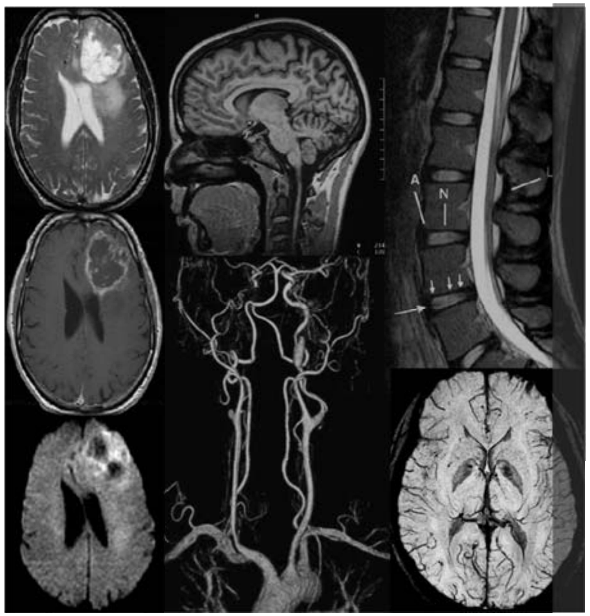

Magnetic Resonance in Medicine
MR Spectroscopy (MRS)

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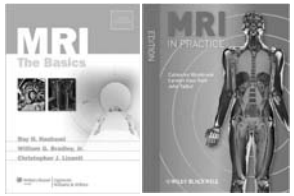
Content http://cflu.lab.nycu.edu.tw/

- **Principle of ^{1}H MR Spectroscopy (MRS)**
  - **磁振頻譜分析**
- **MRS Pulse Sequences**

- **MRI The Basics (3rd edition)**
  - Chapter 29: MR Spectroscopy
- **MRI in Practice, (4th edition)**
  - Chapter 12: Functional Imaging Techniques

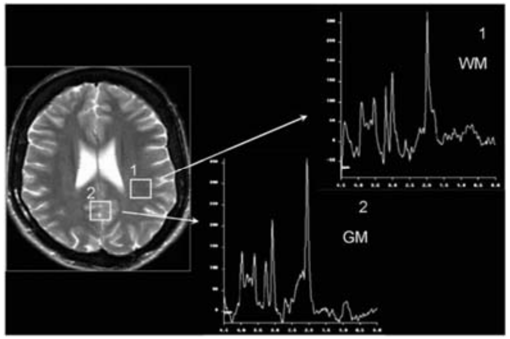


Principles of 1H MR Spectroscopy

磁振頻譜分析簡介

What's MR Spectroscopy

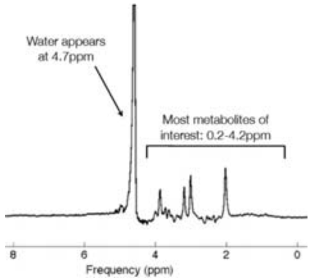
- Rather than providing images, it usually provides spectra consisting of individual peaks, the chemical shift of metabolites.



Bio-chemistry information

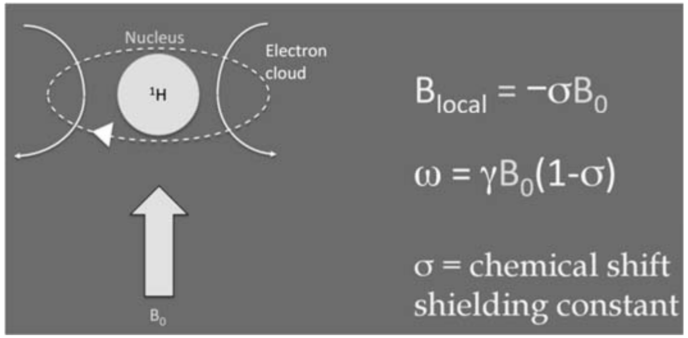
^{1}H Proton Spectroscopy

- Proton spectroscopy is easier to perform and provides much higher SNR than either sodium or phosphorus.
- Proton concentration in water: about 100 M
- Other metabolites: 1~10 mM



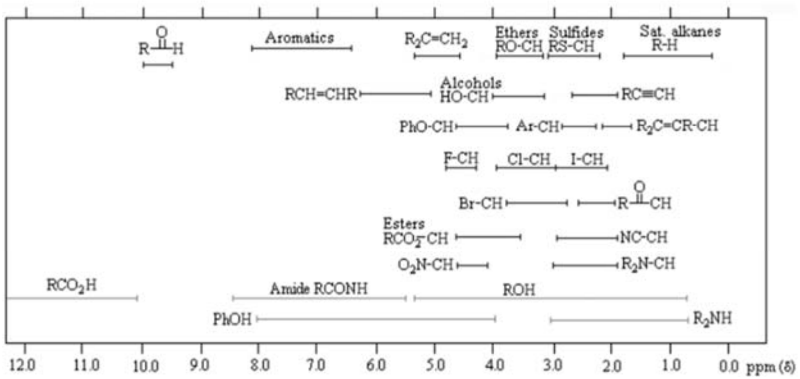
Need to suppress the water signal to investigate the signals from metabolites!

Chemical Shift & shielding effect



http://www.mc.vanderbilt.edu/documents/fmri/files/2013_Phys352A_MRS(1).pdf

MRS Spectrum

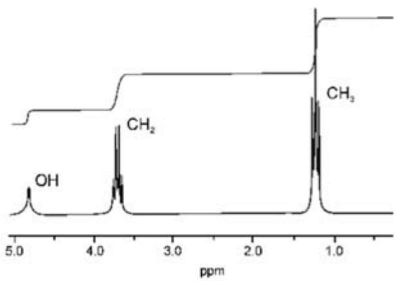


http://www.mc.vanderbilt.edu/documents/fmri/files/2013_Phys352A_MRS(1).pdf

Spectroscopy

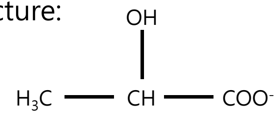
- The area under a given peak is proportional to the number of protons contributing to the peak.
- **Ex: ethanol (CH_3— CH_2—OH) 乙醇**
  - the area under the methyl (CH_3) peak would be 3 (in relative units);
  - the area under the methylene (—CH_2—) peak would be 2;
  - and the area under the hydroxyl (—OH) peak would be 1.
- MRS requires a species to be present in at least a 1 mM concentration to be seen.

NMR spectrum

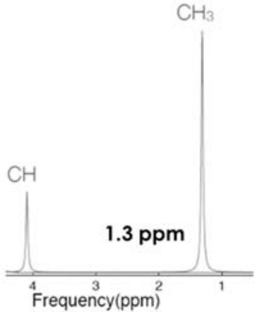


Lactate: $C_3H_5O_3$ 乳酸

- Structure:



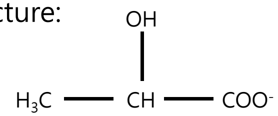
- One methyl group (CH_3)
  - 3 equivalent protons
- One methane group (CH)
- Shielding:
  - Methyl group: high
  - Methane group: low



http://www.mc.vanderbilt.edu/documents/fmri/files/2013_Phys352A_MRS(1).pdf

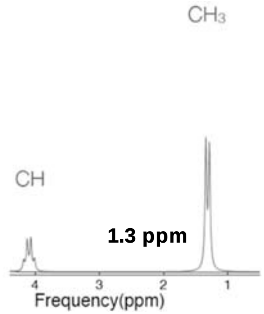
Lactate: $C_3H_5O_3$ 乳酸

- Structure:



- Because the methyl and methane groups share a bond, they are said to be "coupled"
  - Coupling results in peak splitting
  - Splitting or "J-coupling" makes peak identification more difficult.
  - It increases with increasing TE (J-evolution).

NMR spectrum



http://www.mc.vanderbilt.edu/documents/fmri/files/2013_Phys352A_MRS(1).pdf

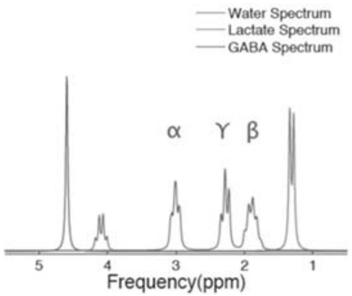
γ-aminobutyric acid (GABA)

- Structure

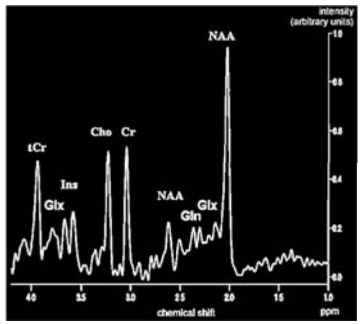
γ β α

$N^+ - CH_2 - CH_2 - CH_2 - COO-$

- Three methylene groups (two equivalent protons per group)
- Coupling:
  - α is coupled to β
  - β is coupled to γ



MRS peaks in Brain



4.0 ppm ← 1.0 ppm

Metabolite	Major Resonance (ppm)	Effect	Visible only at short TE
Lipids (Lip)	0.9, 1.3	Breakdown of tissue	Y
Lactate (Lac)	1.3	Marker of anaerobic glycolysis	N
N-acetyl aspartate (NAA)	2.0	Marker of neuronal health	N
Glutamate/Glutamine (Glx)	2.1, 3.8	Excitatory neurotransmitter	Y
Choline (Cho)	3.2	Marker of membrane metabolism, cell proliferation	N
Creatine (Cr)	3.0	Marker of cellular energetics	N
Myo-inositol (MI or Ins)	3.5, 3.6	glial cell marker	Y

All ppm are given relative to TMS (tetramethylsilane), 0 ppm.

Glutamate(Glu)/Glutamine(Gln)

- Glutamate: essential excitatory neurotransmitter
  - Multiplet: 2.04~2.35 ppm
  - Doublet: 3.75 ppm
- Glutamine
  - Multiplets: 2.12~2.46 ppm
  - Triplet: 3.76 ppm
- Overlapping resonance → Glx

Glutamate-glutamine cycle
glutamate from neurons → astroctyes → glutamine → synthesis of glutamate

Clinical Applications of MRS

Disease	Metabolic Changes
Brain tumors	Cho↑, NAA↓, Cr↓, Lac and Lip↑
Ischemic Stroke	Lac↑, NAA↓, Glx↑, Cr↓, Cho↓
Epilepsy	NAA↓, Lac↑
Multiple Sclerosis	NAA↓, Cho↑, (Cr↓)
HIV/AIDS	NAA↓, Cho↑, MI↑
Traumatic Brain Injury	NAA↓, Cho↑, Lac↑
Hepatic Encephalopathy	Cho↓, MI↓, Glx↑

Radiology Rounds, July 2012-volume 10, issue 7.

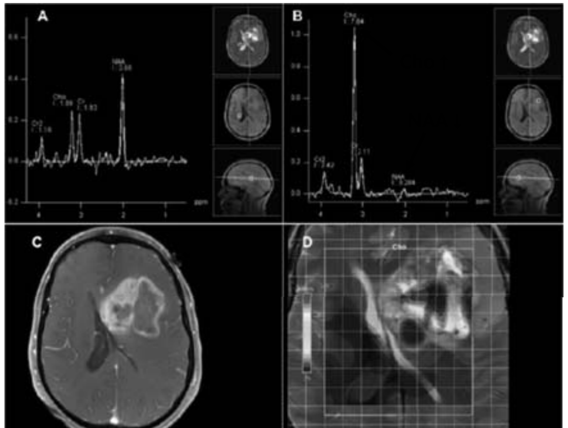
Brain tumor: glioblastoma

Normal region

Tumor region

Contrast Enhanced T1W

Choline Map



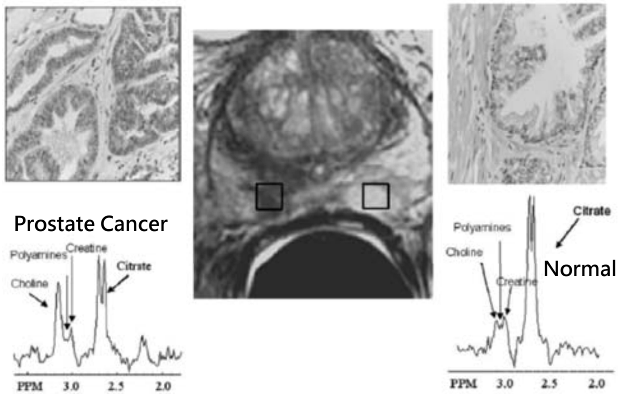
Radiology Rounds, July 2012 e 10, issue 7.

Clinical Applications of MRS

Neurodegenerative Disease	Metabolic Changes
Alzheimer	NAA↓, MI↑
Parkinson	NAA↓ (Striatum)
Huntington	NAA↓, Cho↑ (Basal ganglia)
Amyotrophic Lateral Sclerosis (ALS)	NAA↓ (Motor cortex, Brain Stem)

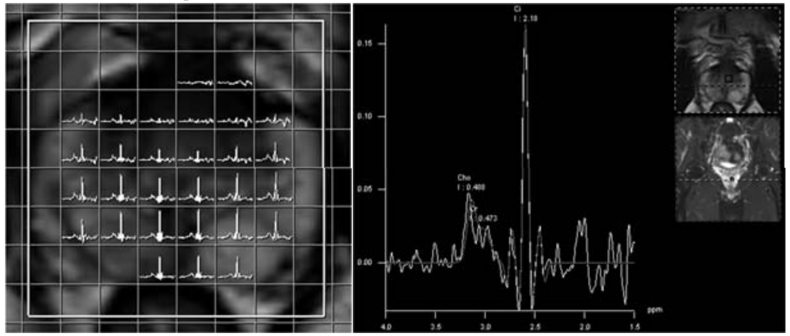
Radiology Rounds, July 2012-volume 10, issue 7.

MRS for prostate



MRS for prostate

- Single voxel spectroscopy (SVS)
- Multi-voxel chemical shift imaging (CSI)



Citrate at 2.6 ppm; Polyamine (spermine) at 3.1 ppm
Peripheral zone contains more glandular tissue – high citrate
Benign sign: low Cho+Cr/Ci and high Polyamine
Prostate cancer: T2 low, ADC drop, high (Cho+Cr)/Ci ratio and low Polyamine

MRS Pulse Sequences

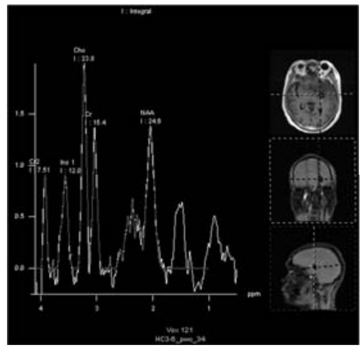
磁振頻譜脈衝程序與分析

MRS Pulse Sequences

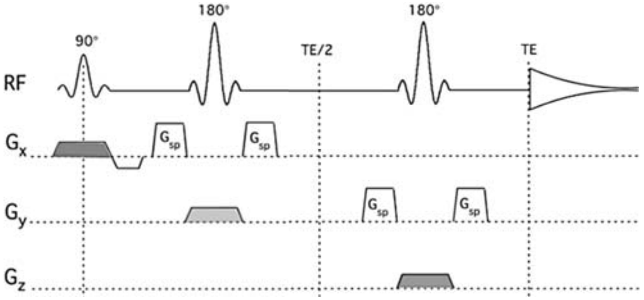
- Localization: Covering lesion and normal sites for the comparison.

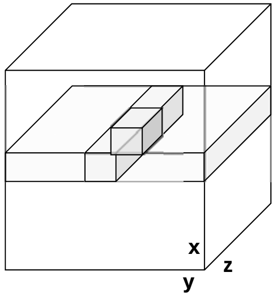
Two major sequences

- **P**oint-**Res**olved **S**pectroscopy, **PRESS**
- **St**imulated **E**cho **A**cquisition **M**ode, **STEAM**



Point-Resolved Spectroscopy, PRESS

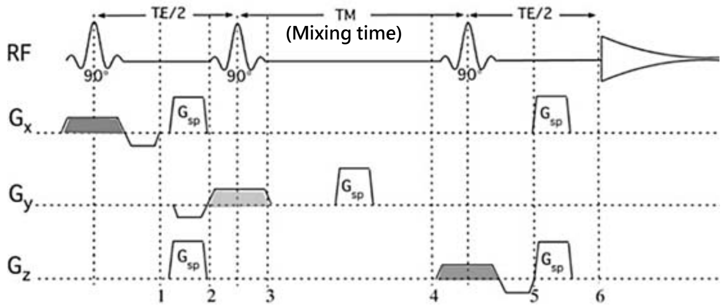




Double spin-echo sequence consisting of three slice selective pulses in orthogonal planes (90 – 180 – 180)

Signal comes from the intersection of the 3 planes!

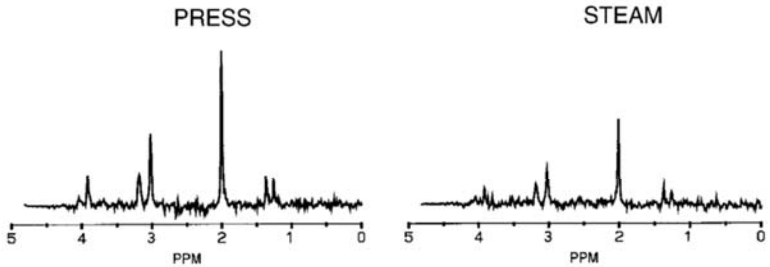
Stimulated Echo Acquisition Mode, STEAM



- Consists of three orthogonally slice selective 90 pulses (90 – 90 – 90)
- T2 decay does not occur during TM

PRESS vs. STEAM

- Stimulated echo amplitude is only half the size of a PRESS spin echo.



Medical Physics, 29(9), 2177-2197, 2002.

PRESS vs. STEAM

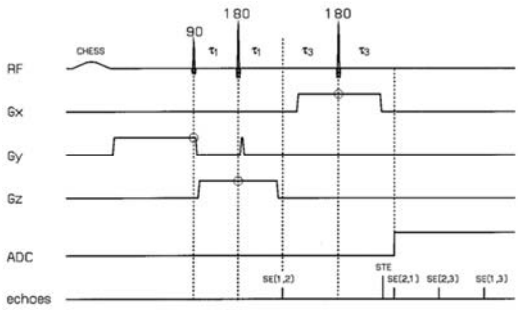
	PRESS	STEAM	Note
SNR	S	S/2	PRESS SNR 2x STEAM SNR
TE	Short TE difficult (>30 ms)	Short TE possible (~7 ms)	STEAM: Better for metabolites with short T2
SAR	High	Low	90 transmit lower power than 180
Location	Sharp	Sharper	90 pulses have sharper profiles than 180s

http://www.mc.vanderbilt.edu/documents/fmri/files/2013_Phys352A_MRS(1).pdf

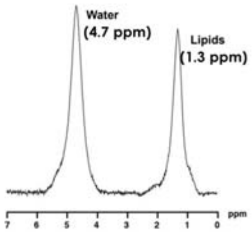
Water/Fat Suppression

- **Che**mical **S**hift **S**election, **CHESS**

  Frequency-selective presaturation pulse

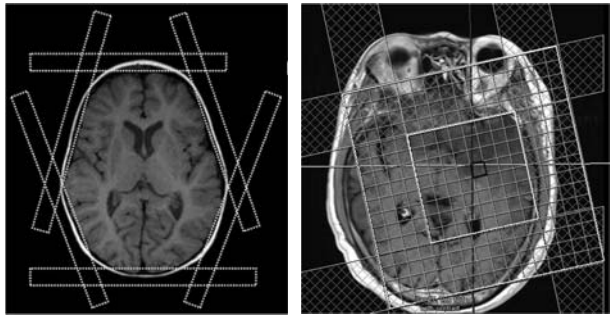


PRESS with one CHESS



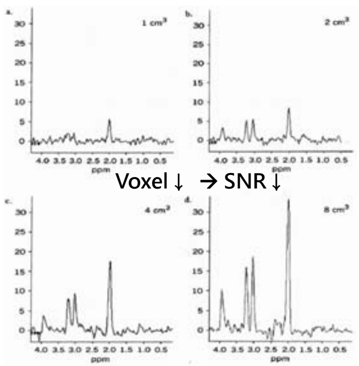
Fat Suppression in Brain

- Add spatial saturation bands.
- **O**uter **V**olume **S**uppression, OVS



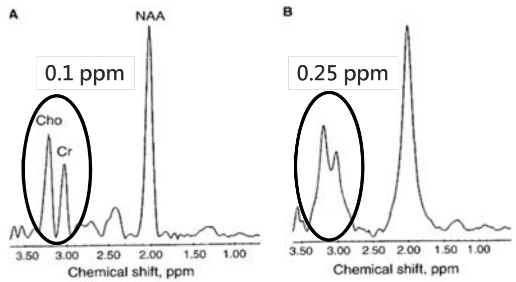
Voxel Size of MRS

- MRS (6~15 min) in the brain is generally performed in conjunction with MRI.
- For single voxel techniques, a volume of 8 cc (2x2x2 cm^3) is generally recommended at 1.5 T.
- Peak height is generally proportional to field strength
  - a smaller voxel can be used at 3 T, reducing partial volume averaging.



Shimming for MRS

- Shimming requirement for MRI is usually less than 5 ppm.
- For MRS, shimming results in improving the uniformity from 1 ppm in the main magnetic field to 0.1 ppm inside the voxel.



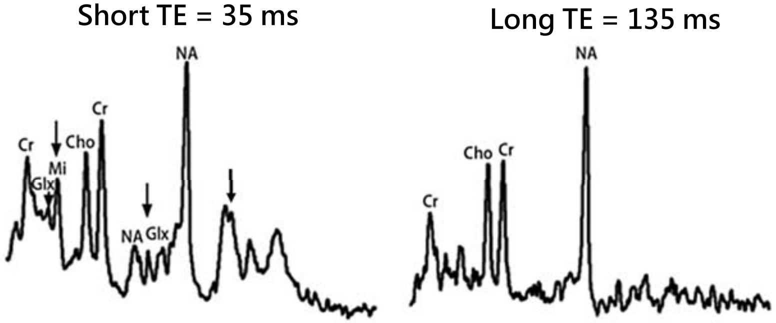
Bad shimming → wider FWHM

TR & TE in MRS

- Most institutions use a TR of 1500 msec and the shortest possible TE of 30 or 35 ms to maximize the SNR.
- This also allows the detection of short T2 species (like myo-inositol and lipid), which would otherwise have already decayed at longer TE.

Peak width is proportional to 1/T2, thus short T2 species will lead to peak broadening.

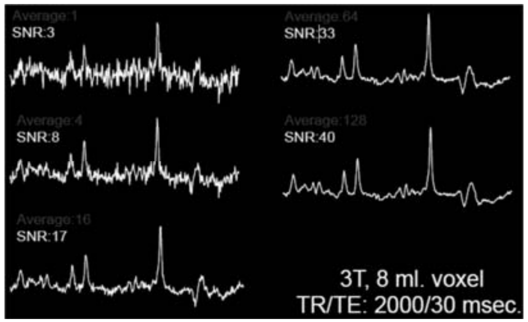
TE Effects



Ricardo André Amorim Leite et al. Arq. Neuro-Psiquiatr. vol.68 no.1 São Paulo Feb. 2010

Average & SNR

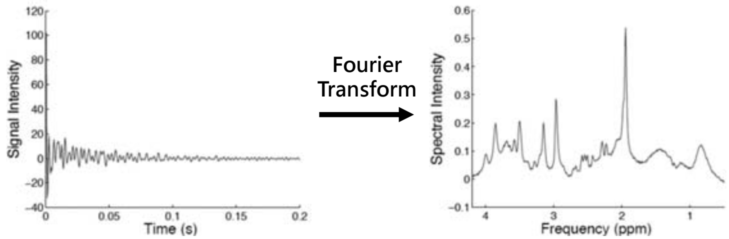
- Another option to increase SNR is to increase the average (NEX).
- Typically, 64~128 averages are demanded to acquire sufficient SNR for short TE.



Quoted from Prof. Tsai, Shang-Yueh's slide

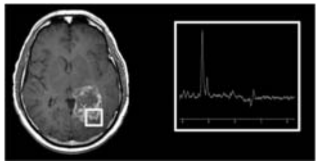
Fourier Transform

- In the simple MRS experiment, **no frequency-encoding gradients** are applied during the readout for spatial encoding.
- the signal does not contain spatial information, just information of the different resonance frequencies within the sample



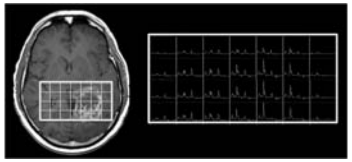
SVS vs. CSI

- Single-voxel spectroscopy (SVS)



- Widely used
- Fast and easy
- Limited application for large or inhomogeneous lesion

- Multi-voxel Chemical Shift Imaging (CSI)

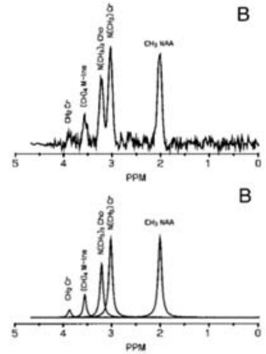


- Time consuming
- Better assessment of large or inhomogeneous lesion
- Better spatial resolution but lower SNR

http://mriquestions.com/single-v-multi-voxel.html

Post-Processing

- FID signal processing
  - Water suppression (removing the 4.7 ppm signal)
  - Zero filling (Increasing frequency resolution)
  - Apodization (noise filtering)
- Fourier Transform
- Spectrum processing
  - Phase correction
  - Baseline correction



THE END

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