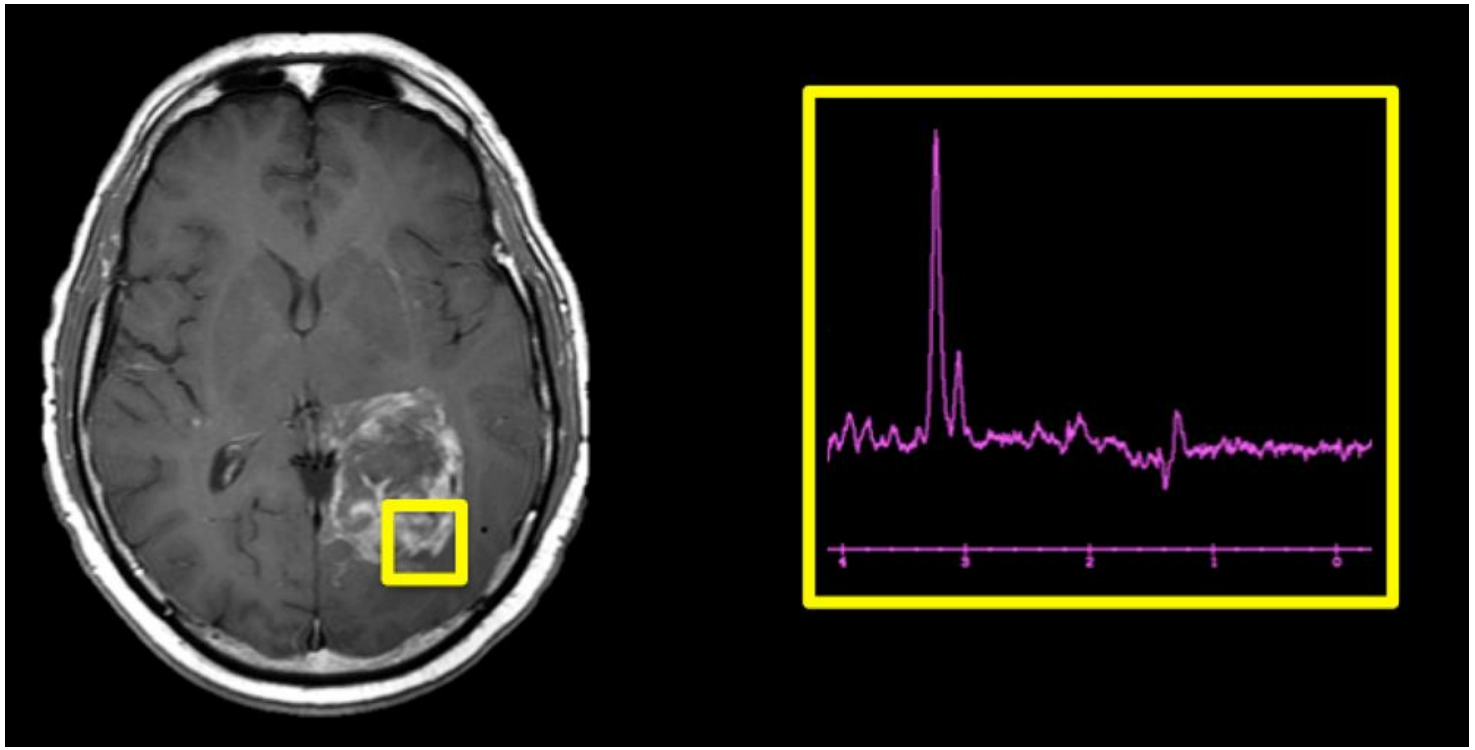
Single voxel Spectroscopy (SVS)

- In SVS, the signal is received of a volume limited to a single voxel
- This acquisition is fairly fast (1 to 3 minutes) and spectrum is easily obtained
- The analyzed volume is selected by a succession of three selective radiofrequency pulses (accompanied by gradients) in the three directions in space

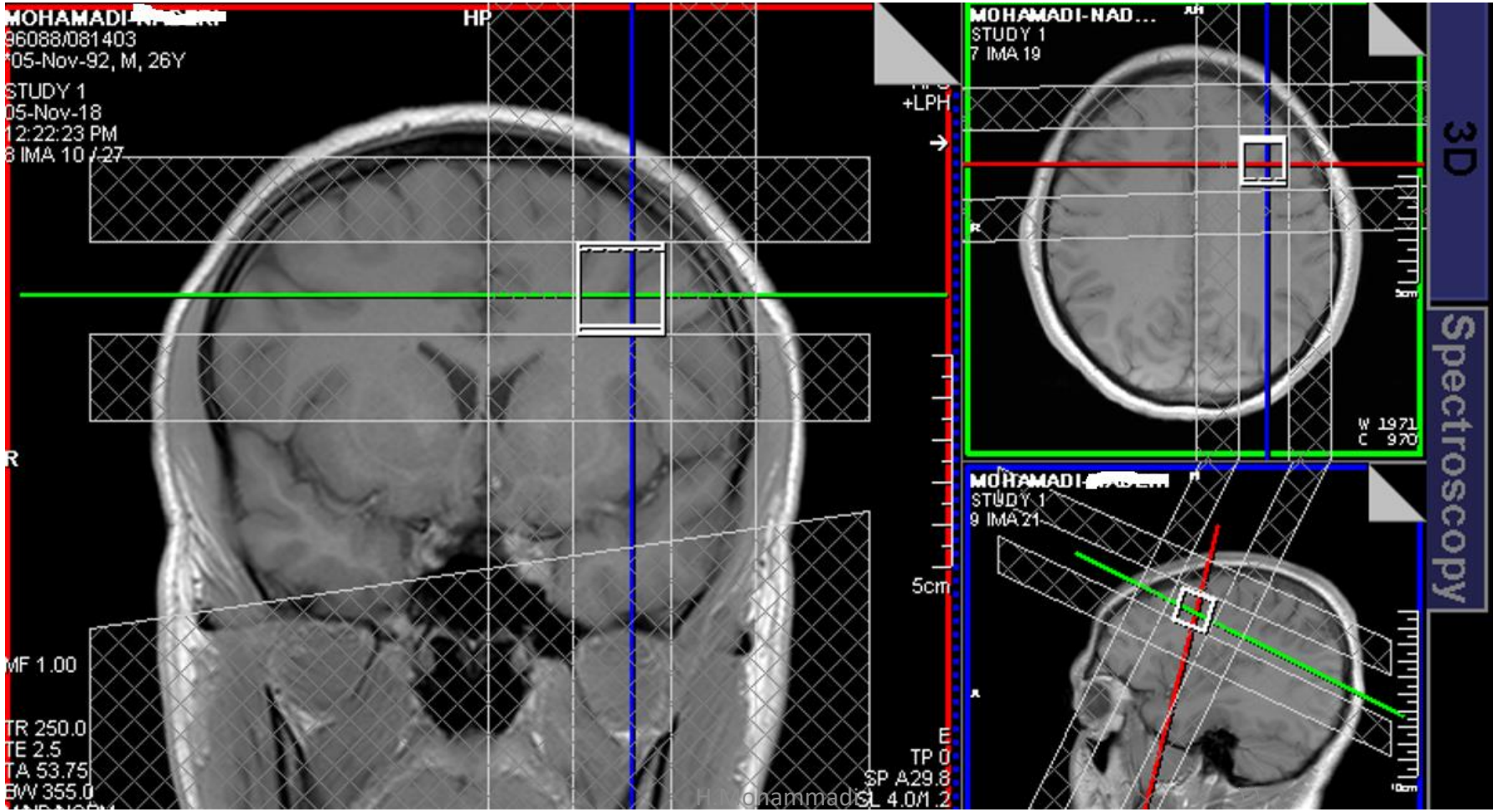


Single voxel Spectroscopy (SVS)



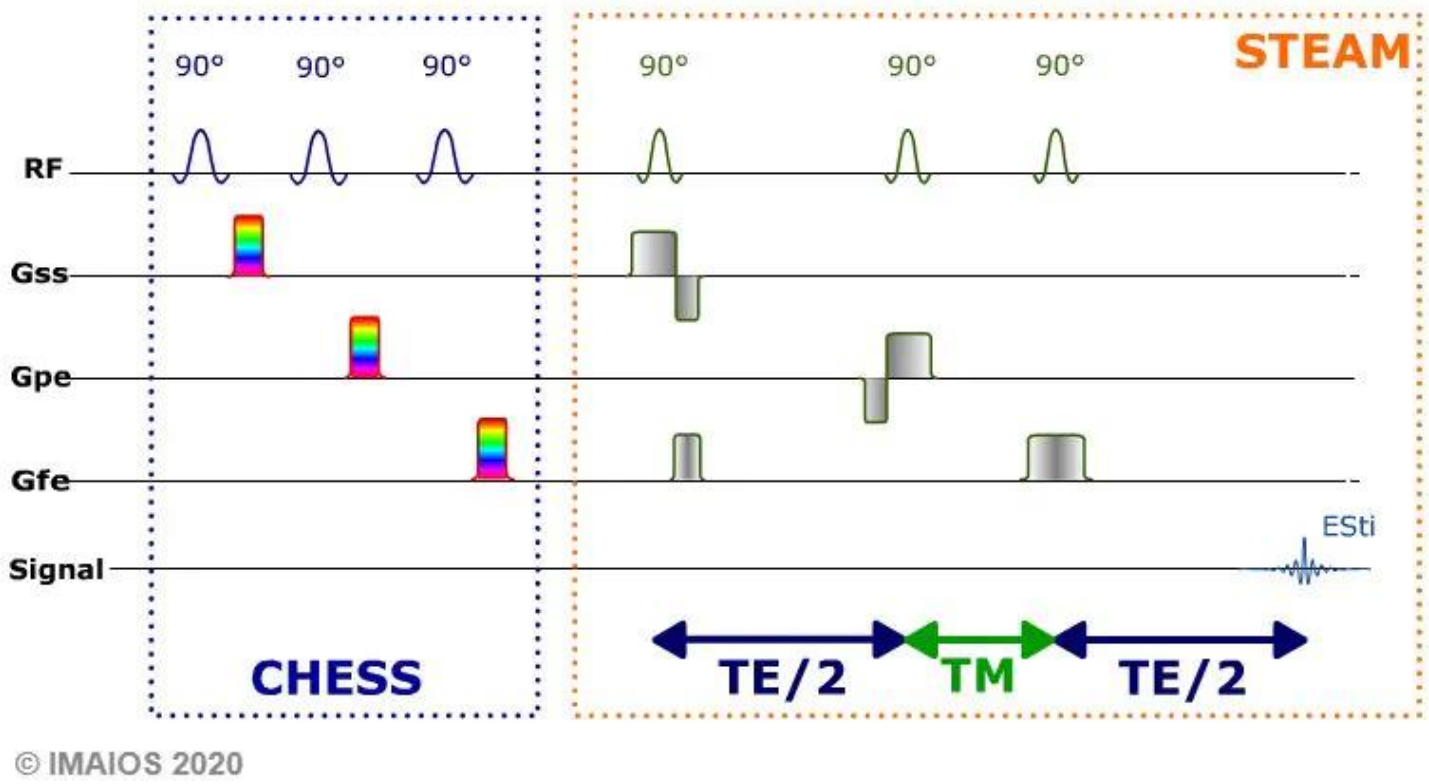


Single voxel Spectroscopy (SVS)



STEAM (Stimulated Echo Acquisition Mode)

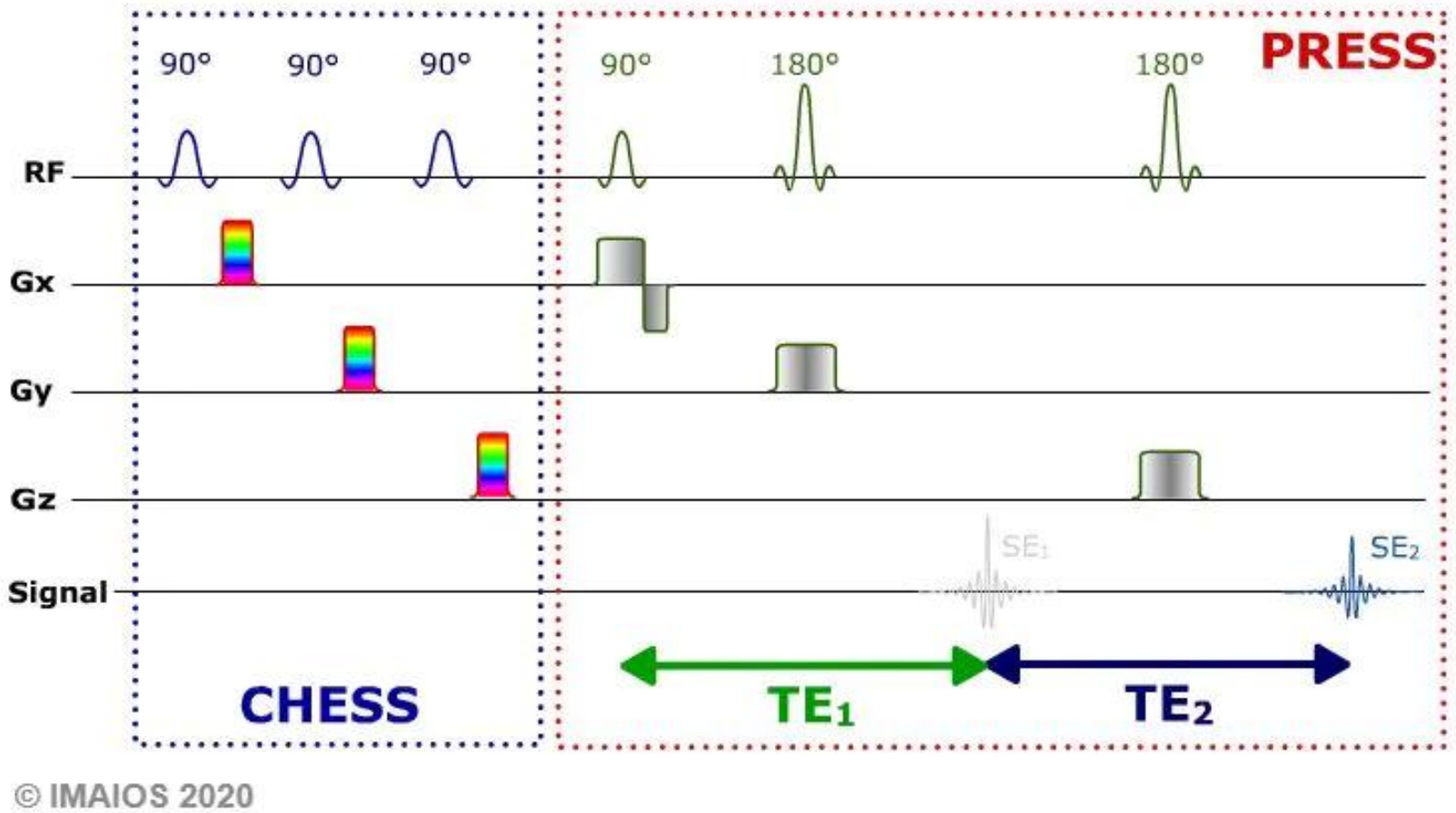
The stimulated echo is recorded from the cumulated effect of the three pulses, thus corresponding to the signal from the only voxel of interest. The TE of the stimulated echo corresponds to double the time interval between the first two pulses. The delay between the second and third RF pulses is the mix time TM. This technique is particularly adapted to short TE spectral acquisitions.



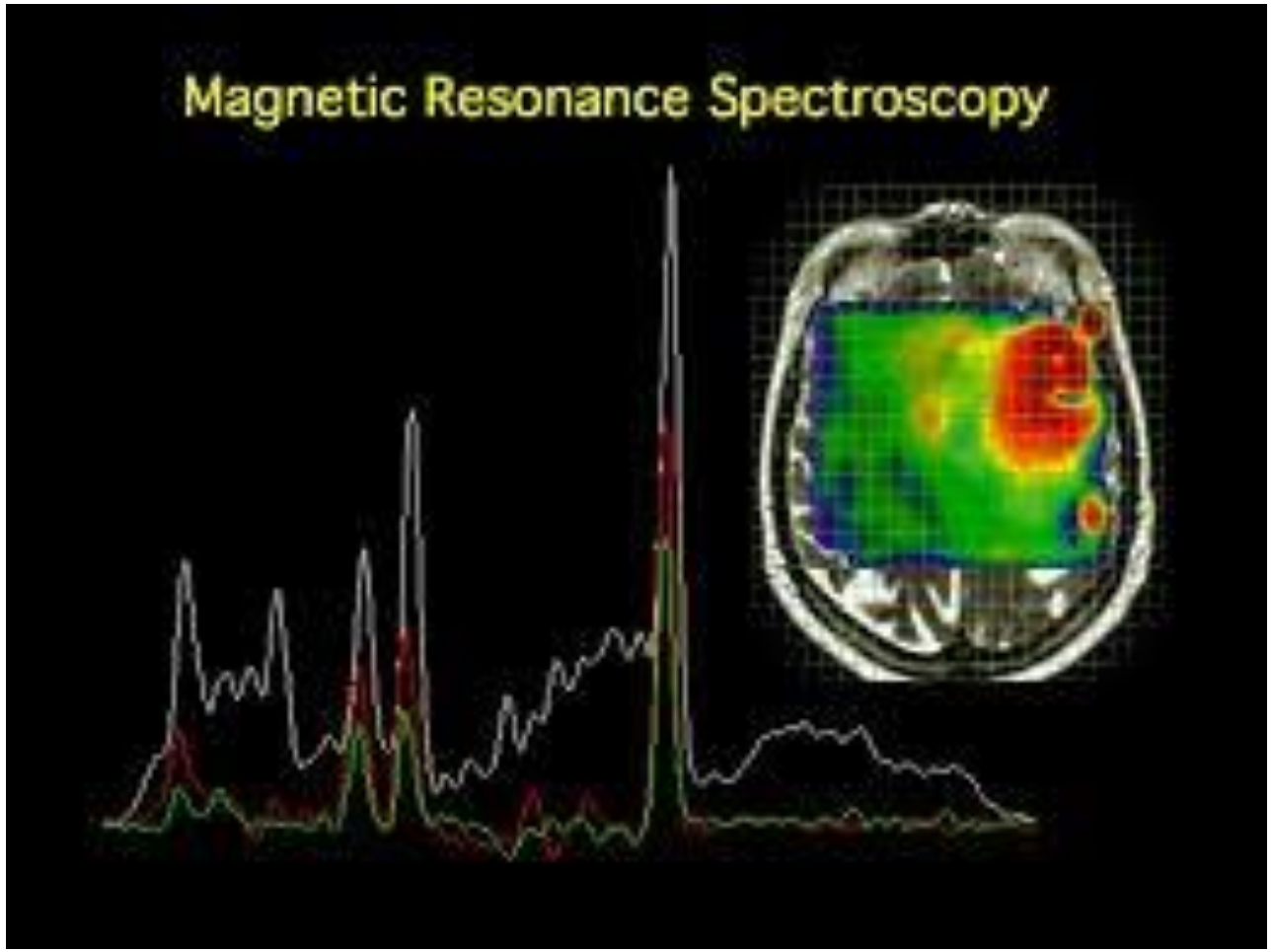
PRESS (Point RESolved Spectroscopy)

In the PRESS method, the RF pulses have flip angles of 90° - 180° - 180°. The signal emitted by the voxel of interest is thus a spin echo. The amplitude of this spin echo is two times greater than the stimulated echo obtained by STEAM. The PRESS technique thus offers a better signal-to-noise ratio than STEAM. It can be used with short TE (15 – 20 ms) or long TE (135 – 270 ms).

PRESS (Point RESolved Spectroscopy)

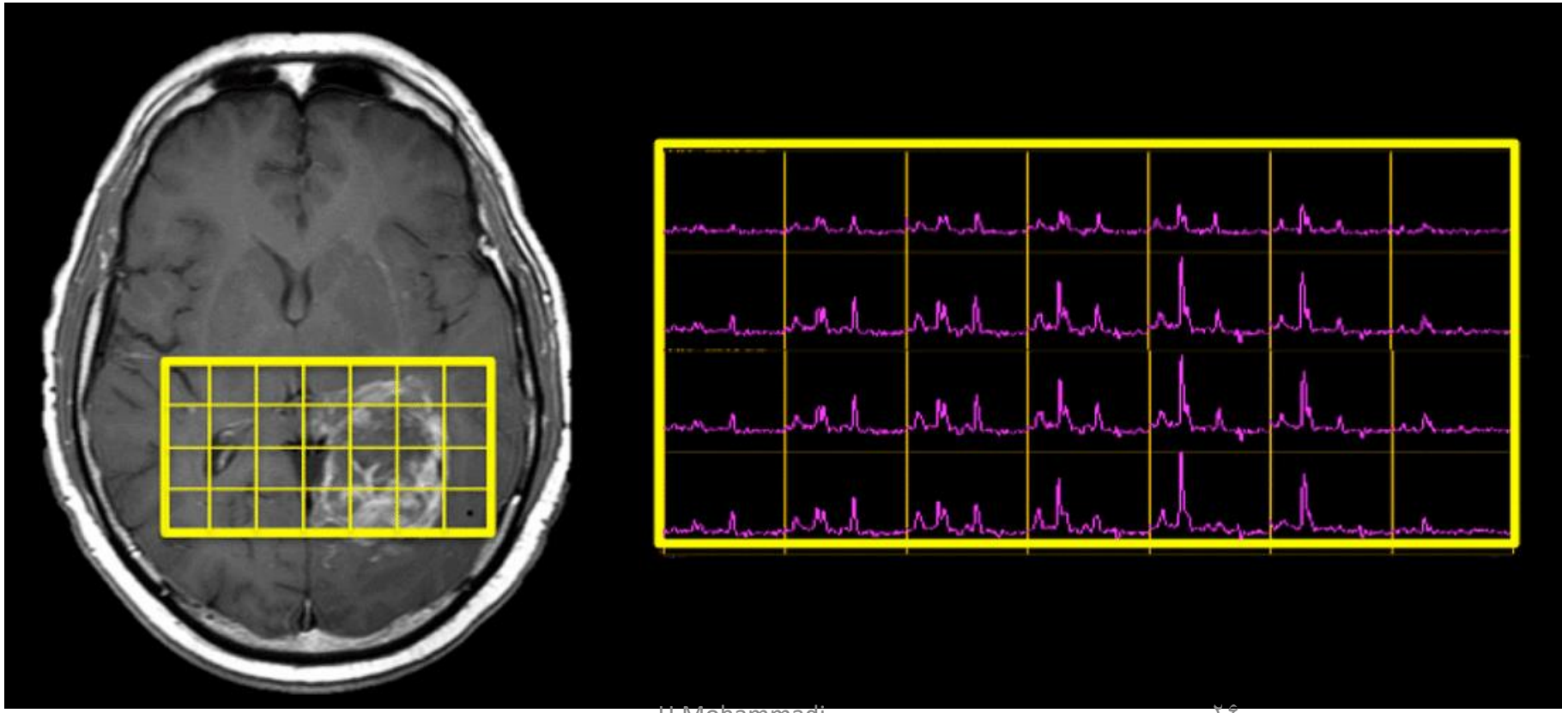


Multi-voxel Chemical Shift Imaging (CSI)



Multi-voxel Chemical Shift Imaging (CSI)

- a larger total coverage area (since the size of the entire multivoxel slab is greater)
- higher spatial resolution (since the individual voxels are smaller)

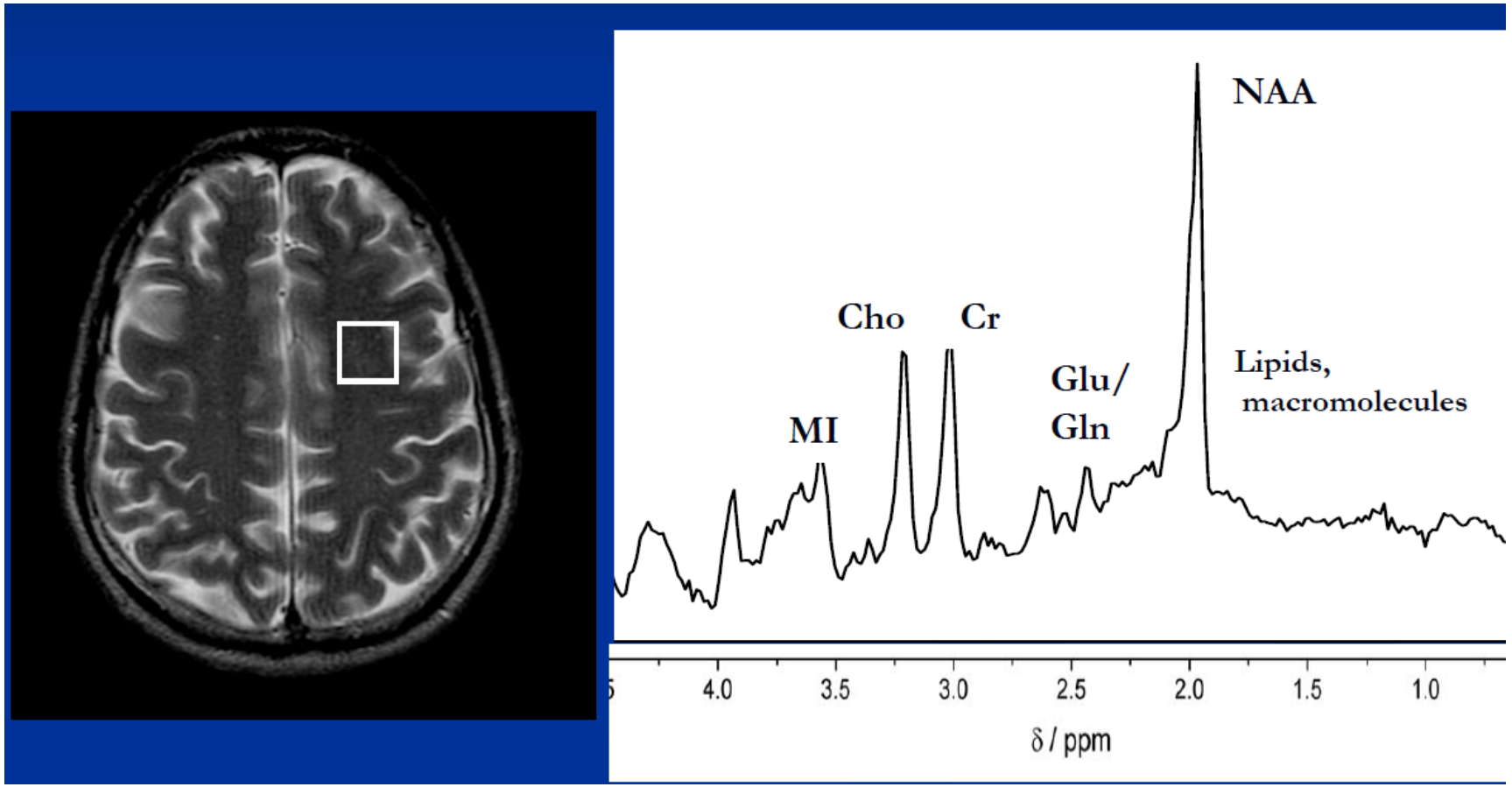


SVS Vs CSI

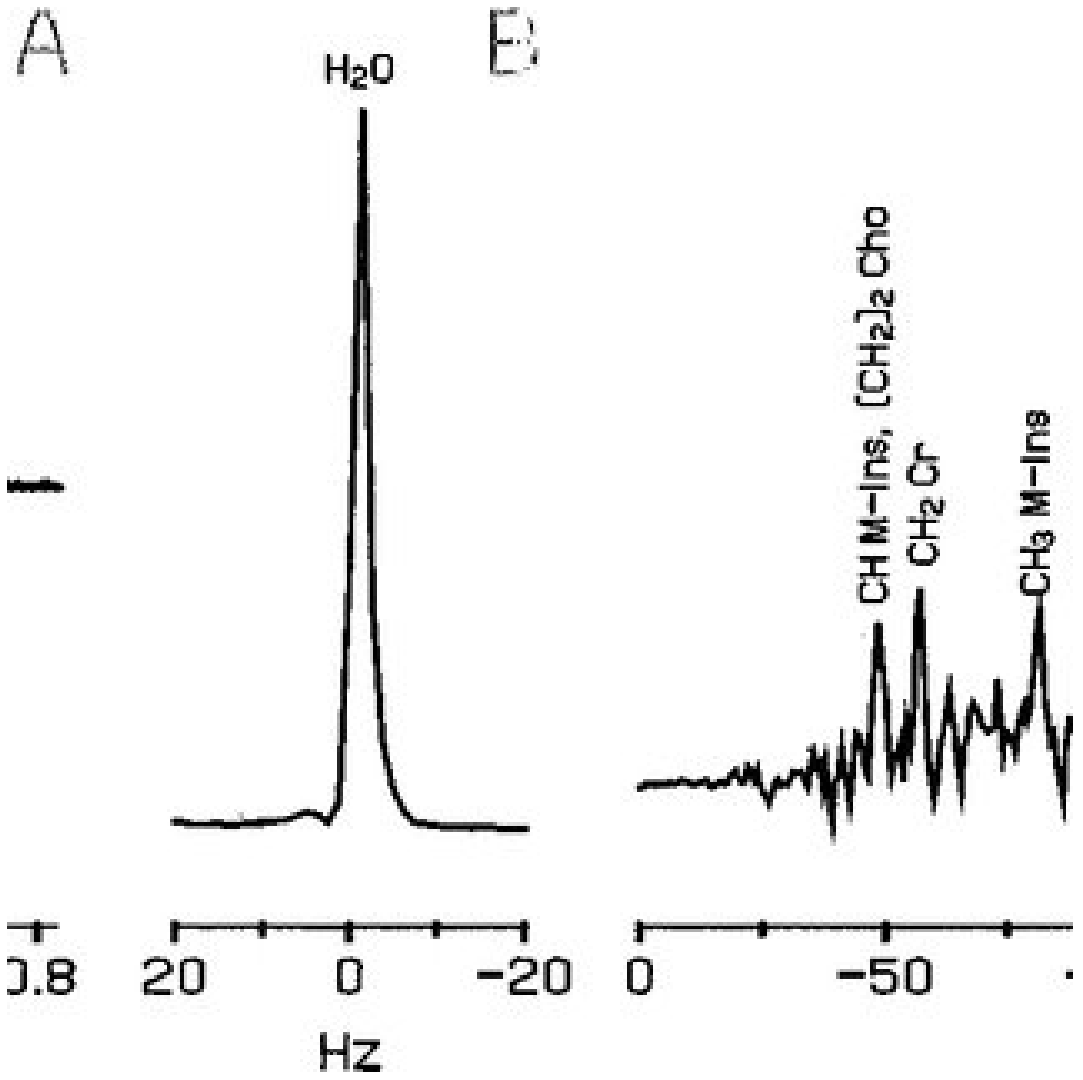
	Single Voxel (SVS)	Multi-voxel (CSI)
Operator set-up	Fast and easy	A little harder and slower
Shimming	Limited volume of interest allows very good shim to be obtained	Difficult to shim well over entire region
Spectral quality and peak separation	Excellent with high signal-to-noise, quantifiable	Lower signal-to-noise, problems with quantification
Spectral contamination	From adjacent tissues due to partial volume and chemical shift displacement effects	Bleeding of spectra from adjacent voxels due to chemical shift aliasing
Imaging time	Fast (3-5 min per voxel)	Slower, depends on resolution: 5-8 min for 2D, 7-15 min for 3D
Suitability based on size/ characteristics of lesion	Best for medium-sized homogeneous lesions in large organs	Best for lesions in small organs or for inhomogeneous lesions in larger organs

MR spectrum

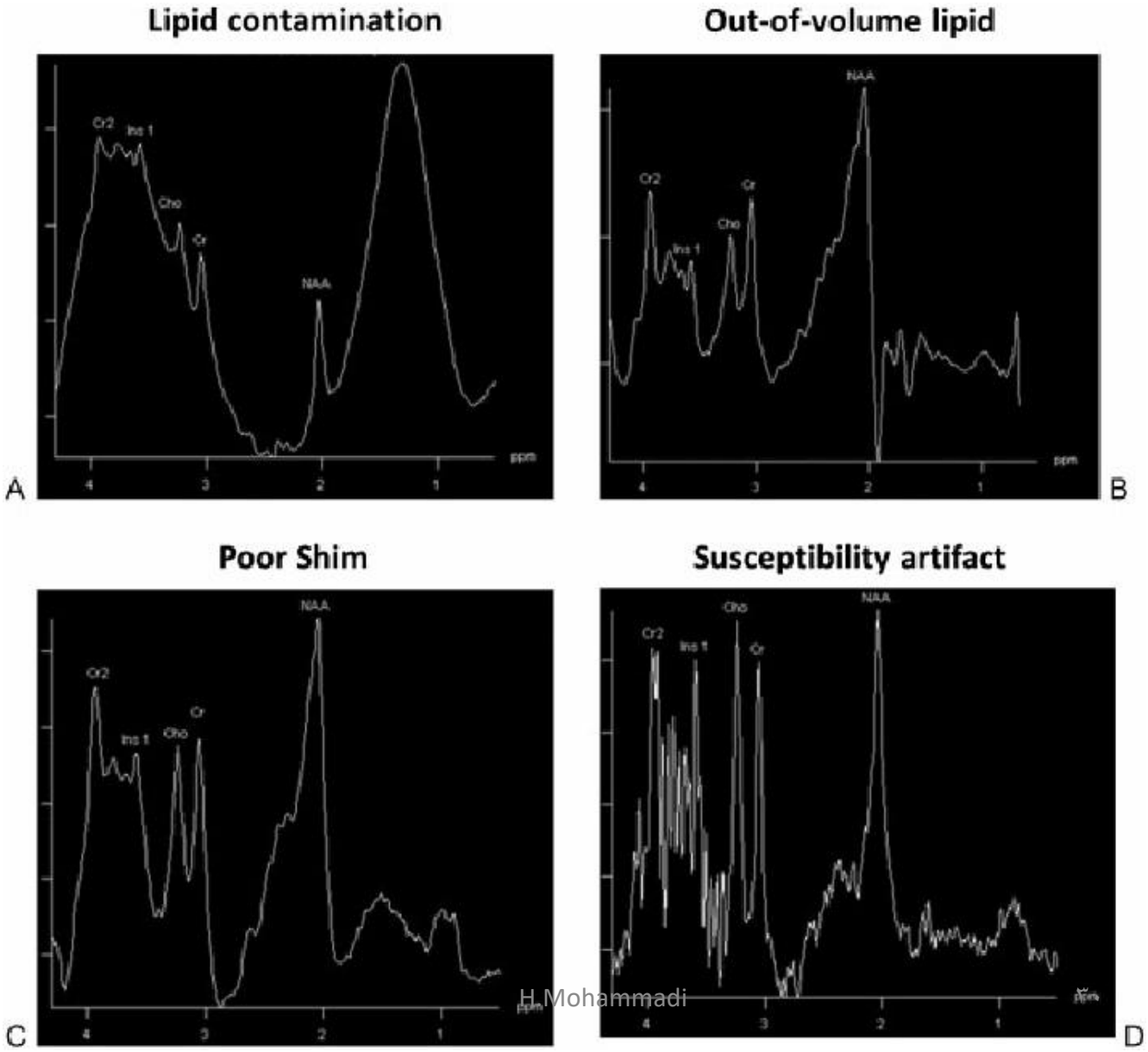
normal human brain spectrum at 3T



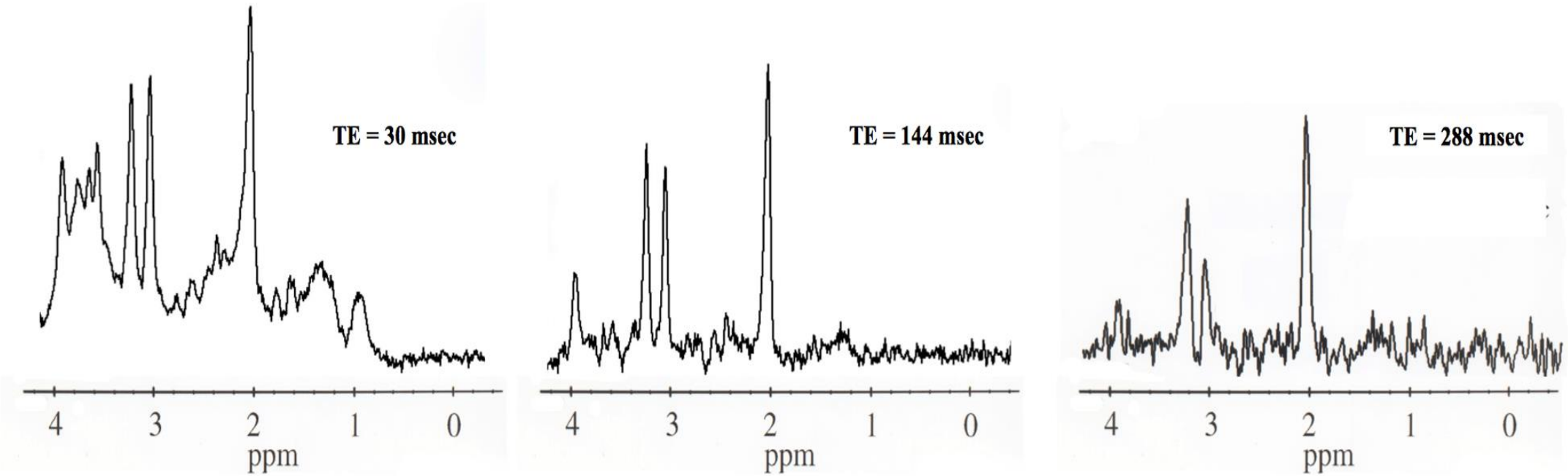
Water signal suppression



Artifacts



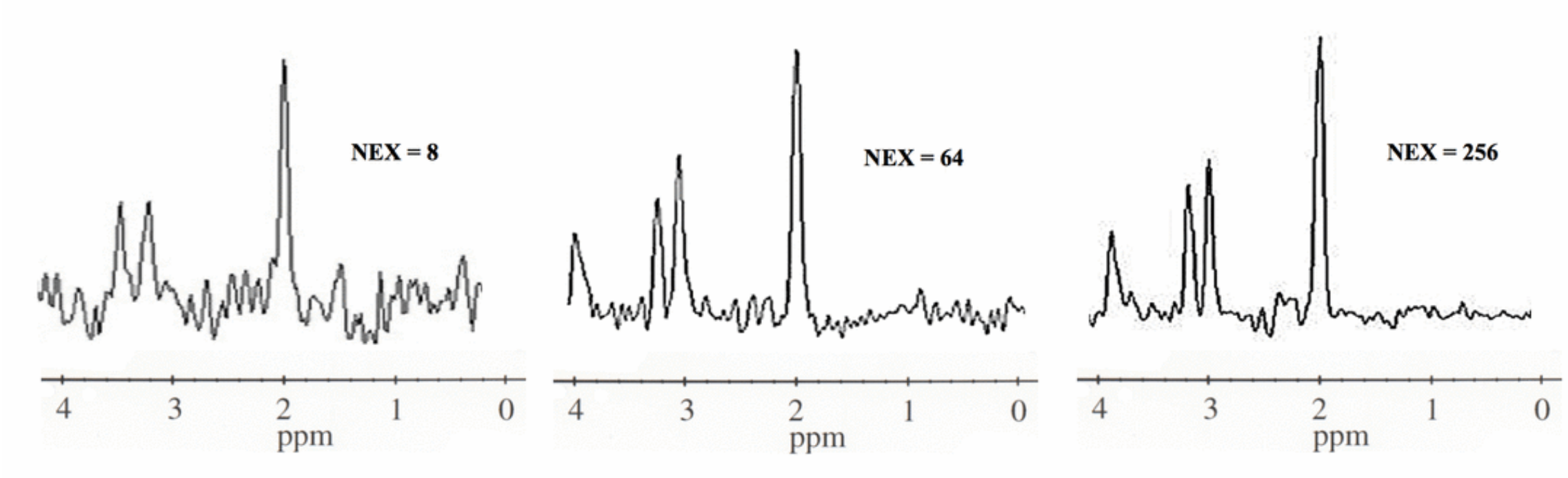
Short TE vs Long TE



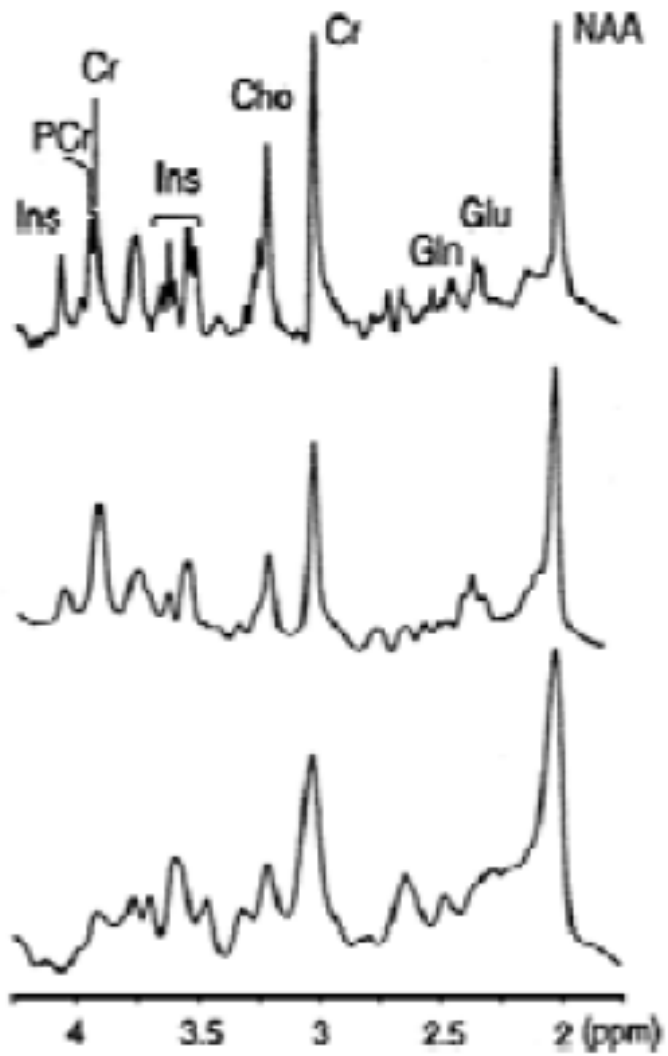
Repetition and Echo Times (TR & TE)

Metabolite	T1 (msec)	T2 (msec)
NAA	1400	250
Creatine ($-CH_3$, $-CH_2$)	1200, 900	160, 125
Choline	1100	190
Myoinositol (mI)	1100	200
Lactate	1200	240
Glutamate	1200	180
Macromolecules	250	15

Number of excitations



Advantages of higher magnetic field strength for MRS



9.4 T : 1ml in dog brain

4.0 T : 27ml in human brain

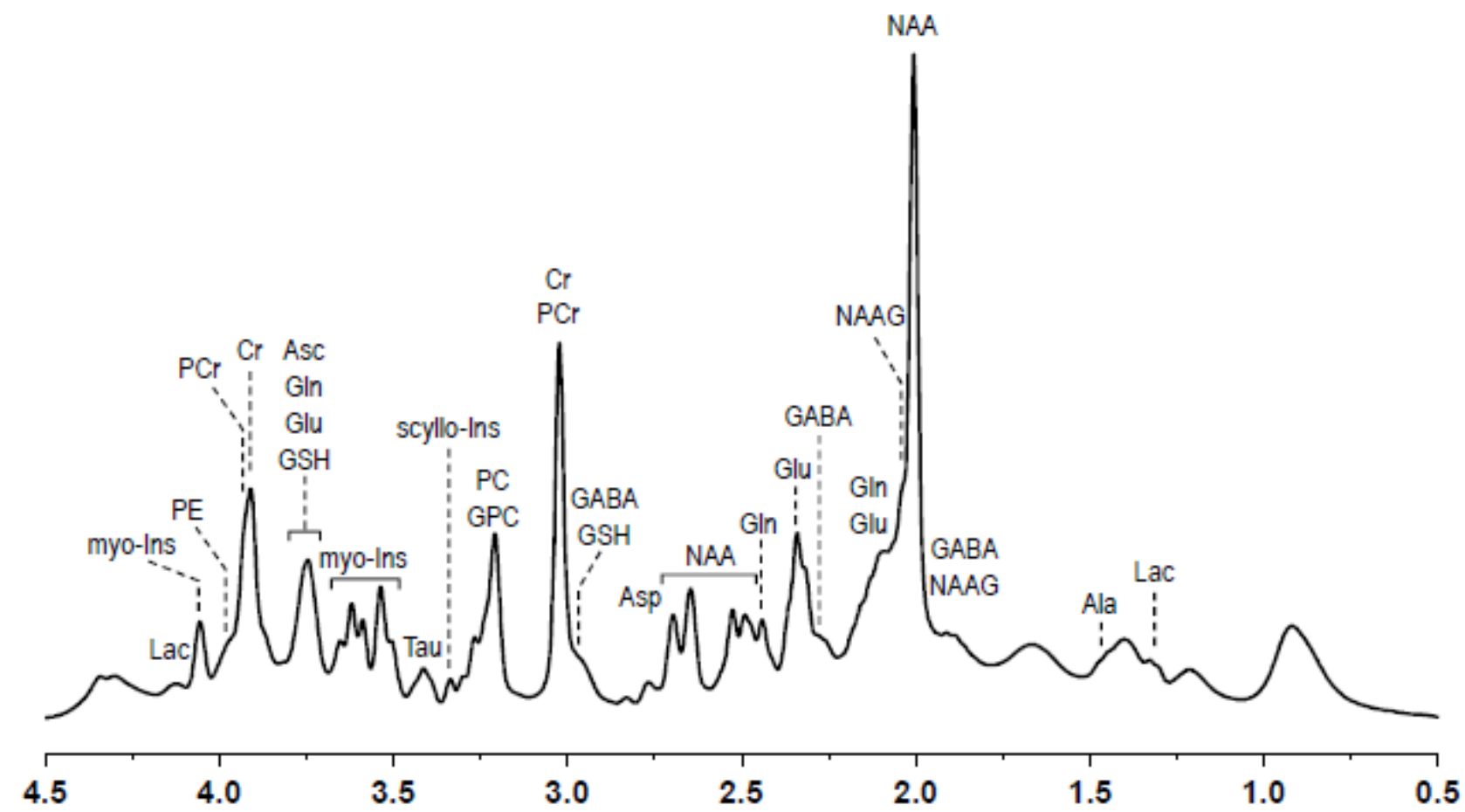
1.5 T : 27ml in human brain

Gruetter et al. J Magn Reson ***135****, 260 (1998)*

MRS Applications in Neuroimaging

- Detection and quantification of tissues chemical compounds
- A powerful tool to access brain composition, metabolism and function
- What can be measured in brain?
  - Water
  - Macromolecules (phospholipids, proteins, DNA, RNA)
  - metabolites (NAA, Creatine(Cr), Choline(Cho), Lipids)
  - neurotransmitters (acetylcholine, norepinephrine, dopamine, serotonin)

^{1}H NMR spectrum of the human brain at 7T



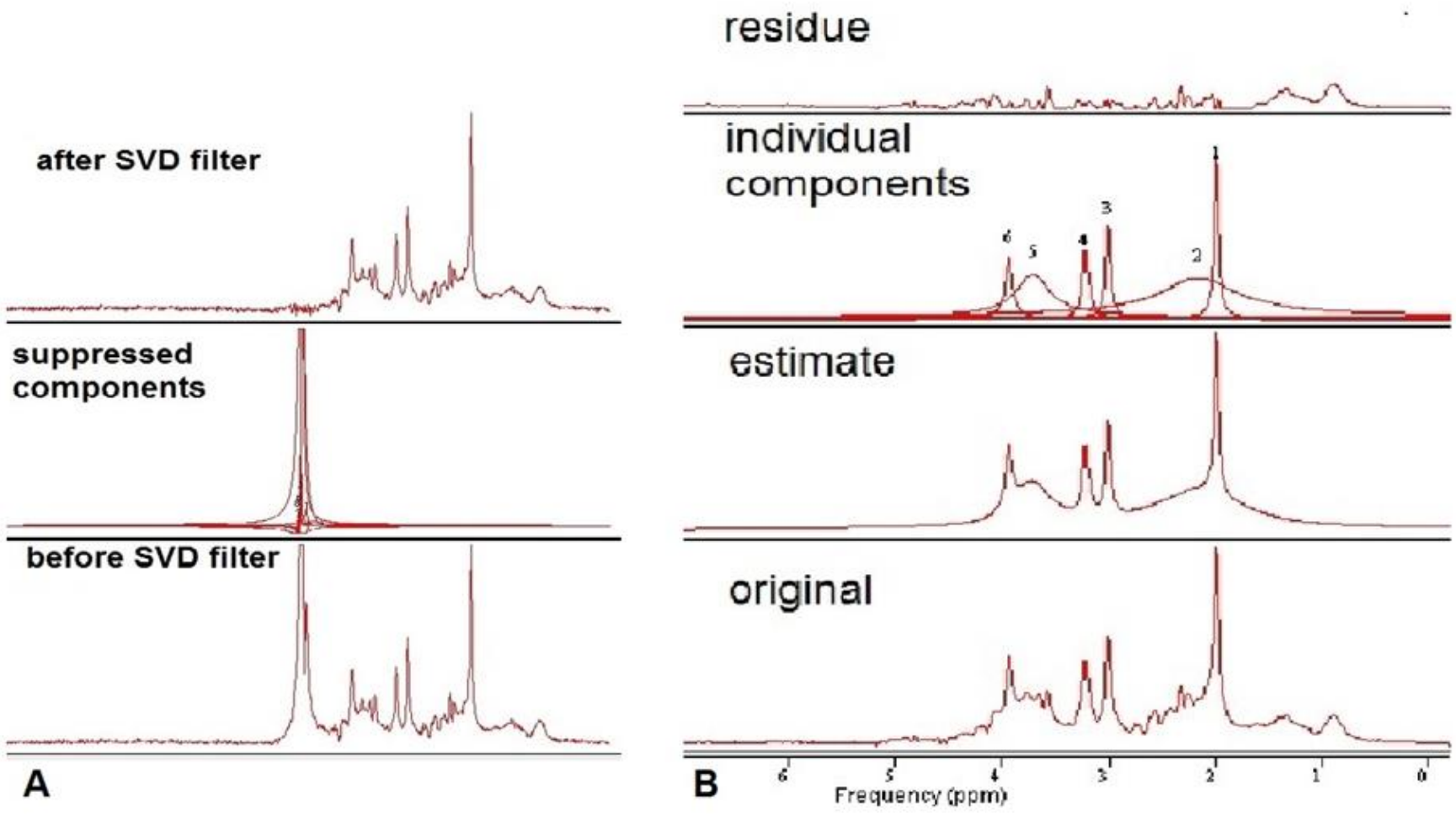
I. TKAC, University of Minnesota

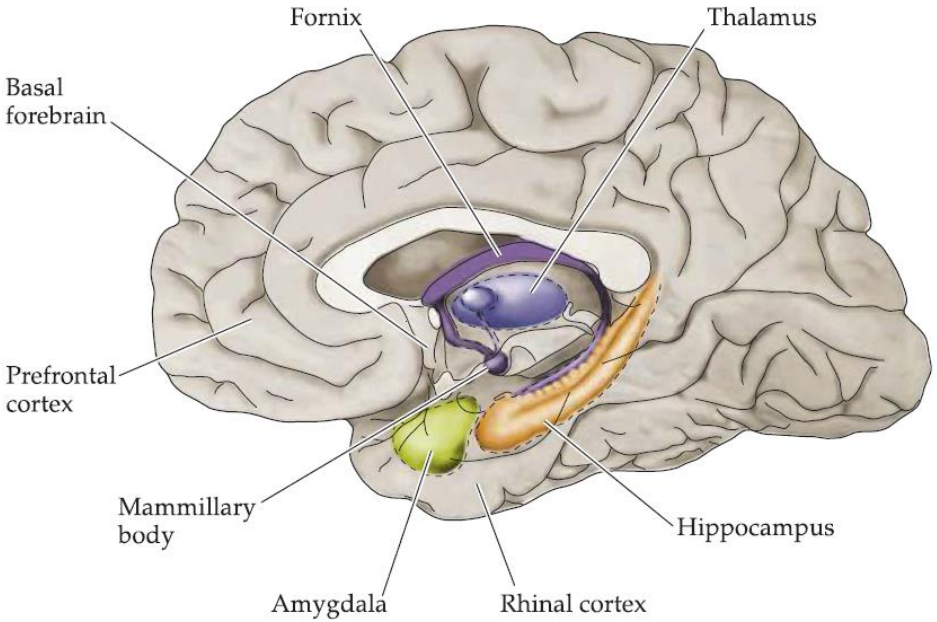
MRS Spectrum processing and Analysis Softwares

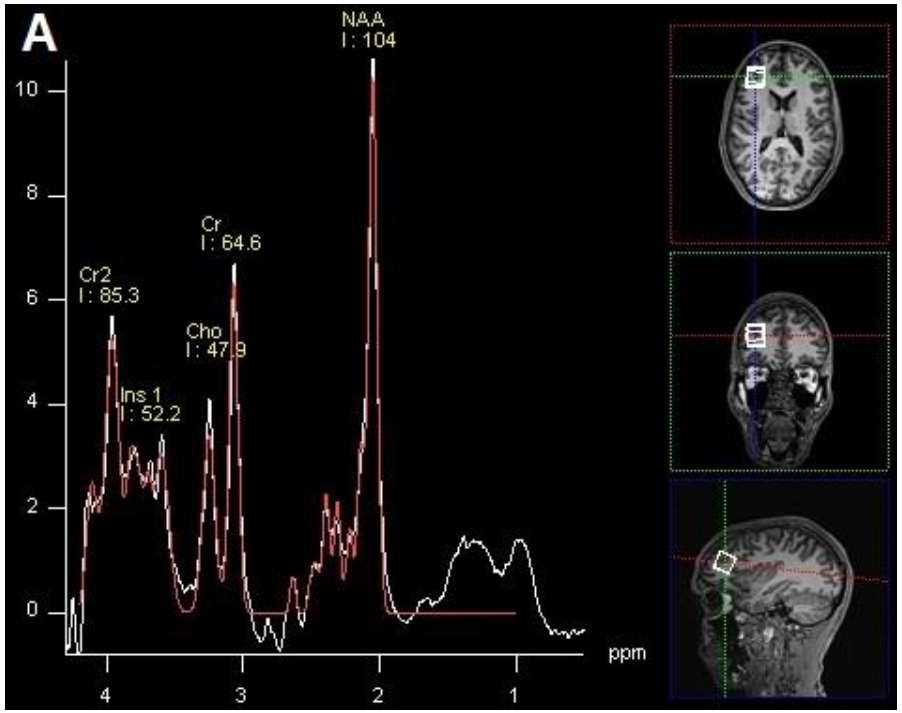
Name	Modelling Domain, Baseline approach	Cost	Code Availability	Published	Cita-tions*
Osprey	FD, spline baseline	free	open	2020	0
LCModel	FD, spline baseline	$13,300	closed	1993	3384
Tarquin	TD, smooth baseline	free	open	2011	243
QUEST (jMRUI)	TD, spline baseline	free	closed	2004	305
AQSES (jMRUI)	TD, spline baseline	free	closed	2007	136
Vespa	FD, wavelet baseline	free	open	2006	66
INSPECTOR	FD, 1st-order polynomial	free	closed	2018	0

Table 1 – Overview of linear-combination modelling algorithms. The domain (either time TD or frequency FD) of modelling and the baseline model approach is specified. *Citations reported from Google Scholar on May 7 2020.

Quantification of MRS spectrum







l of Biomedical Physics and Engineering

Measurement of Post-Treatment Changes in Brain Metabolites in Patients with Generalized Anxiety Disorder using Magnetic Resonance Spectroscopy

Document Type : Original Research

Authors
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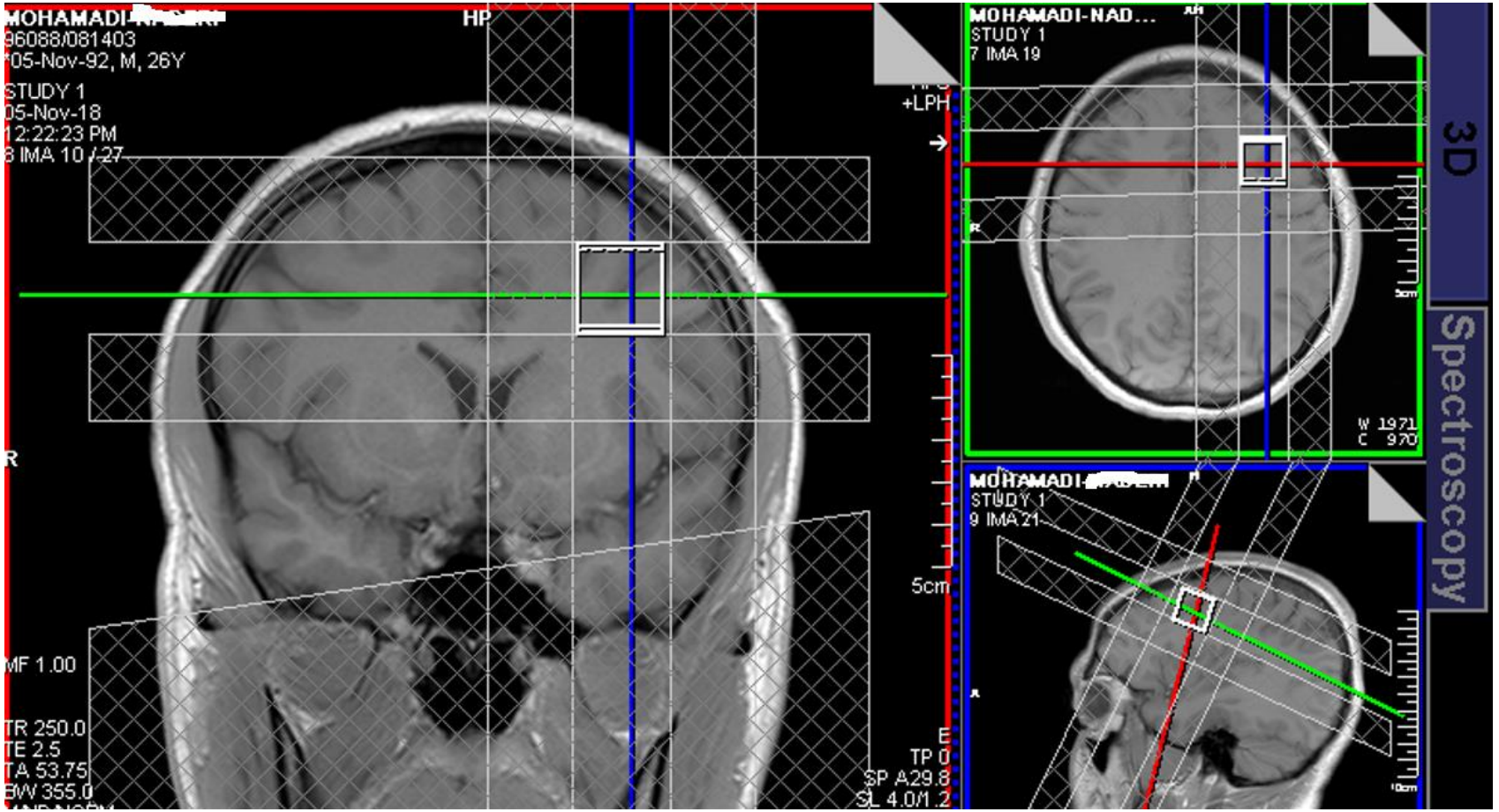
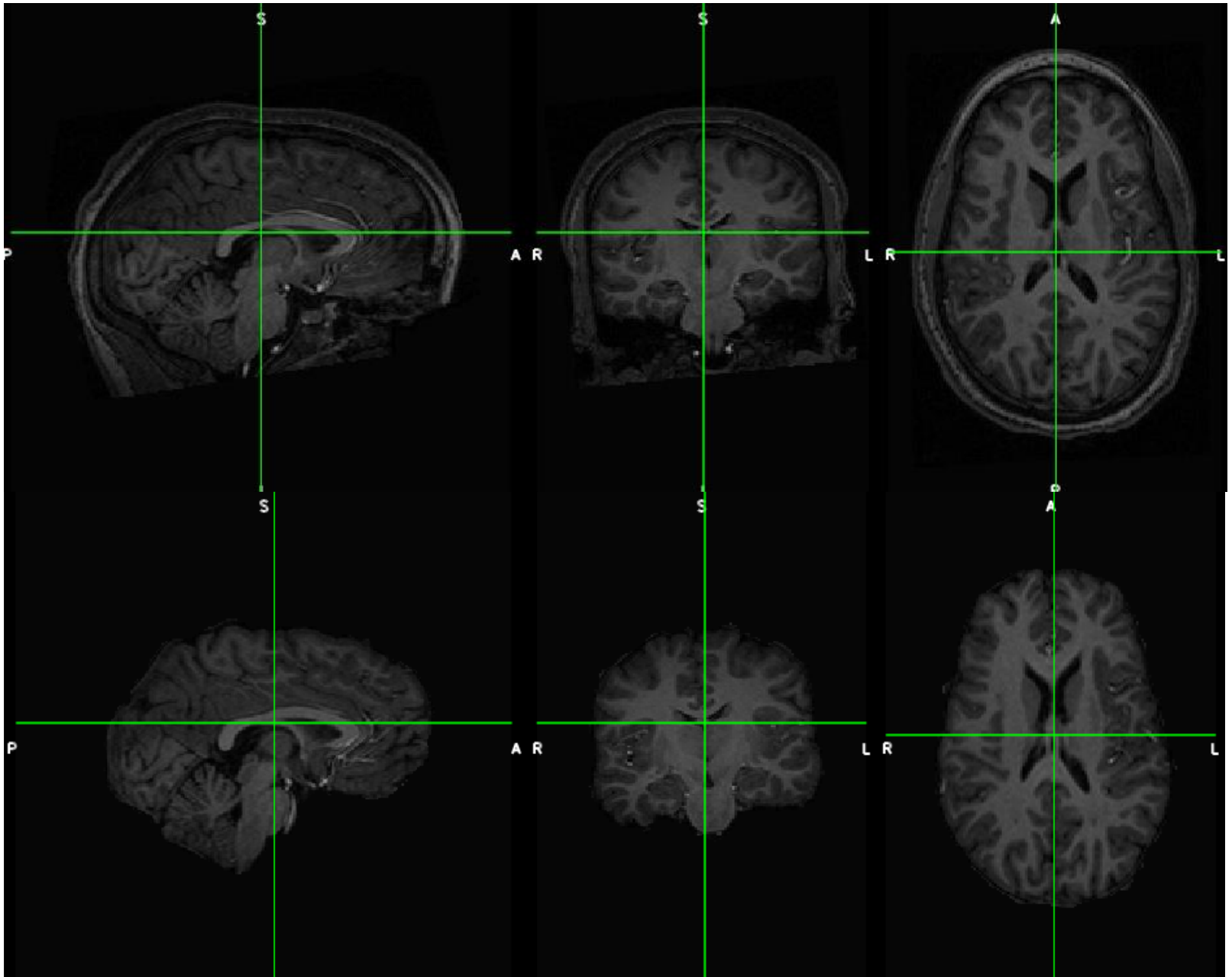
Files

XML

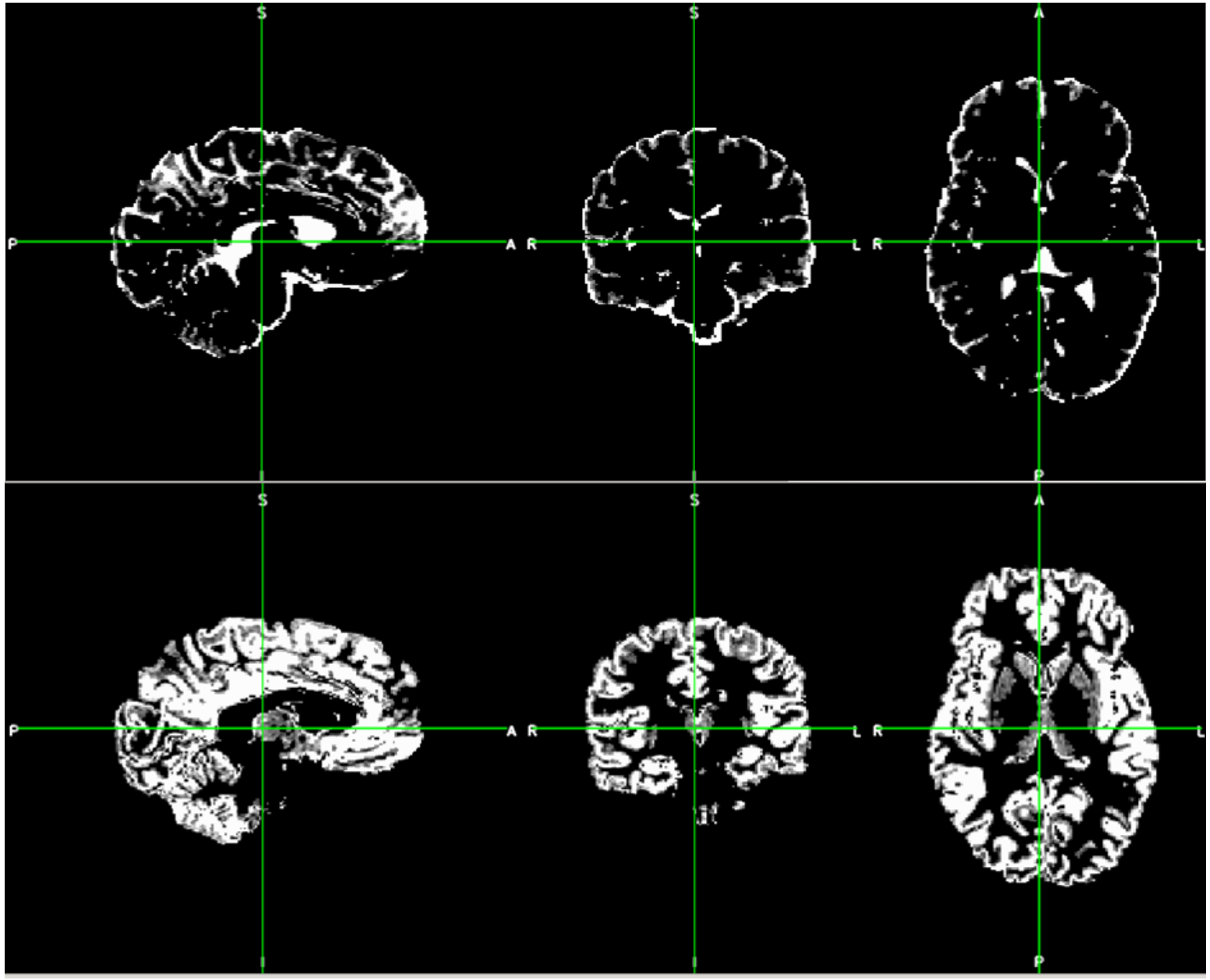
Partial Volume Effect & Tissue Correction



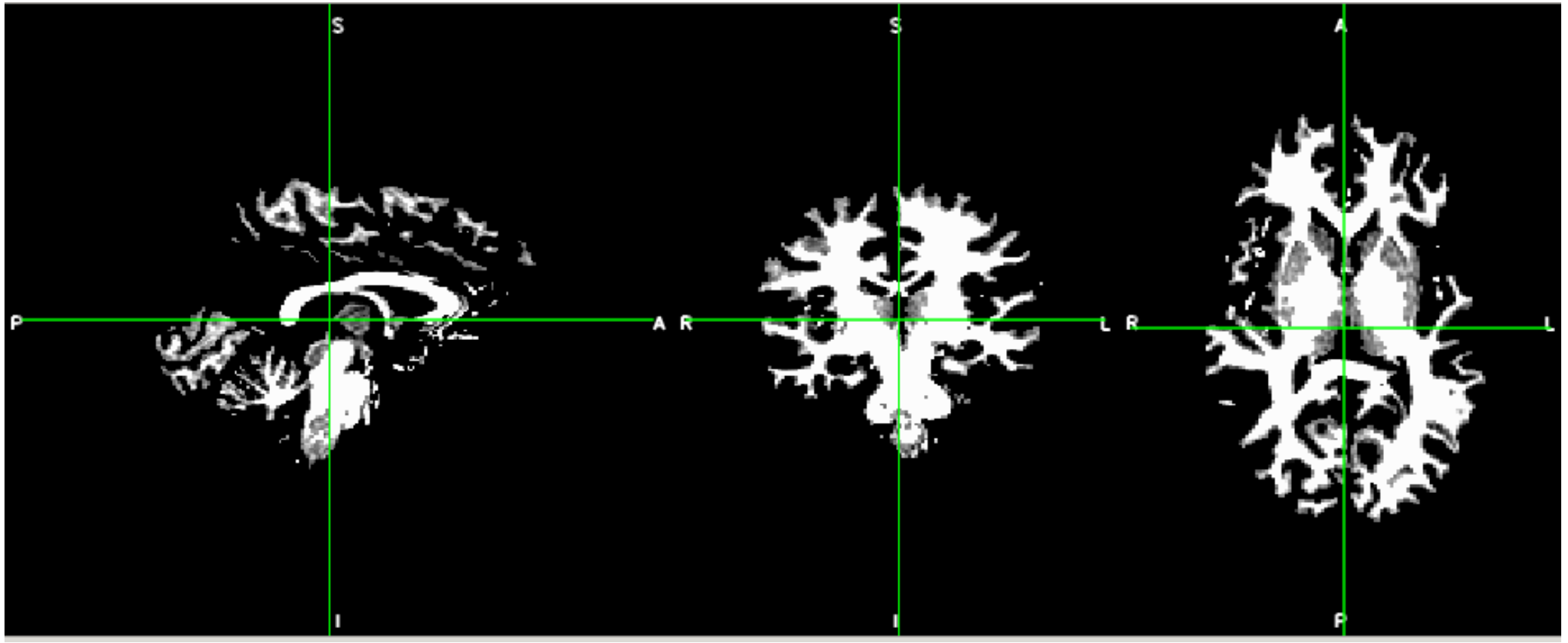
T1 Weighted Structural Images & Brain Extraction



CSF & Gray Matter



White Matter

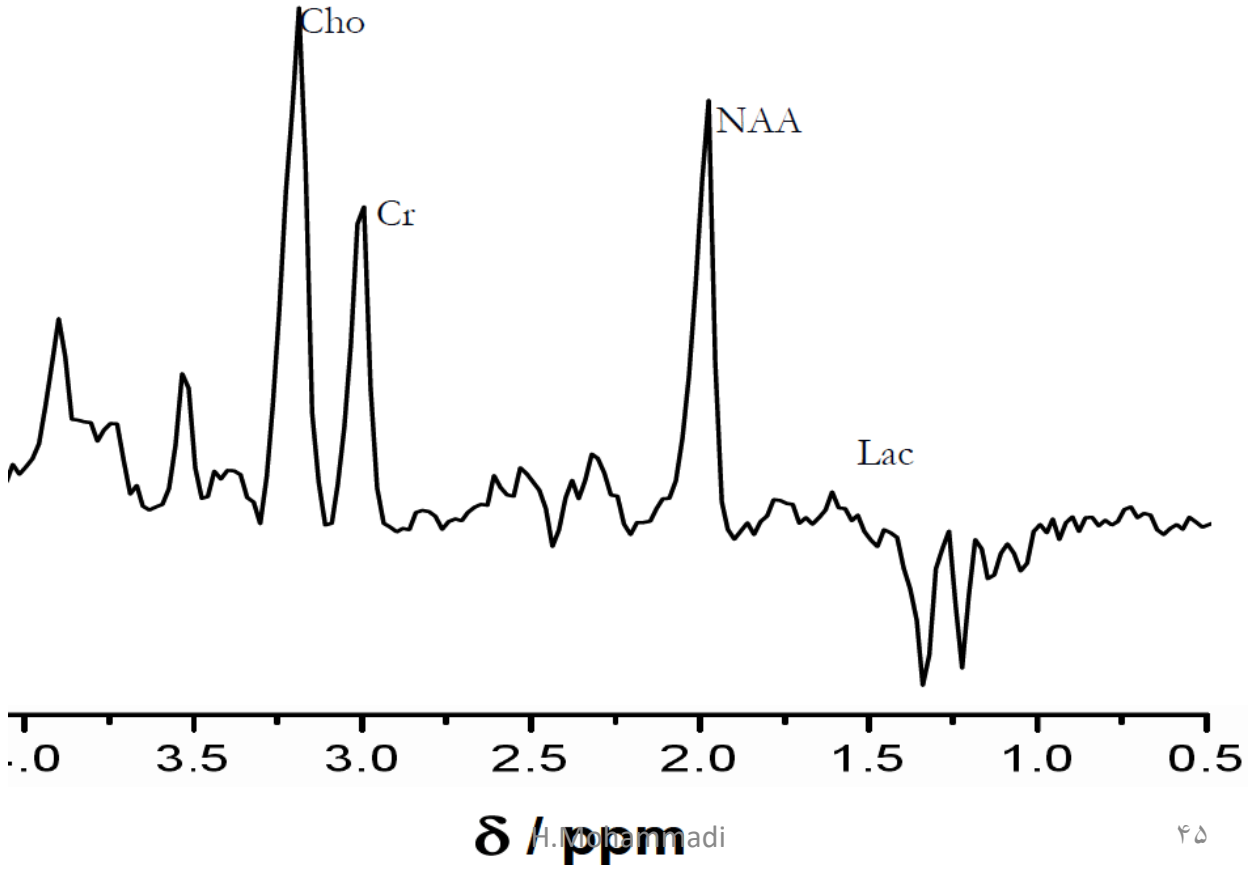


Proton MRS main metabolites

- N-Acetyl Aspartate(NAA) at 2 ppm: Marker of neuronal density and viability
- Creatine(Cr) at 3 ppm: Energy metabolism, generation of ATP
- Choline(Cho) at 3.2 ppm: Pathological alterations in membrane turnover, increased in tumors
- Lipids (Lip) between 0.8 –1.5 ppm: Breakdown of tissue, elevated in brain tumors -lipids indicate necrosis

Proton MRS main metabolites

- Lactate (Lac) at 1.3 ppm, inverted at 144ms: produced by an anaerobic metabolism, found in tumor containing zones of necrosis



MRS Applications in Neuroimaging

- **Research**

the only noninvasive technique that can reliably quantify in vivo concentration levels of key metabolites

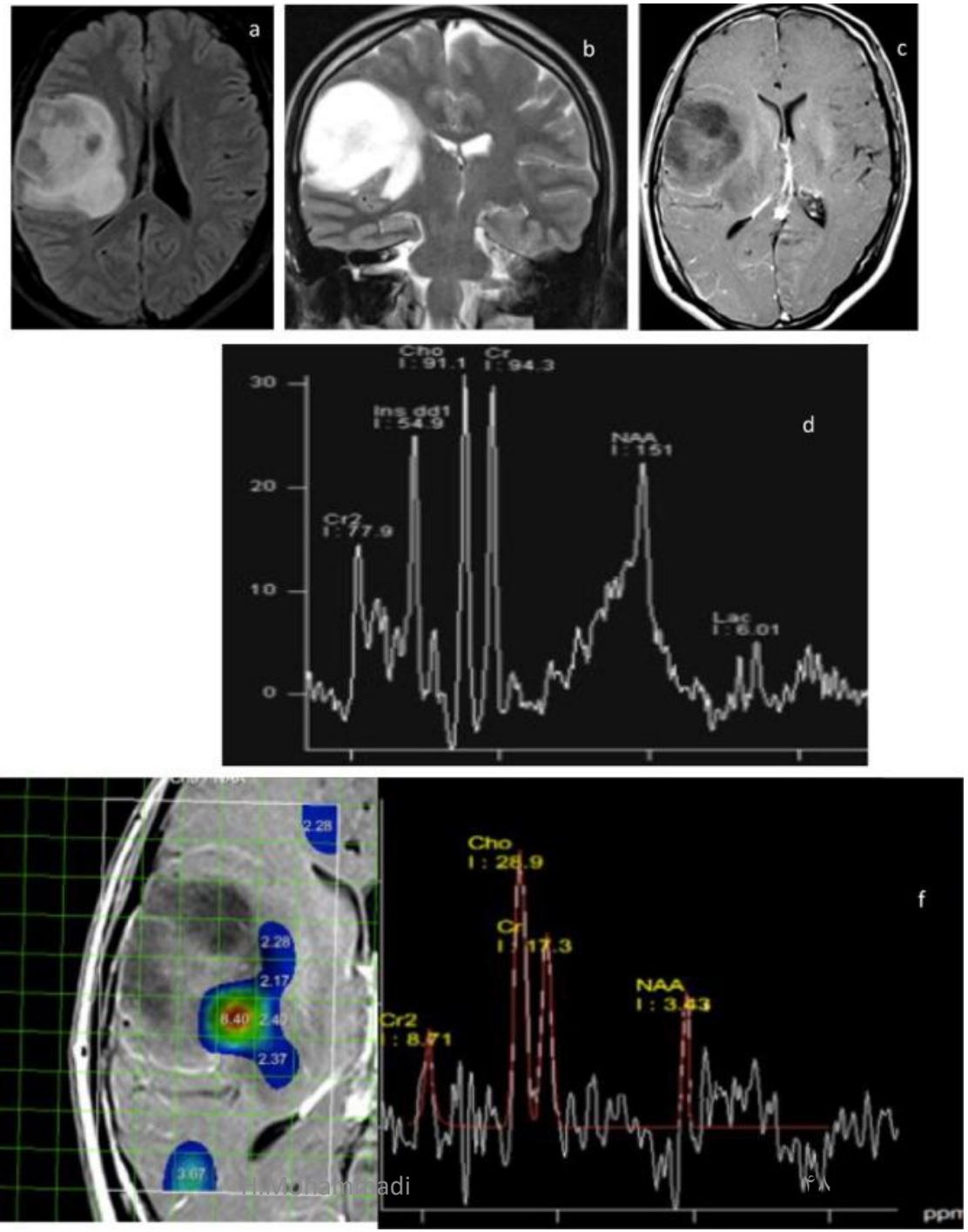
- **Clinic**

metabolic changes in brain tumors, strokes, seizure disorders, Alzheimer's disease, depression and other diseases affecting the brain

Glioma

- MRS can help increase our ability to predict grade. As the grade increases, NAA and creatine decrease and choline, lipids and lactate increase.
- In the setting of gliomas, choline will be elevated beyond the margins of contrast enhancement in keeping with cellular infiltration.
- Cho/Cr ratio of more than **1.5** was used as a marker of tumor presence

Astrocytoma



- **Non-glial tumors**

May be difficult but in general non-glial tumors will have little, if any, NAA peak.

- **Radiation effects**

Distinguishing radiation change and tumor recurrence can be problematic. In recurrent tumor choline will be elevated, whereas in radiation change, NAA, choline and creatine will all be low.

- **Ischemia and infarction**

Lactate will increase as the brain switches to anaerobic metabolism. When infarction takes place then lipids are released and peaks appear.

- **Infection**

As in all processes which destroy normal brain tissue, NAA is absent. Within bacterial abscess cavities, lactate, alanine, cytosolic acid and acetate are elevated/present.

- **White matter diseases**

progressive multifocal leukoencephalopathy (PML) may demonstrate elevated myoinositol

Canavan disease characteristically demonstrates elevated NAA

- **Hepatic encephalopathy**

Markedly reduced myoinositol, and to a lesser degree choline. Glutamine is increased.

- **Mitochondrial disorders**

Leigh syndrome (psychomotor regression): elevated choline, reduced NAA and occasionally elevated lactate

My: Myo-inositol 3.5

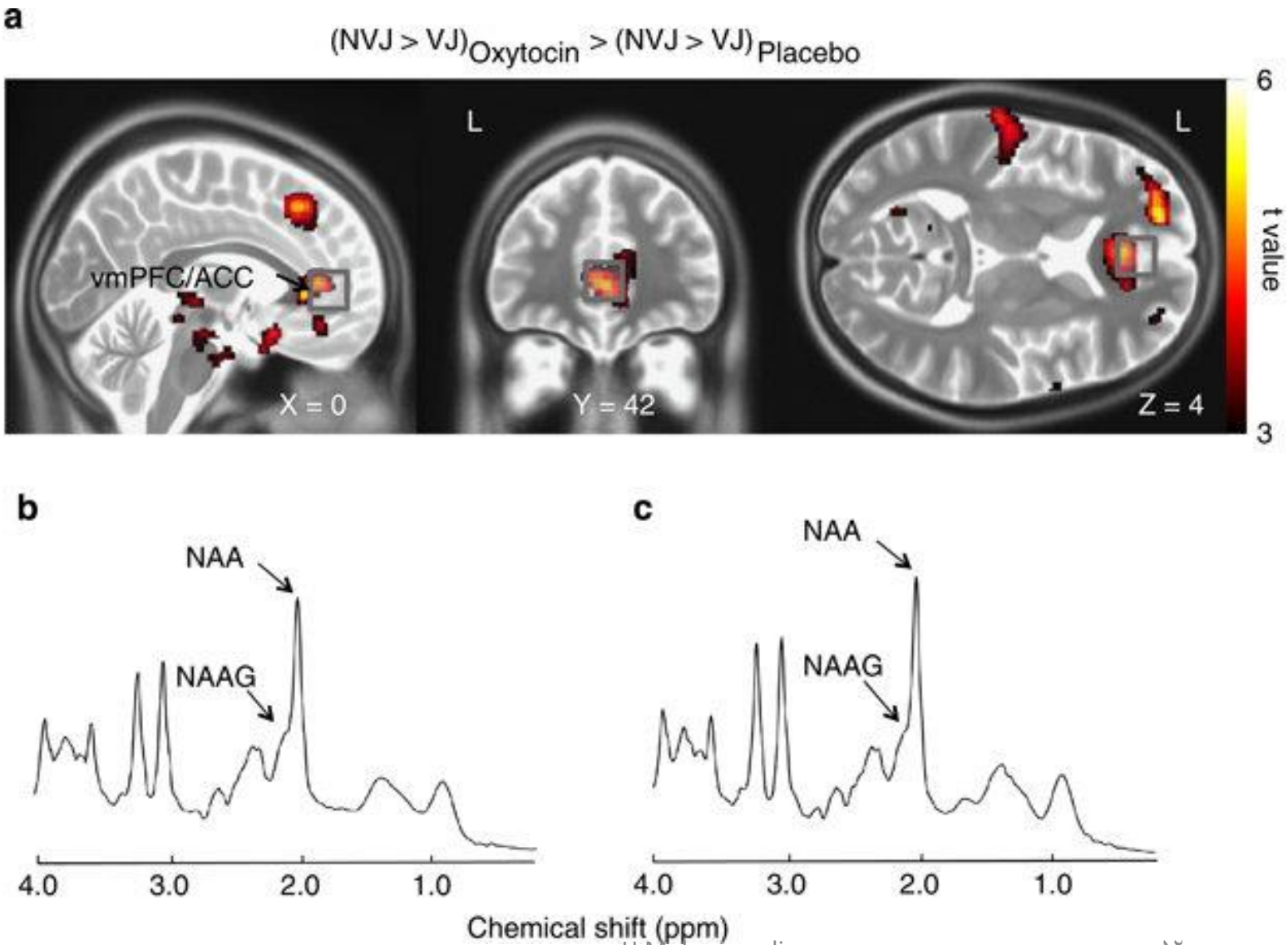
Cho: Choline 3.2

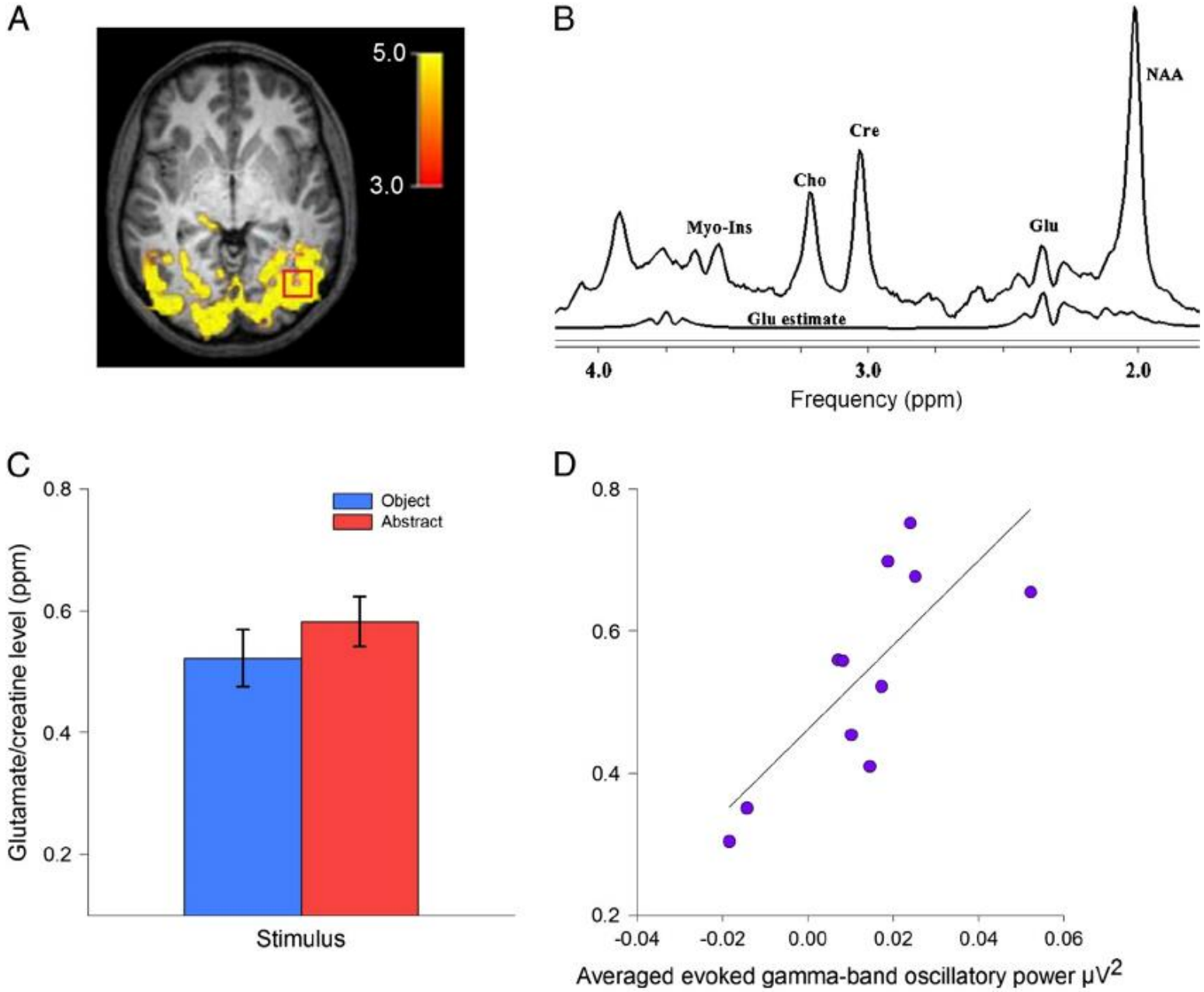
Cr: Creatine 3.0

NAA: N-acetylaspartate 2.0

L: Lactate 1.3

New methods of MRS for Neuroimaging




A
5.0
3.0
B
NAA
Cre
Cho
Myo-Ins
Glu
Glu estimate
4.0
3.0
2.0
Frequency (ppm)
C
Object
Abstract
Glutamate/creatine level (ppm)
0.8
0.6
0.4
0.2
Stimulus
D
0.8
0.6
0.4
0.2
-0.04
-0.02
0.00
0.02
0.04
0.06
Averaged evoked gamma-band oscillatory power μV2

Thanks for your attention

There is no failure, only feedback!

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