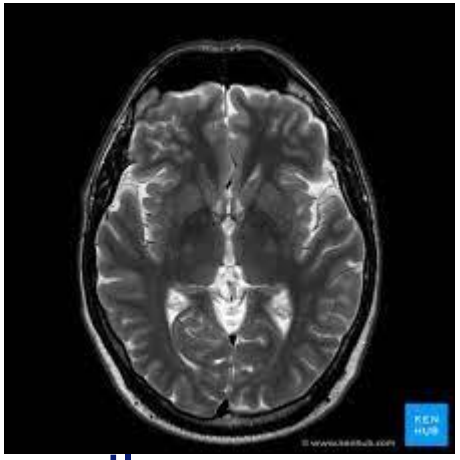
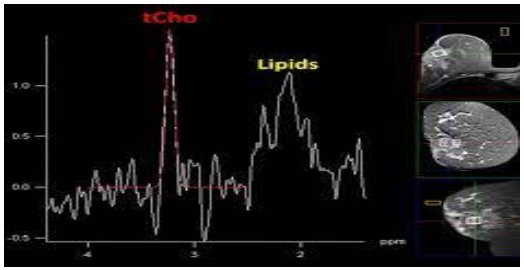
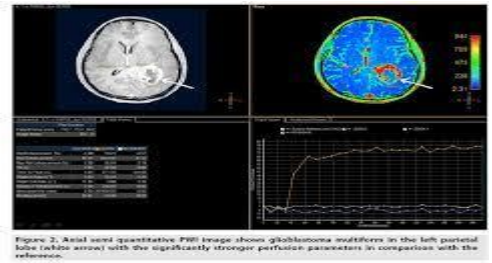
Introduction

- In MRI, we have two types of data acquisition
- Qualitative and quantitative
- The product of qualitative imaging is an image



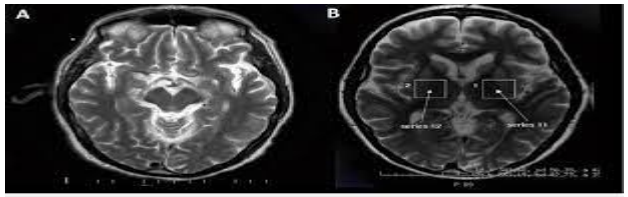
- The product of quantitative imaging is not necessarily an image, it can be a graph or a specific curve or data



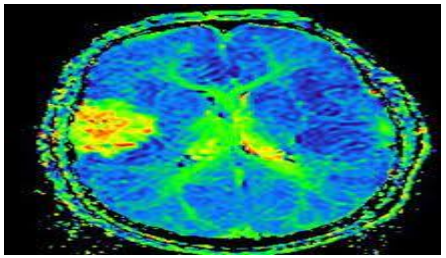


Introduction

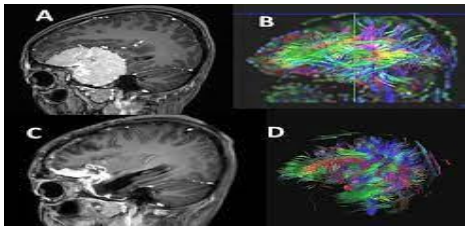
- Quantitative imaging included :
- DWI



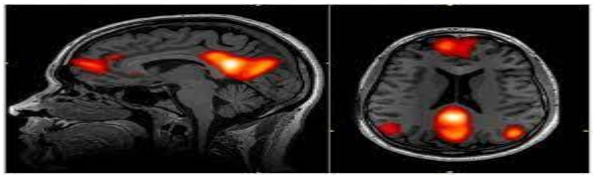
- PWI



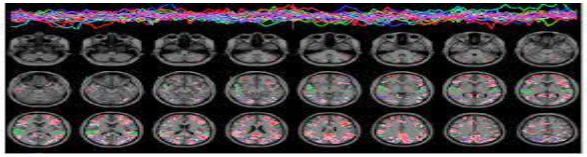
- DTT
- DTI



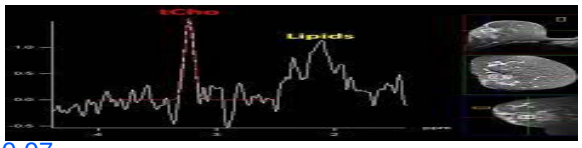
BOLD



- Functional MRI

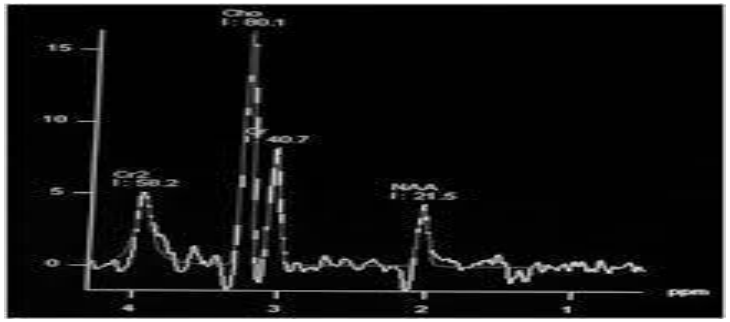


- MRS



Introduction

- **MRS**
- Finally, it gives us a curve or graph that should eventually be evaluated and converted into the data we want.

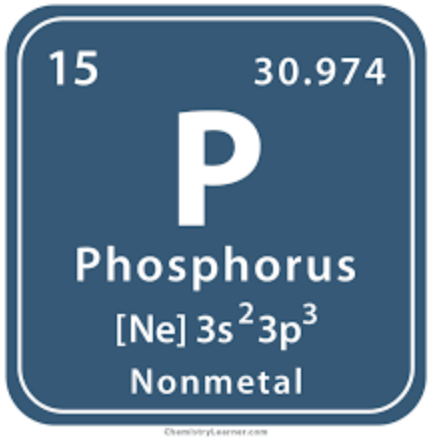


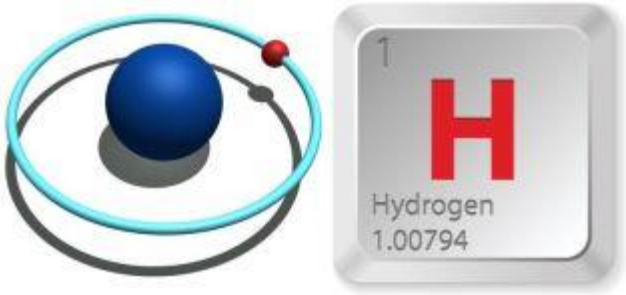
- Spectroscopy increases the diagnostic distance from 0 to 100 to 100%

.

Introduction

- In the devices that we currently have, with a field strength of 1.5 Tesla, imaging is done with two elements, hydrogen and phosphorus.



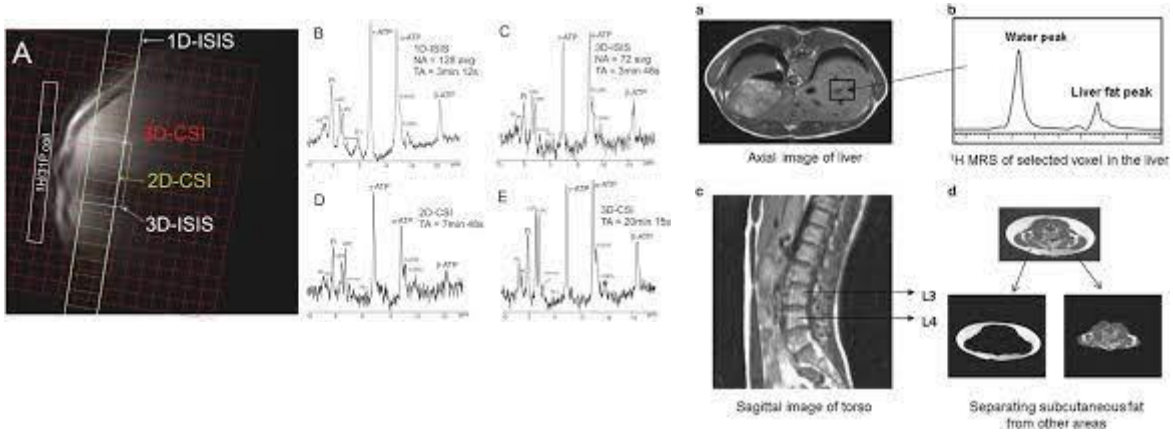


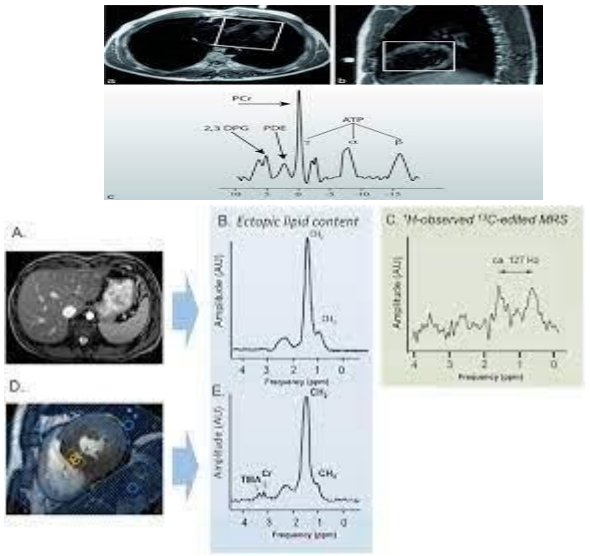
siemens-3t-mri-scanner.webp

Introduction

In 1.5 Tesla more hydrogen can be used and the element phosphorus is usually set up for three Tesla devices and for some different organs.

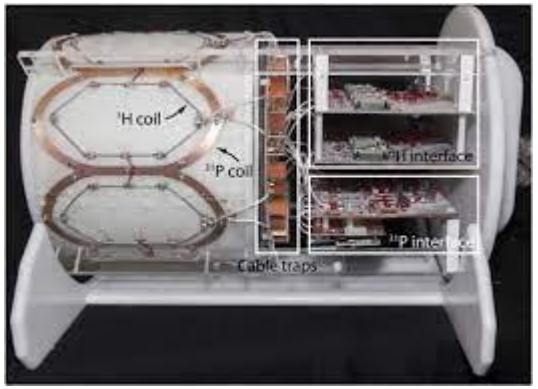
.in practice Hydrogen can be used in all pulse spectroscopic sequences, but phosphorus is only used to examine the heart, liver, and muscles.





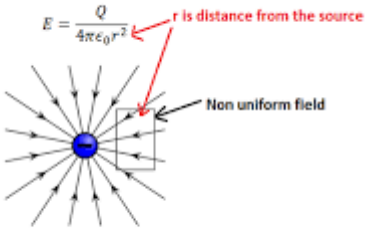
Introduction

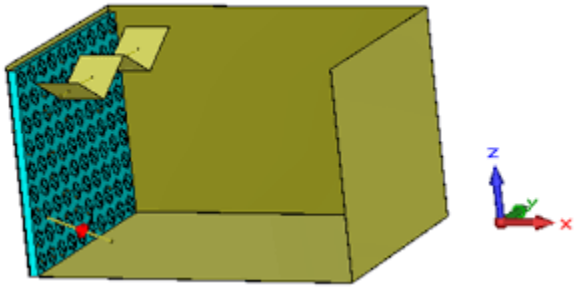
The difference between imaging with hydrogen and phosphorus is that when using phosphor we have a phosphor coil that must be tuned to the device and is known and is usually used in devices with three Tesla and above.

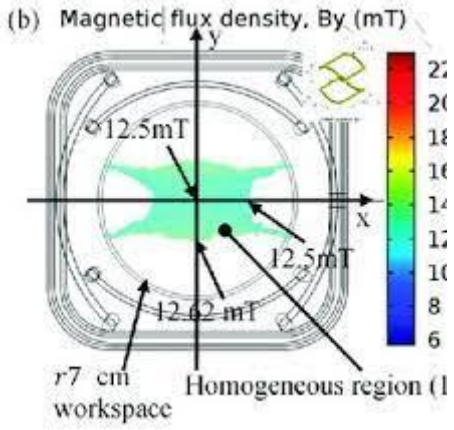


Introduction

- MRS is strongly related to the homogeneity and uniformity of the field.
- Designed for 1 Tesla and above devices and not lower than that

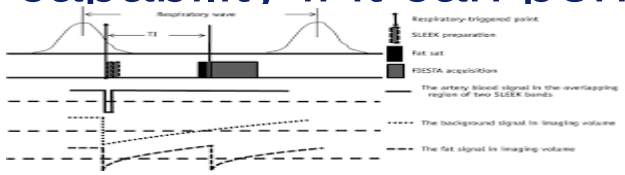


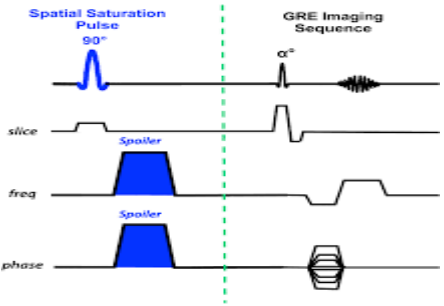


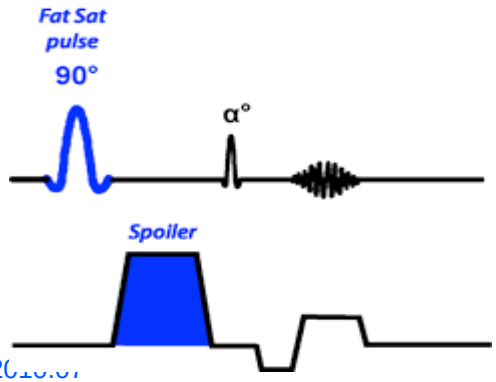


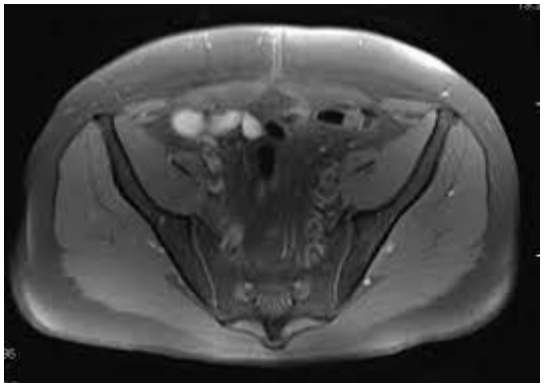
Introduction

- Used on devices above a Tesla when the magnet of device has uniformity and homogeneity and good tuning
- Spectroscopy is practically unusable if a metal or case sticks to the device that disrupts the homogeneity of the device.
- To check the homogeneity of the device, we must see how capable the device is in fatsat pulses
- It has good spectroscopic capability if it can perform fatsats evenly







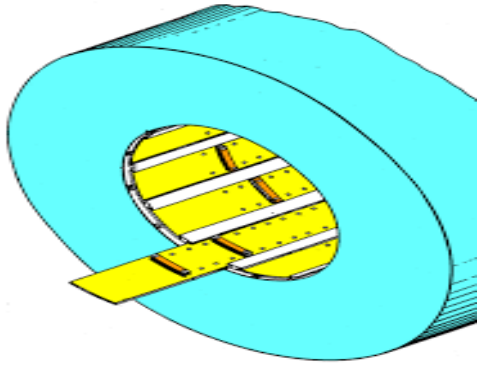


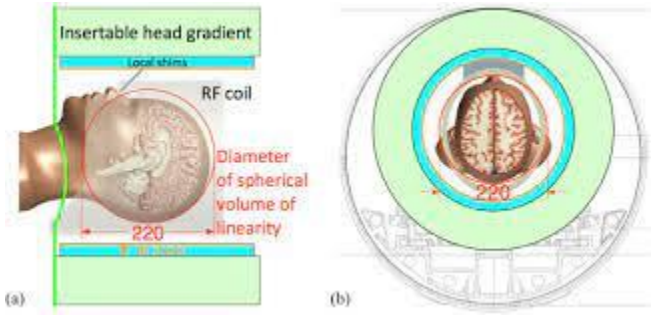
Introduction

- In siemens devices at our disposal, those designed for neurological centers.
- Two shimming samples are performed on them.

- Basic or standard or passive shimming for common devices for which passive shim and basic shim are performed

- Advanced shimming is for devices designed for neuroimaging and advanced shimming is performed on them.

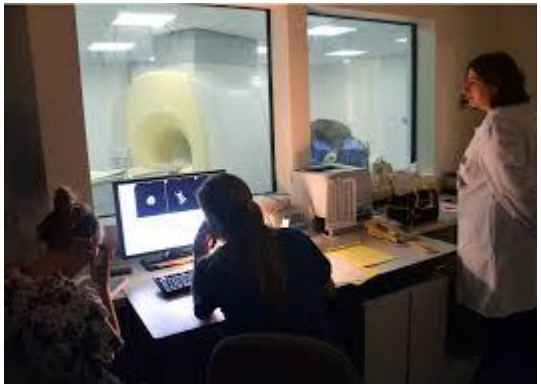




Introduction

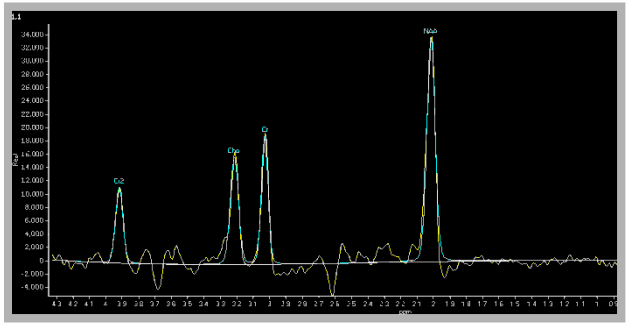
- The difference between a Siemens and a Philips magnet is that for the Philips, full shimming is done from the beginning and when the Siemens magnet is advanced, it equals the Philips.

- MRS is extremely sensitive to inhomogeneity and even opening and closing the magnet door can disrupt data.



Introduction
What is Spectroscopy

- What is Spectroscopy?
  - Study of spectra
- What is a Spectrum?
  - A graphic representation of the distribution of energy emitted by a radiant source, arranged in order of frequencies
- What is MR spectroscopy?
  - Study spectra acquired on basis of the (N) MR principle

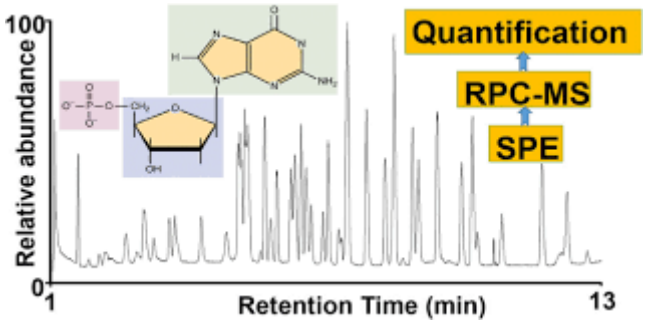


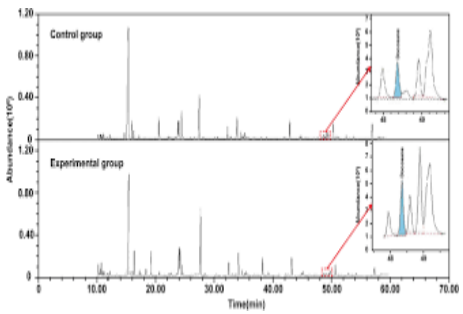
Introduction

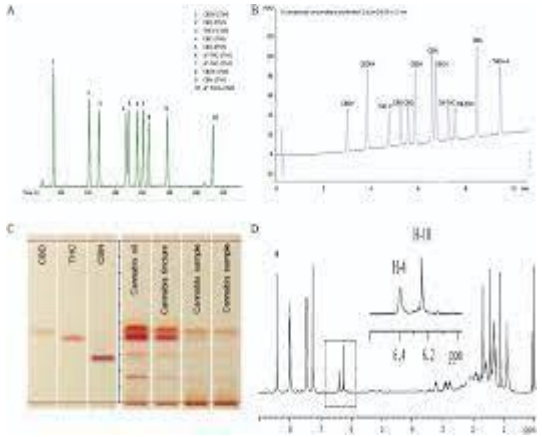
- • Magnetic resonance spectroscopy:
- is an analytical method that enables:
- the identification and quantification of metabolites in samples.

It differs from conventional MRI in that spectra provide physiologic and neurochemical state instead of anatomy

Metabolic changes may not be appear in anatomical image.







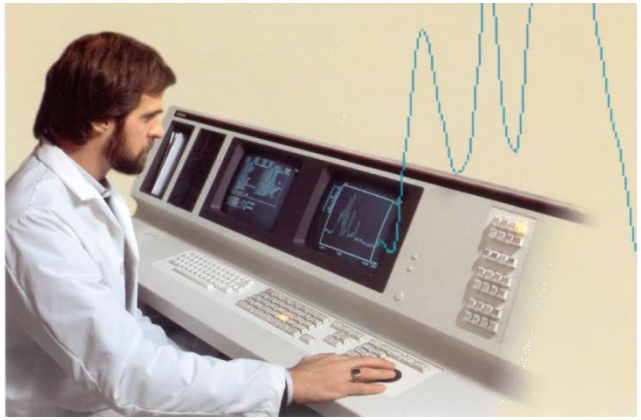
Introduction

MRS was first described in 1946 simultaneously by the Nobel Prize winner Edward Purcell.

Introduction:
MR Spectroscopy, history

- MR spectroscopy, or NMR spectroscopy is used since the 1950's as a non-destructive analytical method in chemistry and biochemistry
  - Small bore magnets
  - Very high field strength
  - In vitro measurements

- In 1986 MR spectroscopy was combined for the first time with an imaging system, the Gyroscan S15
  - Whole body scanner
  - High field strength
  - In vivo measurements

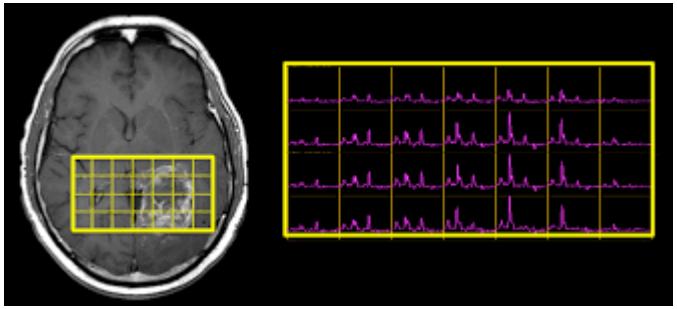


Introduction
MR Spectroscopy

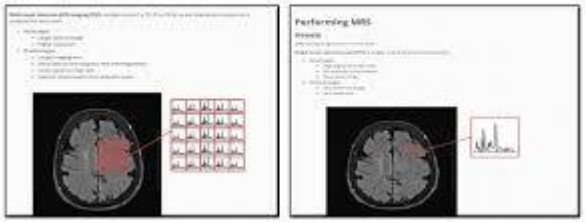
- MR spectroscopy (MRS) and imaging (MRI) share the same physical principles
- MRI is a way to produce a cross-sectional image based on proton (water) signal
- MRS is a method of gathering information about the chemical composition of the tissue of interest

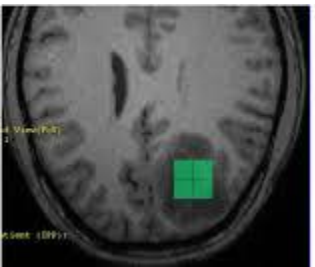
  The information is based on the difference in the resonance frequency of tissue metabolites: ‘Chemical shift’

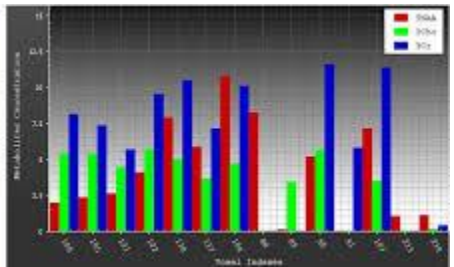
  – Output:
    * Spectrum per voxel
    * Cross-sectional image based on a certain metabolite



MR Spectroscopy



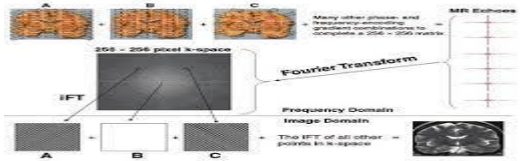


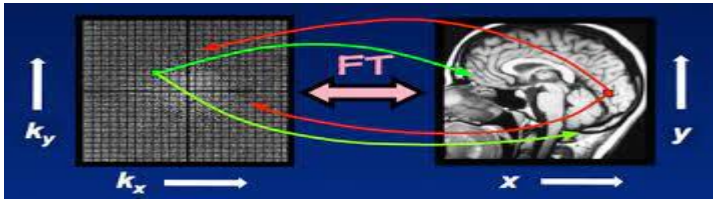


Introduction

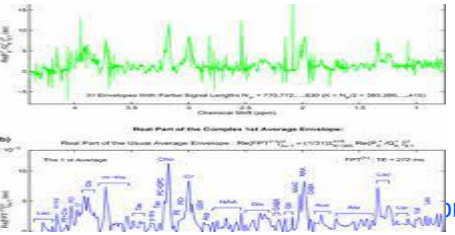
- MRI & MRS are one and the same! Only differ in:

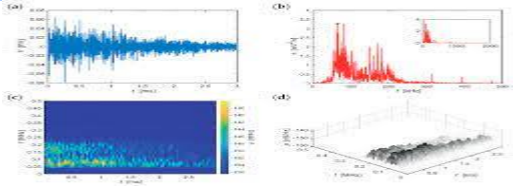
- manner in which data is processed and presented - In MRI:
- – signal obtained in a time unit
- -generates image by Fourier transform & k-space •

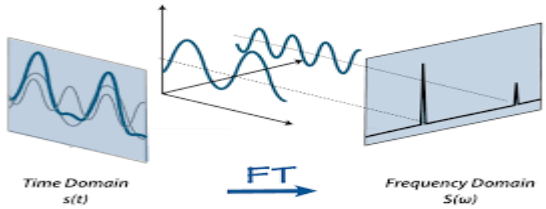




- In MRS: Fourier transform of image signal generates a frequency spectrum of the image components
-



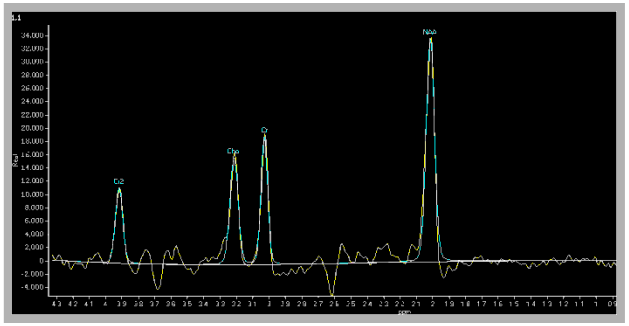




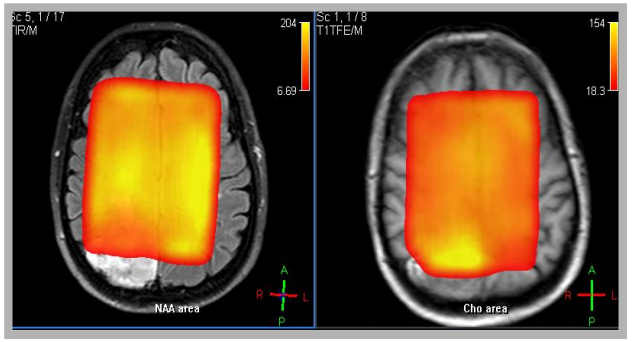
Introduction

MR Spectroscopy Results:

- Spectra
  - Graphical display of amplitude vs. frequency



- Chemical shift images
  - A representation of the amplitude (abundance) of a certain chemical (metabolite) over position (image)



Introduction
MR Spectroscopy vs. MR Imaging

	Spectroscopy	Imaging
Physical Phenomena	NMR	NMR
Applied Nuclei	^{1}H, ^{31}P, (^{13}C)	^{1}H
Magnetic Field	High	Low ⟶ high
Scan process	Collecting time signals (averaging)	Collecting different profiles
Presentation of information	1) Frequency spectrum 2) Spectroscopic Imaging	Cross sectional view of object
Application area	Metabolism Physiology	Anatomy Pathology
Gradients	1) (Single) Volume selection 2) Phase encoding (up to 3 directions)	Slice (volume) selection Frequency encoding Phase encoding (1 or 2 directions)
Shimming	Optimize homogeneity in the volume of interest (small)	Optimize homogeneity in the volume of interest (large)

Introduction:
MR Spectroscopy, Clinical use

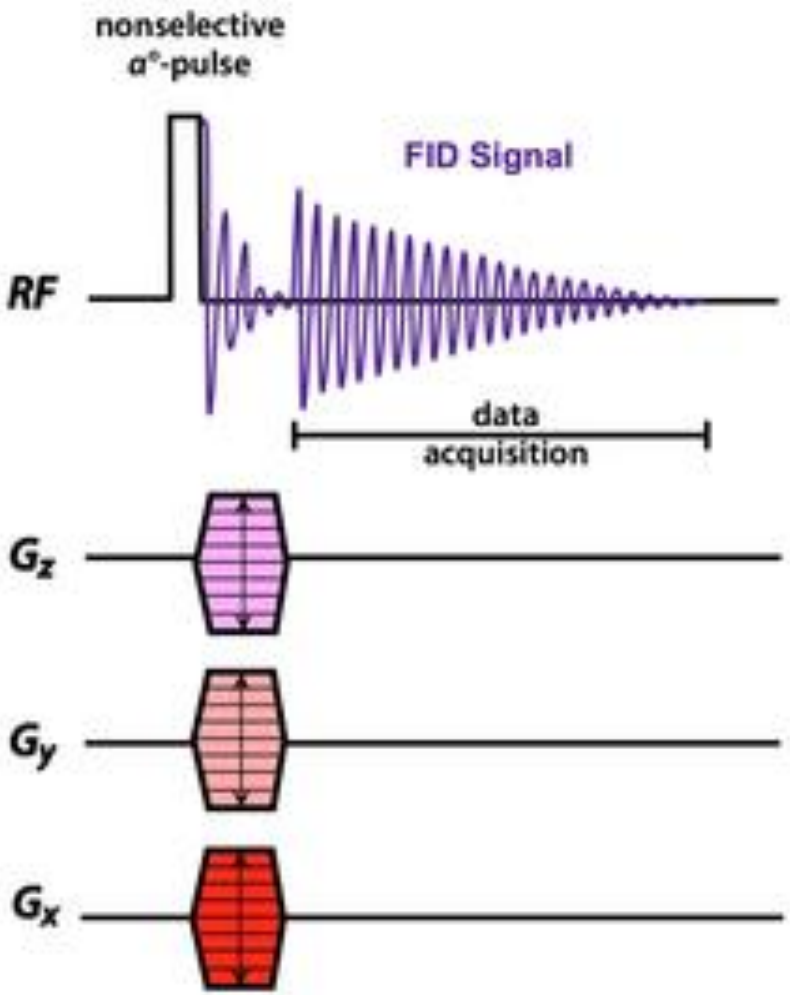
- Research
- Increased use for diagnostic (and follow up) purposes
  - Spectroscopy as part of comprehensive neuro exam
    - Tumors (differentiation, grading)
    - Epilepsy (lateralization)
    - Abscess
    - Ischemia (stroke)
    - Dementia/white matter diseases
    - Neonatal applications
    - Hepatic encephalopathy
  - Spectroscopy in body
    - In principle everywhere in the body
    - Prostate*****
    - Liver
    - Breast

MR Spectroscopy
Metabolite sensitivity

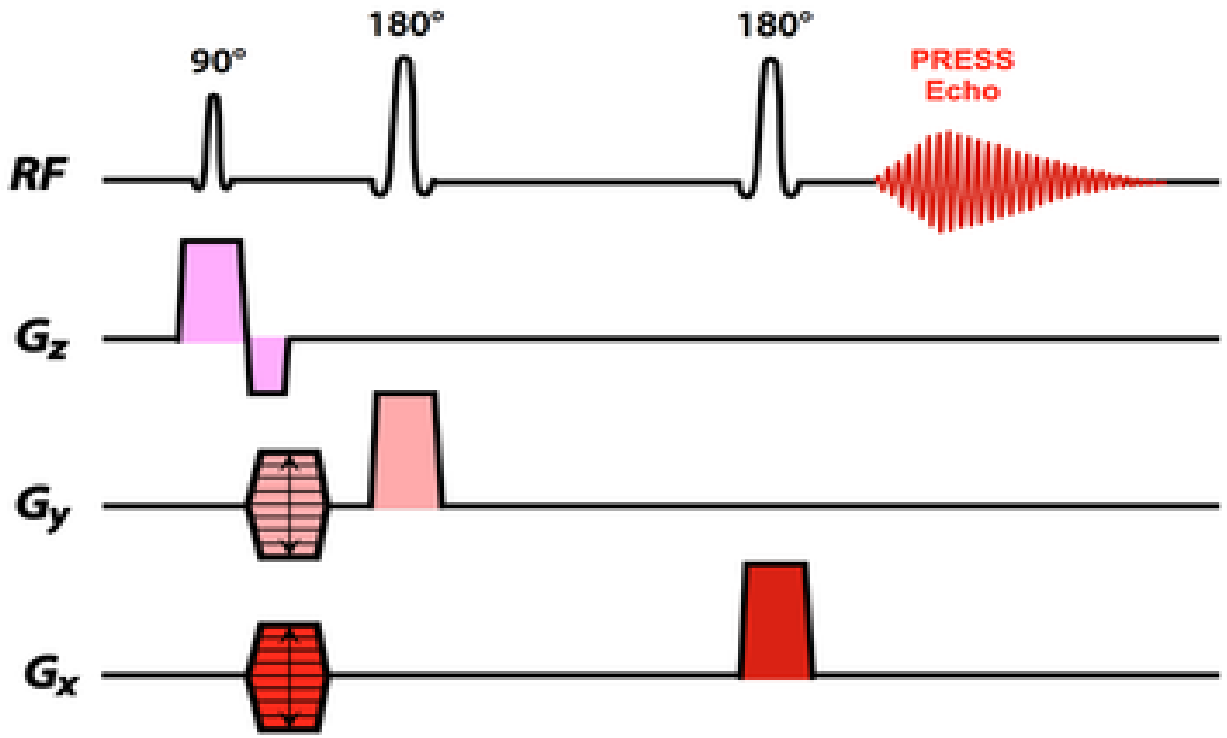
Chemical substance	Relative sensitivity (MR signal strength)	
	Percentage	Factor
Water	100 %	1
NAA, N-acetyl aspartate (^{1}H spectrum)	0.03 %	3500
PCr, Phosphocreatine (^{31}P spectrum)	0.0007 %	140,000
^{13}C Spectroscopy	0.000002 %	50,000,000

Chemical Shift Imaging (CSI)

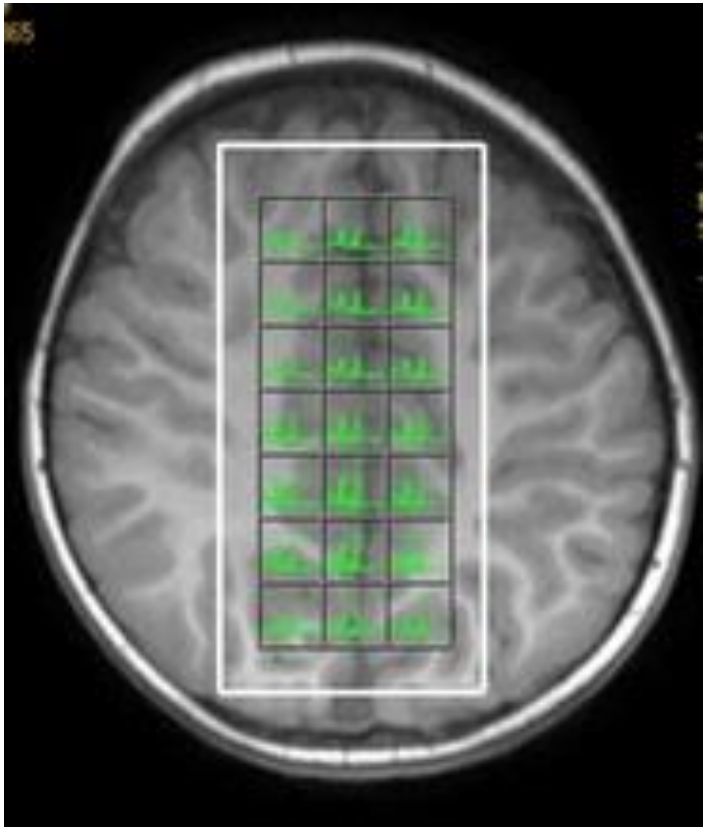
- ***Chemical Shift Imaging (CSI)***, also known as ***MR Spectroscopic Imaging (MRSI)***,



3D CSI sequence using nonselective volume excitation and stepped phase-encoding gradients along all three axes (common method for ^{31}P MRS)



2D-PRESS CSI sequence with slice-selective excitation pulses in 3 planes with stepped phase-encoding gradients along 2 axes (common method for ^{1}H brain MRS). Diagram has been simplified by leaving out preparatory water/fat saturation modules and crusher gradients)



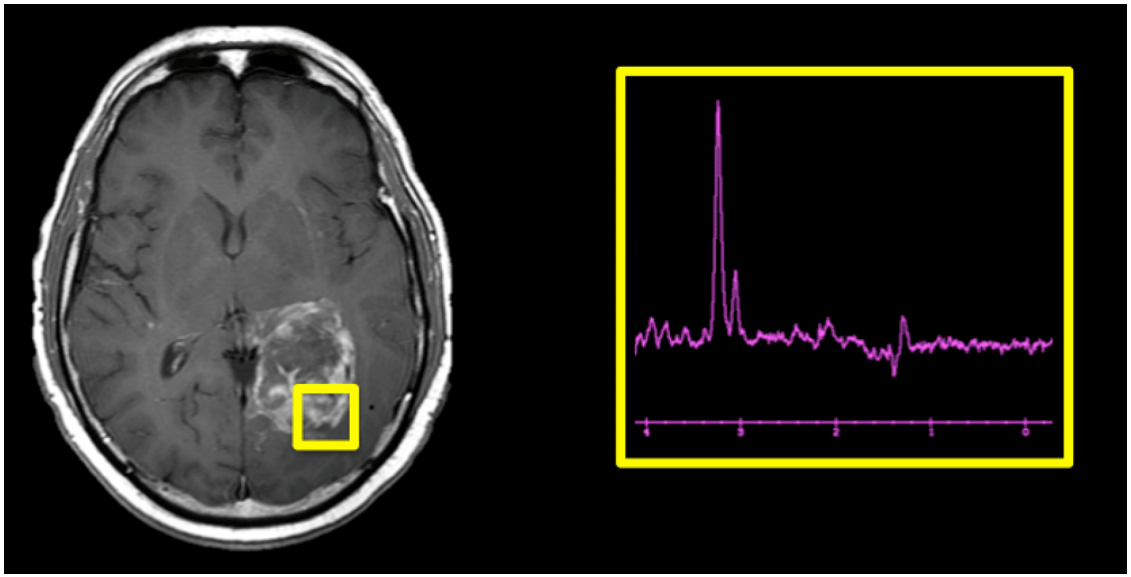
2D CSI ^{1}H brain MRS

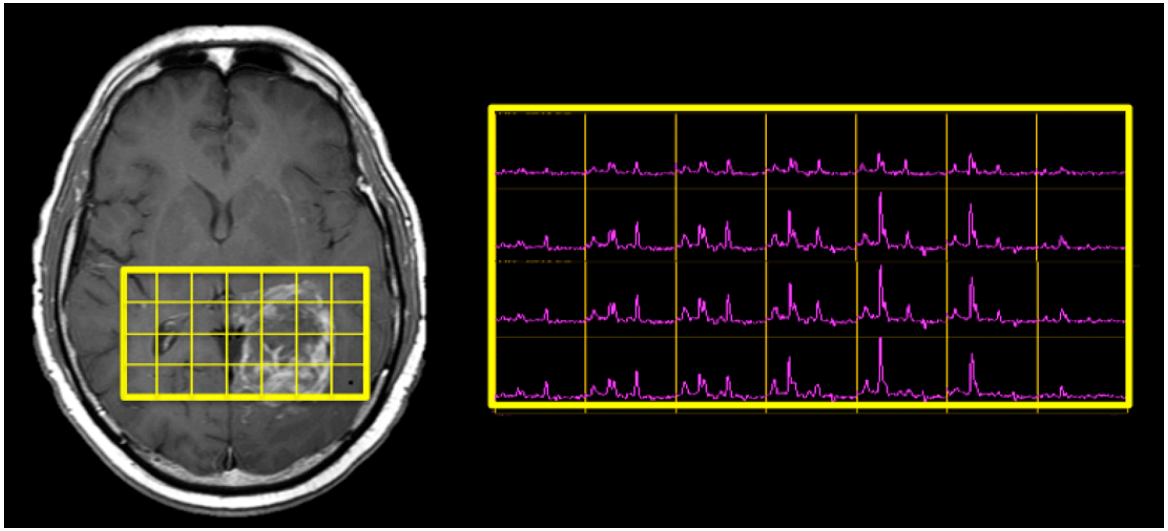
CSI offers both a larger total coverage area and higher spatial resolution than single-voxel methods.

The potential for a wide coverage area allows evaluation of large, heterogenous lesions, while smaller size of individual voxels is advantageous for small or irregularly shaped lesions.

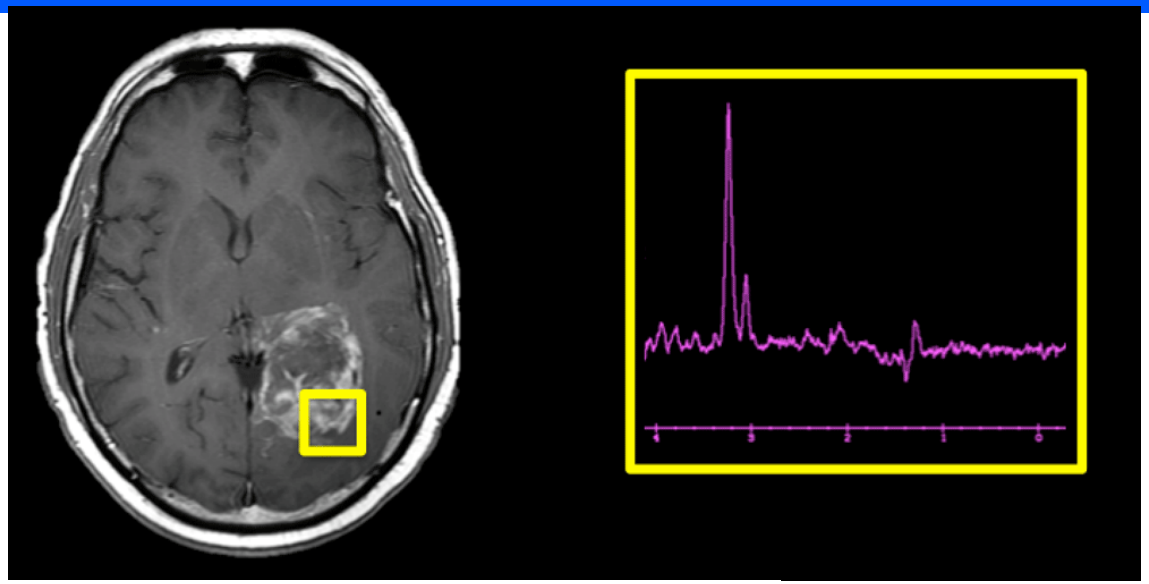
The major disadvantages of multi-voxel CSI include:
1) Longer set-up and imaging time;
2) difficulties obtaining homogenous shim over the entire region;
3) lower signal-to-noise and spectral quality for individual voxels;
4) spectral contamination from adjacent voxels.

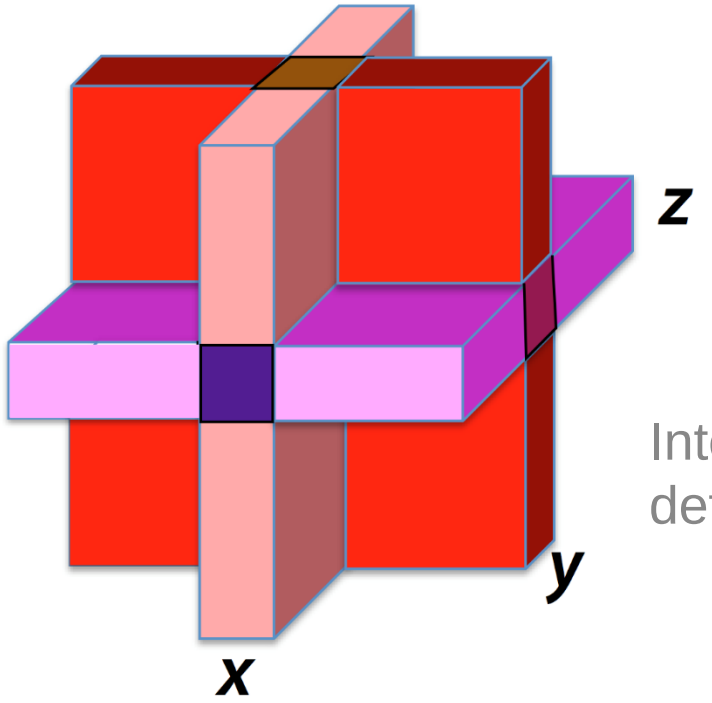
Single-voxel spectroscopy (SVS





Multi-voxel spectroscopy





Single Voxel Spectroscopy (SVS)

Intersection of 3 orthogonal planes defines a cubic voxel for SVS.

Single Voxel Spectroscopy (SVS)

- **Point RESolved Spectroscopy (PRESS**
- (90º–180º–180º)

- **Stimulated Echo Acquisition Mode (STEAM)**

- **Image-Selected In vivo Spectroscopy (ISIS)**.

(Multi-Voxel) Chemical Shift Imaging (CSI)

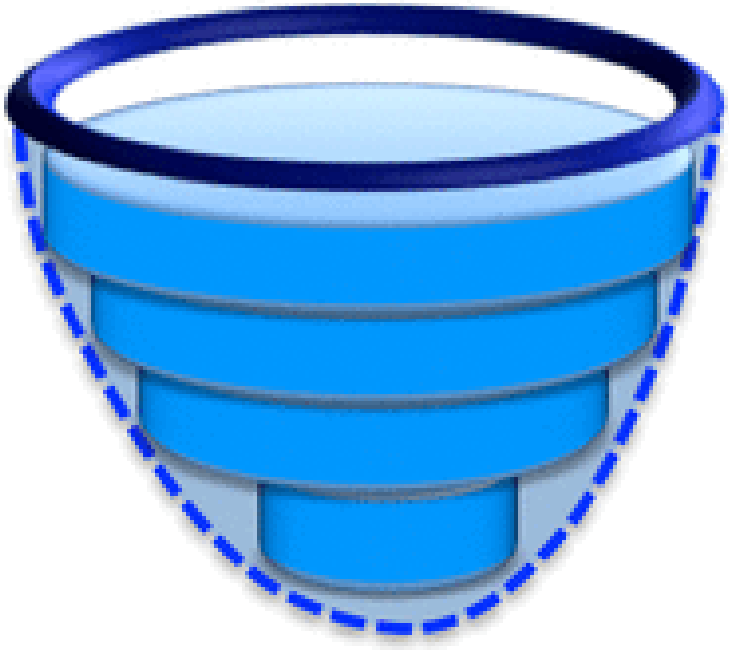
- **1D (a column of voxels), 2D (a plane of voxels), or 3D (block of voxels).**

- parallel imaging,
- reduced *k*-space sampling,
- multi-band excitation

- ***Turbo Spectroscopic Imaging (TSI)***,

	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

Surface Coil Localization



Surface coil localization combining sensitive volume with 1D CSI

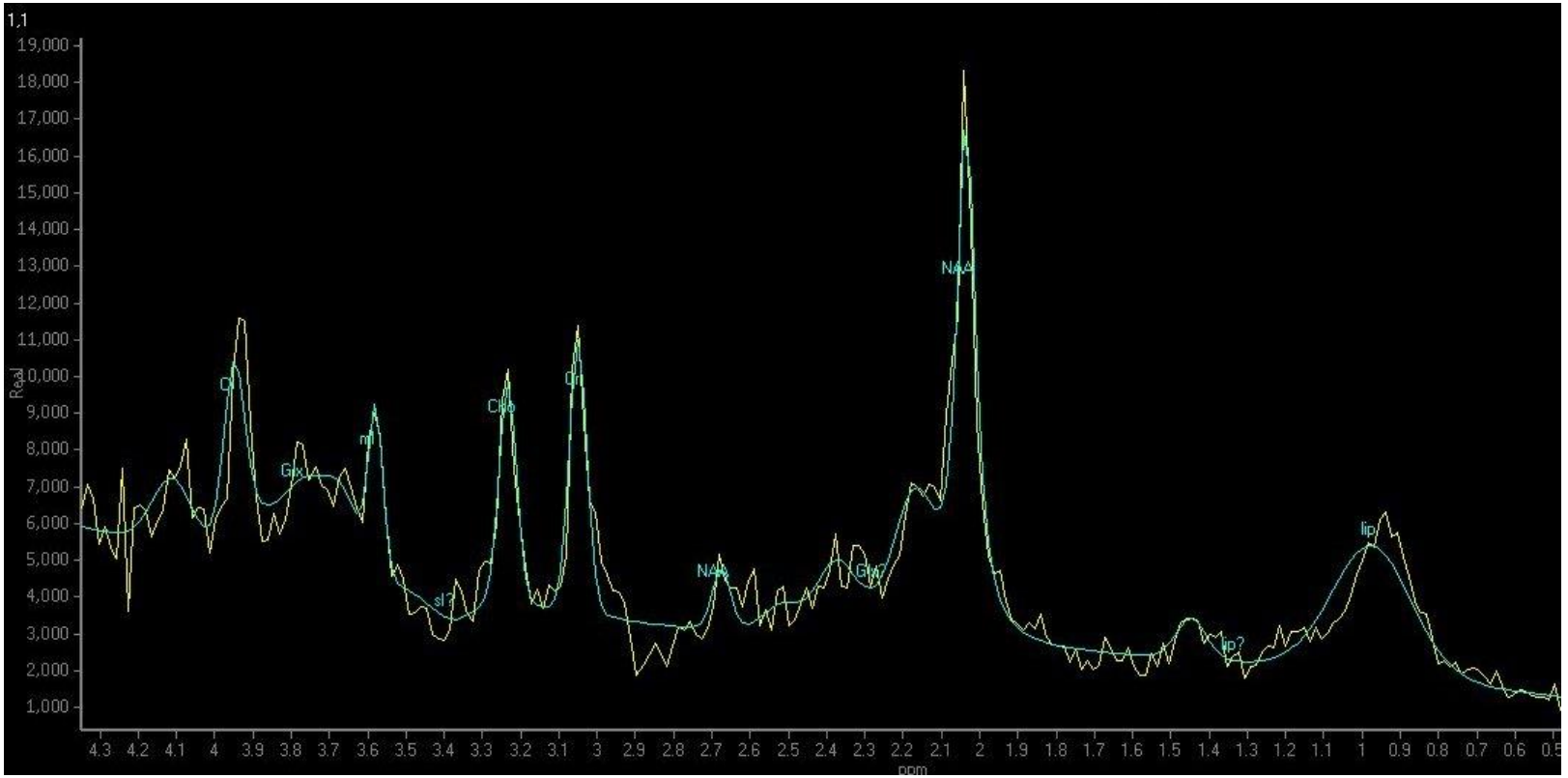
Method	Description	Comments
PRESS (Point RESolved Spectroscopy)	90°–180°–180° slice-selective pulses applied together with orthogonal gradients; generates spin echo (SE) signal at their intersection	Overwhelmingly most popular method for ^{1}H MRS; can be used for both single and multi-voxel studies; minimum *TE* is limited due to multiple RF pulses, so not suitable for short T2 metabolites
STEAM (Stimulated Echo Acquisition Mode)	90°–90°–90° slice-selective pulses applied together with orthogonal gradients; generates stimulated echo (STE) signal at their intersection	Because STE's are recorded instead of SE's, STEAM signal is only 50% as large as PRESS; for ^{1}H MRS at ≤ 3T, PRESS is now preferred. STEAM does have lower RF-power deposition (since no 180° pulses used), and allows for somewhat shorter *TE's* than PRESS.
ISIS (Image Selected In vivo Spectroscopy)	Series of spatially selective 180° adiabatic pulses and orthogonal gradients in various on/off combinations, followed by a non-selective adiabatic 90° pulse with free induction decay (FID) signal detection	Primary use for non-^{1}H MRS applications (esp. ^{31}P) where T2 values may be very short; tolerant to B_1 field inhomogeneities (major advantage if transmit surface coils are used); can be used for both single and multi-voxel studies; 8 separate acquisitions must be performed for SVS with pairwise addition/ subtraction, resulting in motion sensitivity
CSI (Chemical Shift Imaging)	Employs phase-encoding gradients in 1, 2, or 3 directions to segment larger stimulated volume into multiple smaller voxels	Also known as Multi-Voxel Spectroscopic Imaging (MVSI); may be 1D (column of voxels), 2D (plane of voxels), or 3D (block of voxels), depending on the number of phase-encoding directions used; larger volume is usually excited/defined by (PRESS, STEAM, ISIS) although other methods possible (FID, SE, TSE)
Surface Coil Localization Methods	Use receive and/or transmit properties of local surface coils to define spectroscopic volume	Primarily used for non-^{1}H spectroscopy of superficial organs (esp. ^{31}P MRS of muscle, heart, and liver); whole coil reception without gradients defines hemispherical volume; this can be improved by use of slice-selective depth pulses and phase-encoding (CSI)

LASER (Localization by Adiabatic SElective Refocusing)

- "semi-LASER",
- resemble PRESS
- ., reduce chemical shift artifacts and are more tolerant to B1 inhomogeneities than PRESS or STEAM methods.

Proton spectrum of the brain

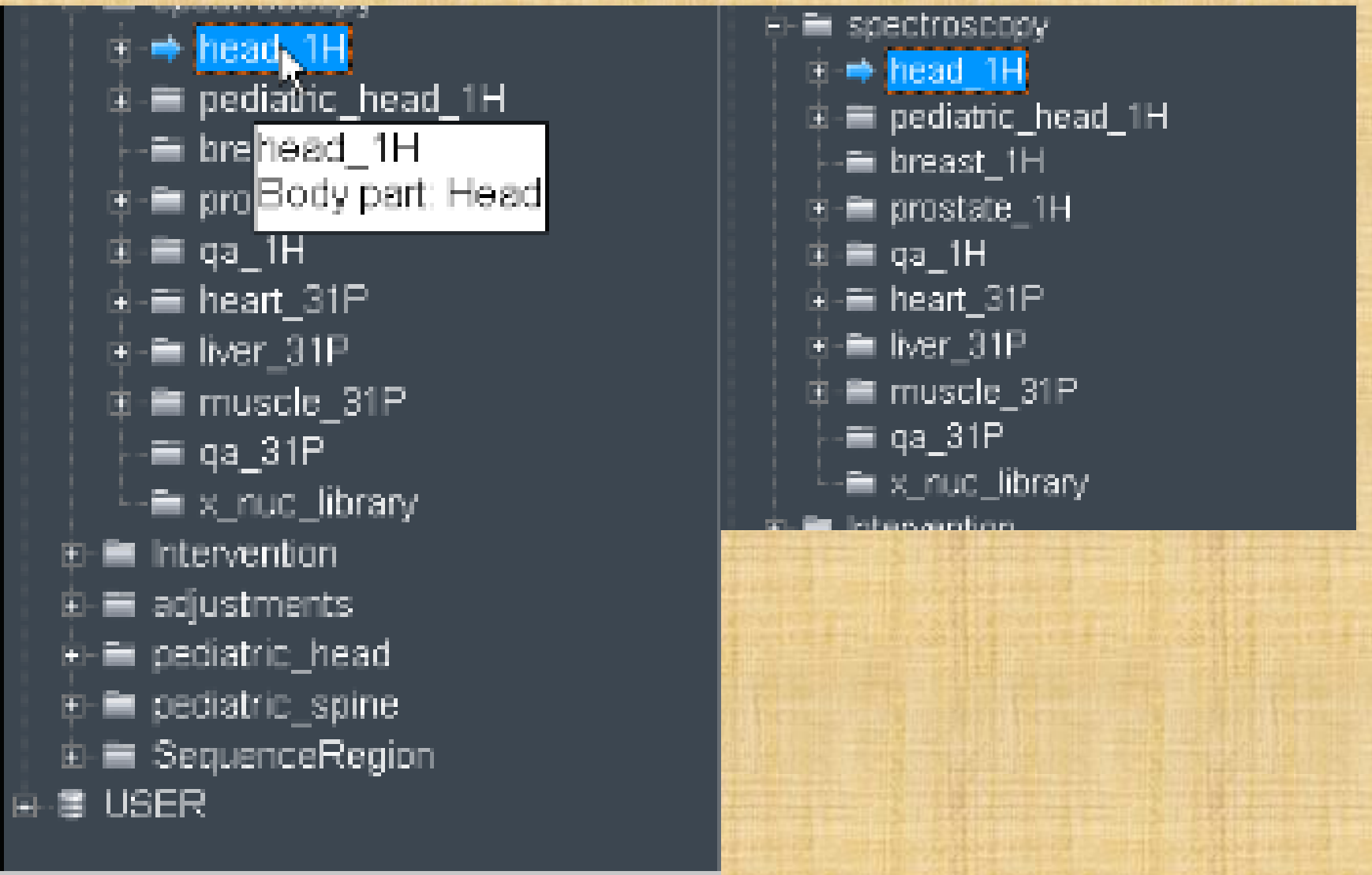
1H Spectrum of human brain:



Choline Creatine NAA Lactate

1H Metabolites
Some typical values @ 1.5T

Metabolite	Chemical Shift (ppm)	T_1 (ms)	T_2 (ms)	Concentration (mMol/l)
Tetramethyl silane (TMS) (Reference)	0.0			
Lipids	1.1 - 1.6			
Lactate (Lac)	1.3 - 1.5	1550	1200	-
N-acetyl Aspartate (NAA)	2.0	1450	450	~10
Creatine + Phospho-creatine (Cr + PCr)	3.0	1550	240	6-12
Choline (Cho)	3.2	1150	330	~2
Taurin	3.3	1700	270	-
Myo-Inositol (mIns) + Glycine	3.5	900	110	6.6
Water	4.65			$110*10^3$
Tyrosine/Histidine/Tryptolan	6.0 - 7.5			
Cholesterol	6.5 - 8.0			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breast_1H
prostate_1H
qa_1H
heart_31P
liver_31P
muscle_31P
qa_31P
x_nuc_library
Intervention
adjustments
pediatric_head
pediatric_spine
SequenceRegion
USER
spectroscopy
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pediatric_head_1H
breast_1H
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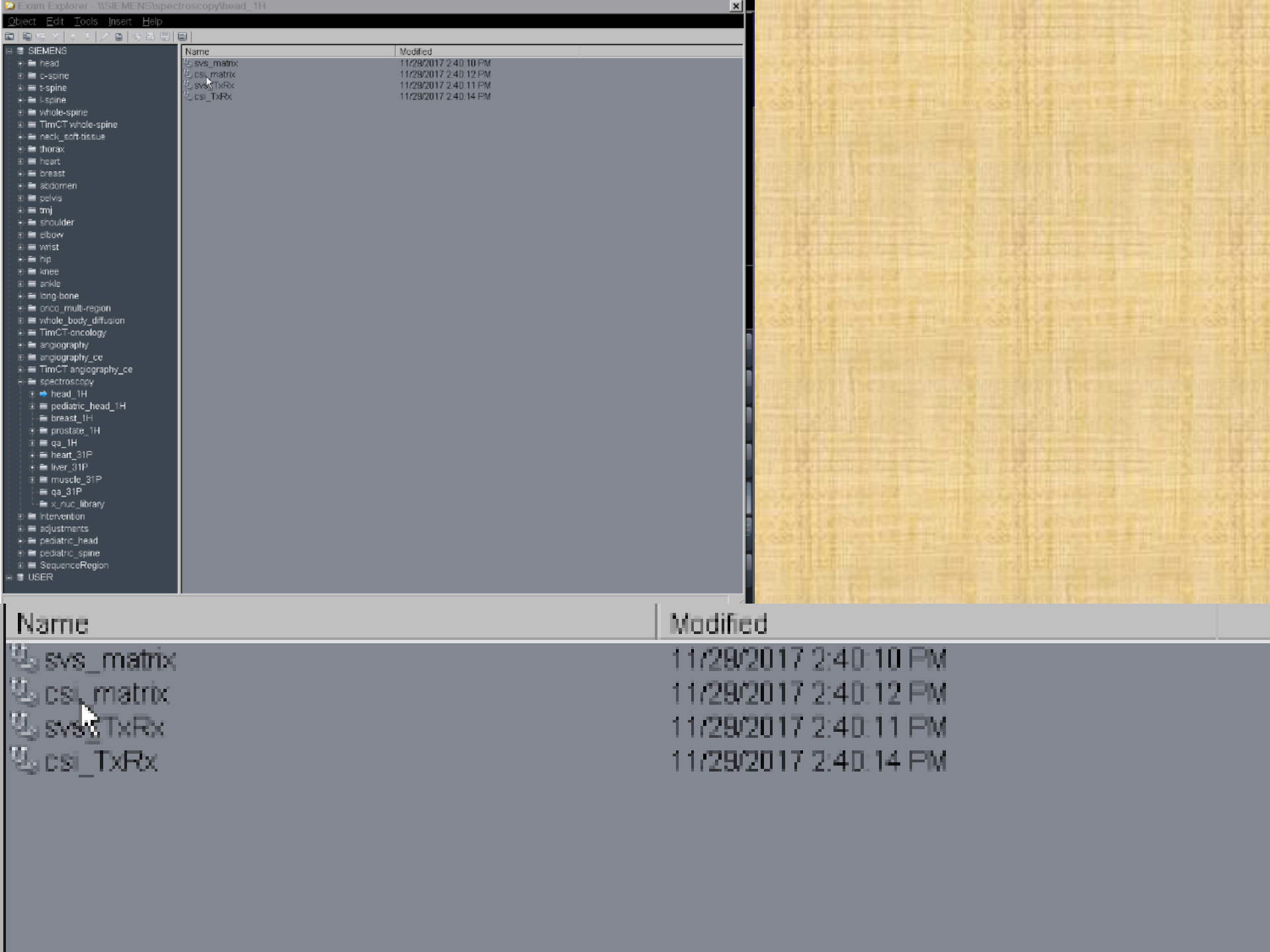
Body part: Head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l-spine
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breast
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tmj
shoulder
elbow
wrist
hip
knee
ankle
long bone
onco_multi-region
whole_body_diffusion
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angiography
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adjustments
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csi_TxRx 11/29/2017 2:40:14 PM

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3		localizer_5	00:40
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6		svs_se_135	04:56
7		svs_se_270	07:00
8		svs_st_20	06:32
9		svs_st_135	06:32
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12		csi_st_135	07:12
13		csi_st_270	07:24

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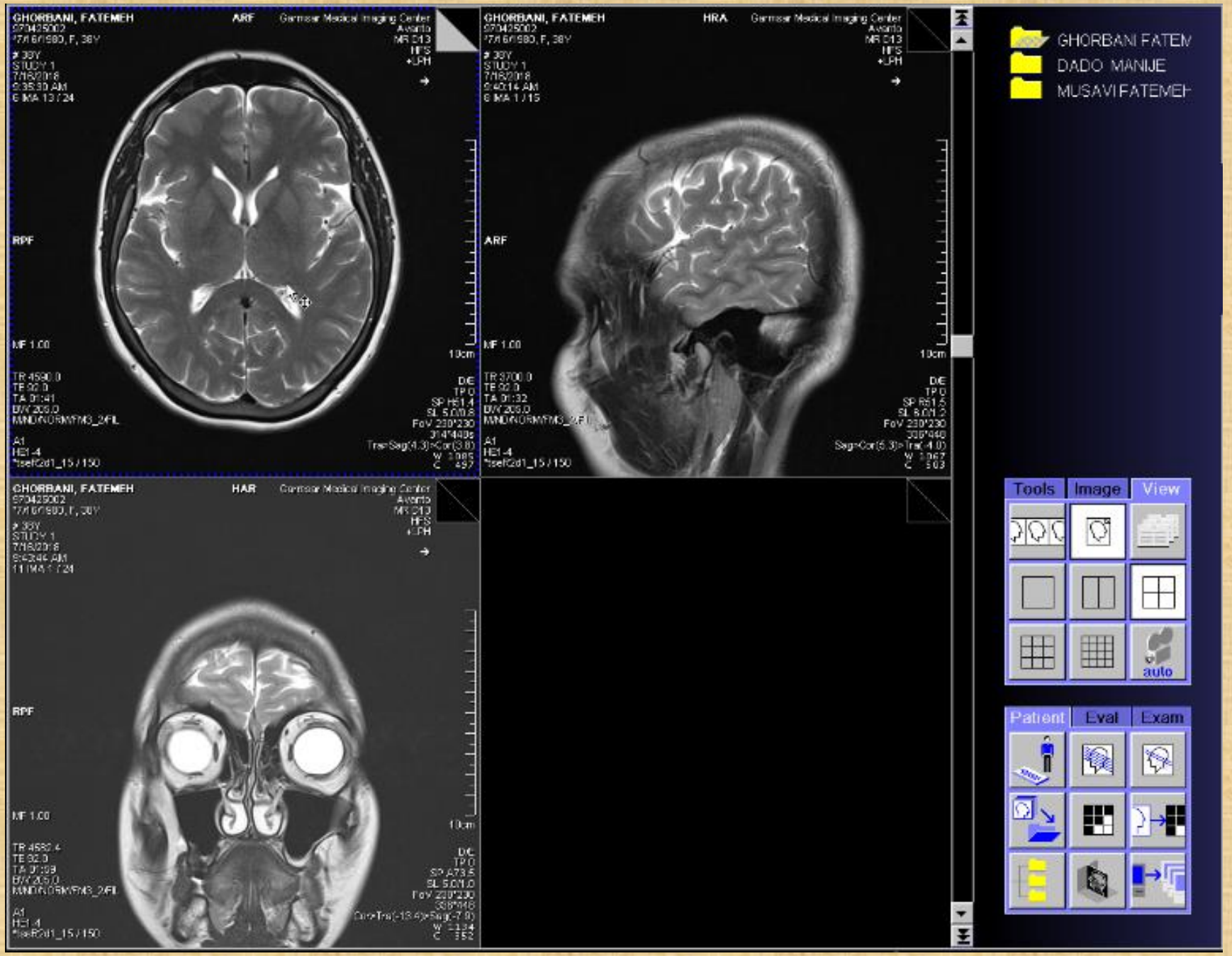
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ARF
HRA
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DADO MANIJE
MUSAVI FATEMEH
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View
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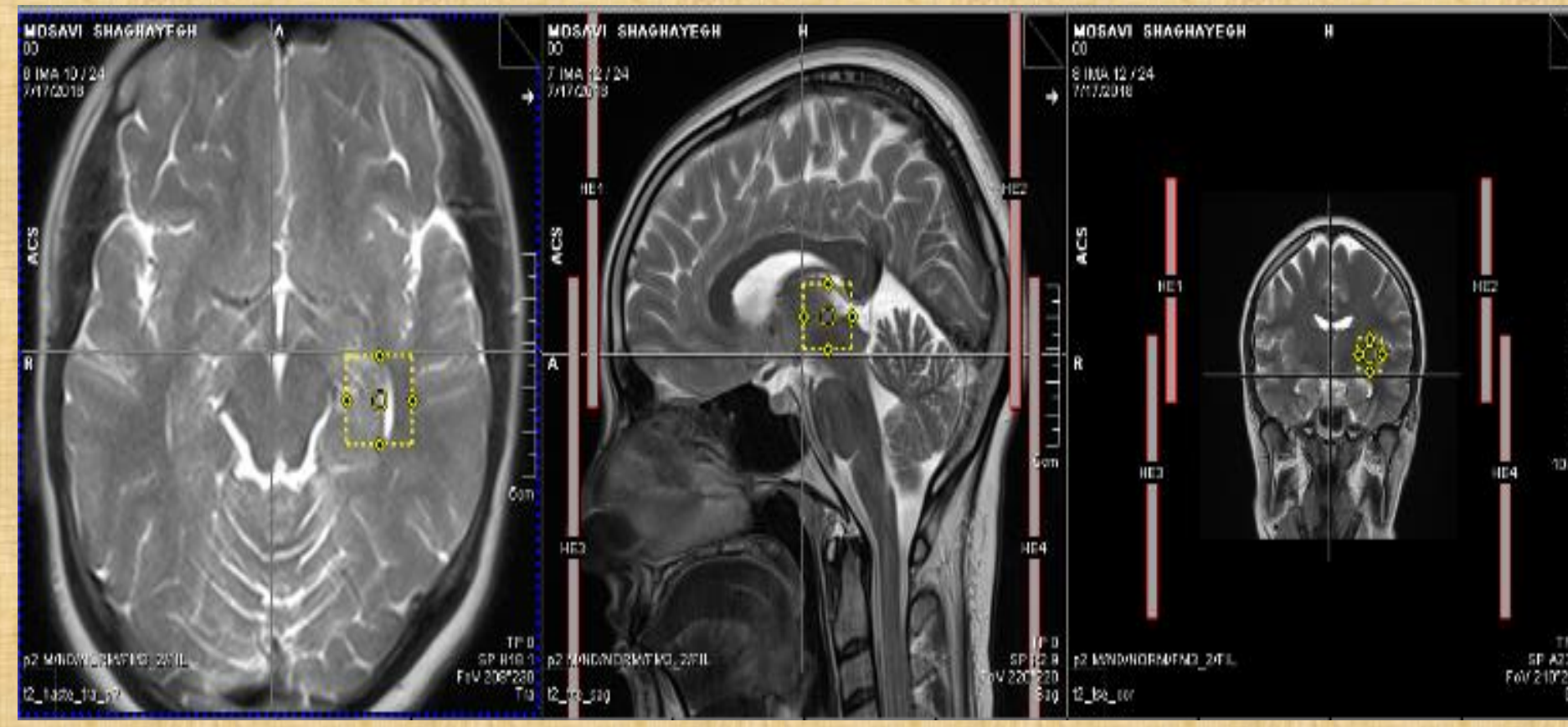
Patient
Eval
Exam

SVS_se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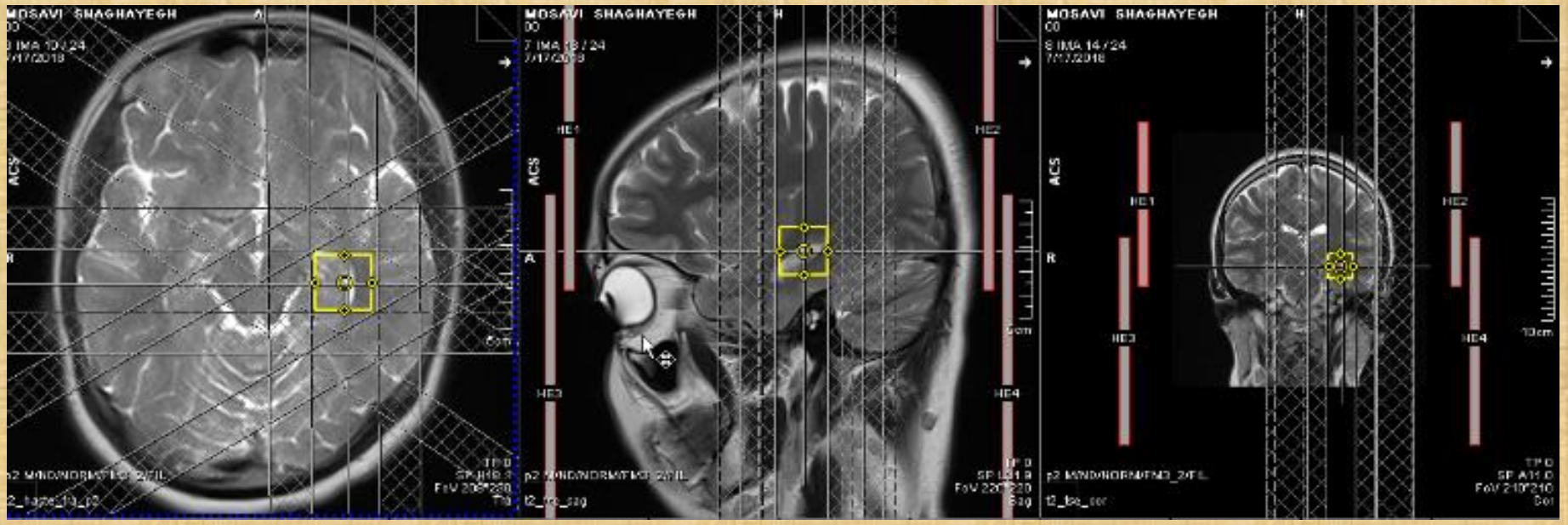
MOSAVI SHAGHAYEGH
MOSAVI SHAGHAYEGH
ACS
ACS
ACS
HE1
HE2
HE3
HE4

SVS_se



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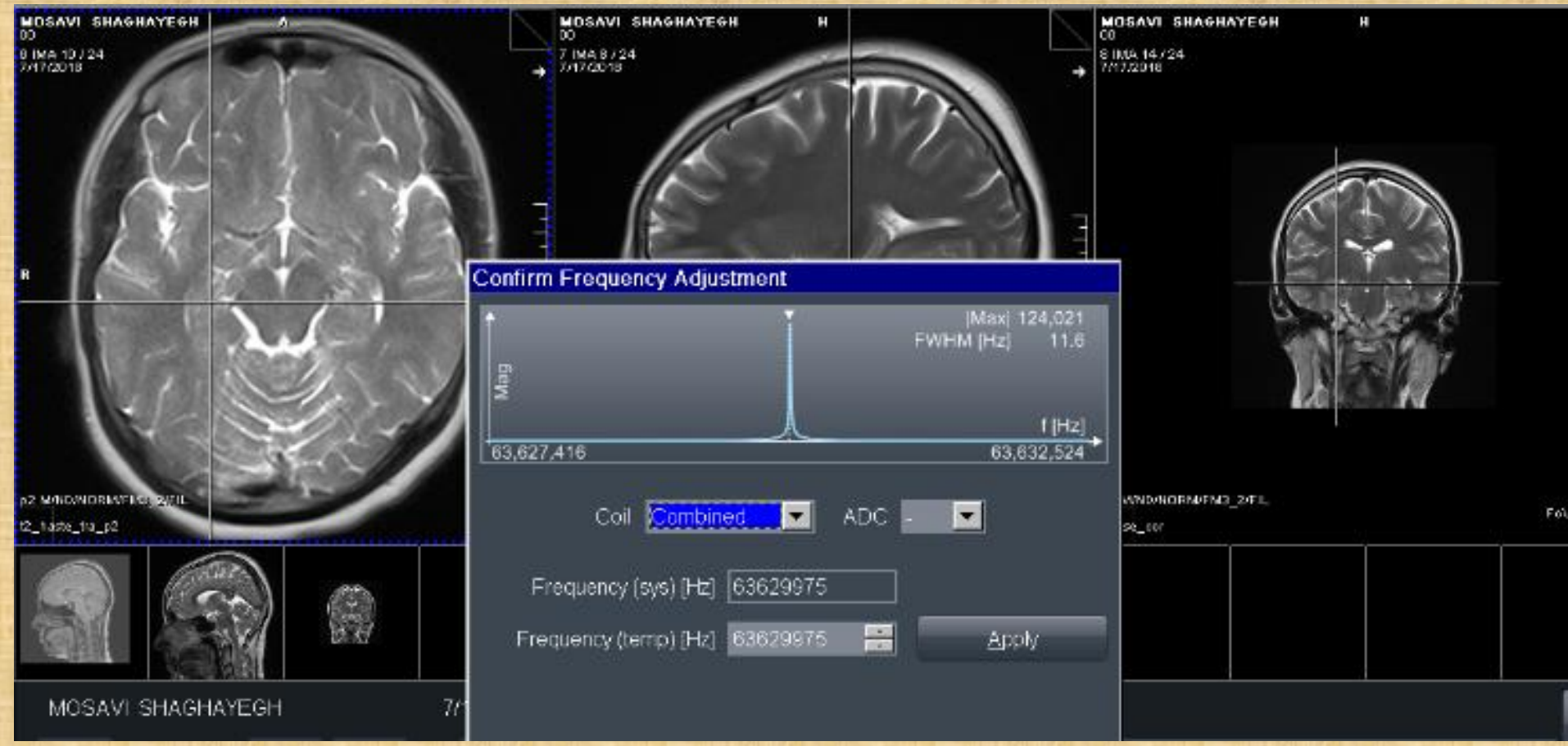
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MOSAVI SHAGHAYEGH
MOSAVI SHAGHAYEGH
Confirm Frequency Adjustment
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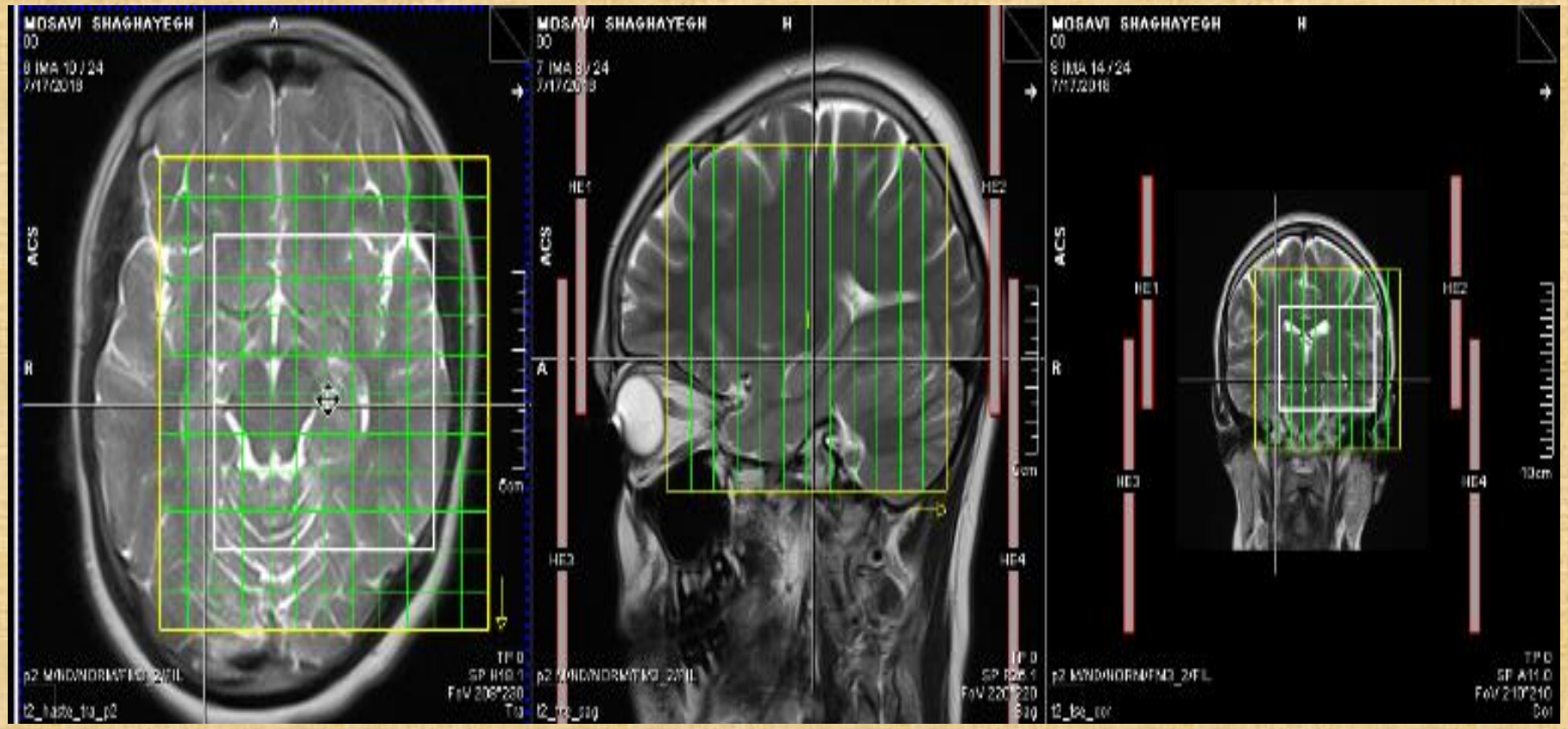
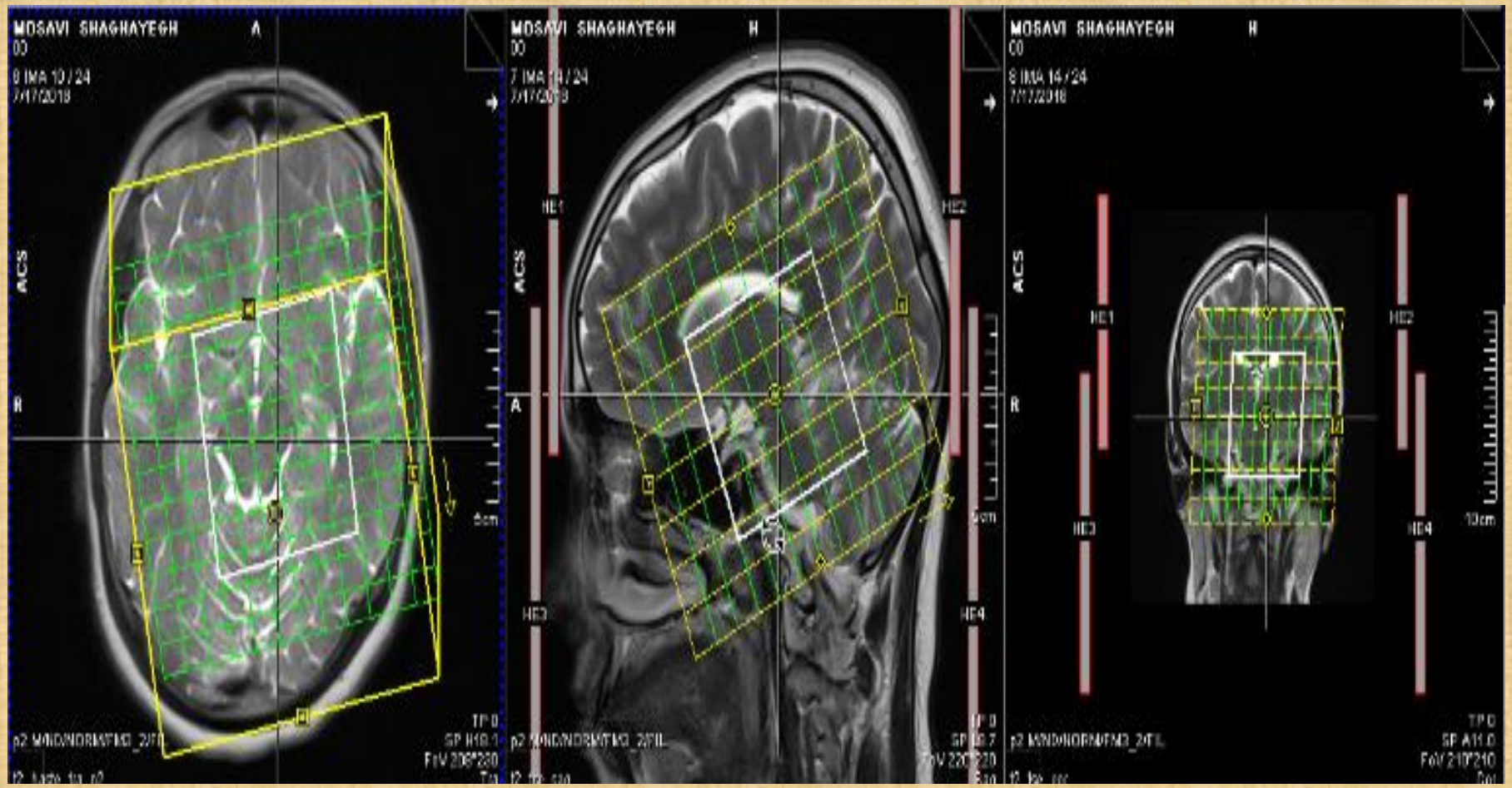
FWHM [Hz] 11.6
Mag
f [Hz]
63,627.416
63,632,524
Coil
Combined
ADC
Frequency (sys) [Hz]
63629975
Frequency (temp) [Hz]
63629975
Apply
MOSAVI SHAGHAYEGH

CS-3D-se-

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ACS
R
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HE2
HE3
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ACS
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HE1
HE2
HE3
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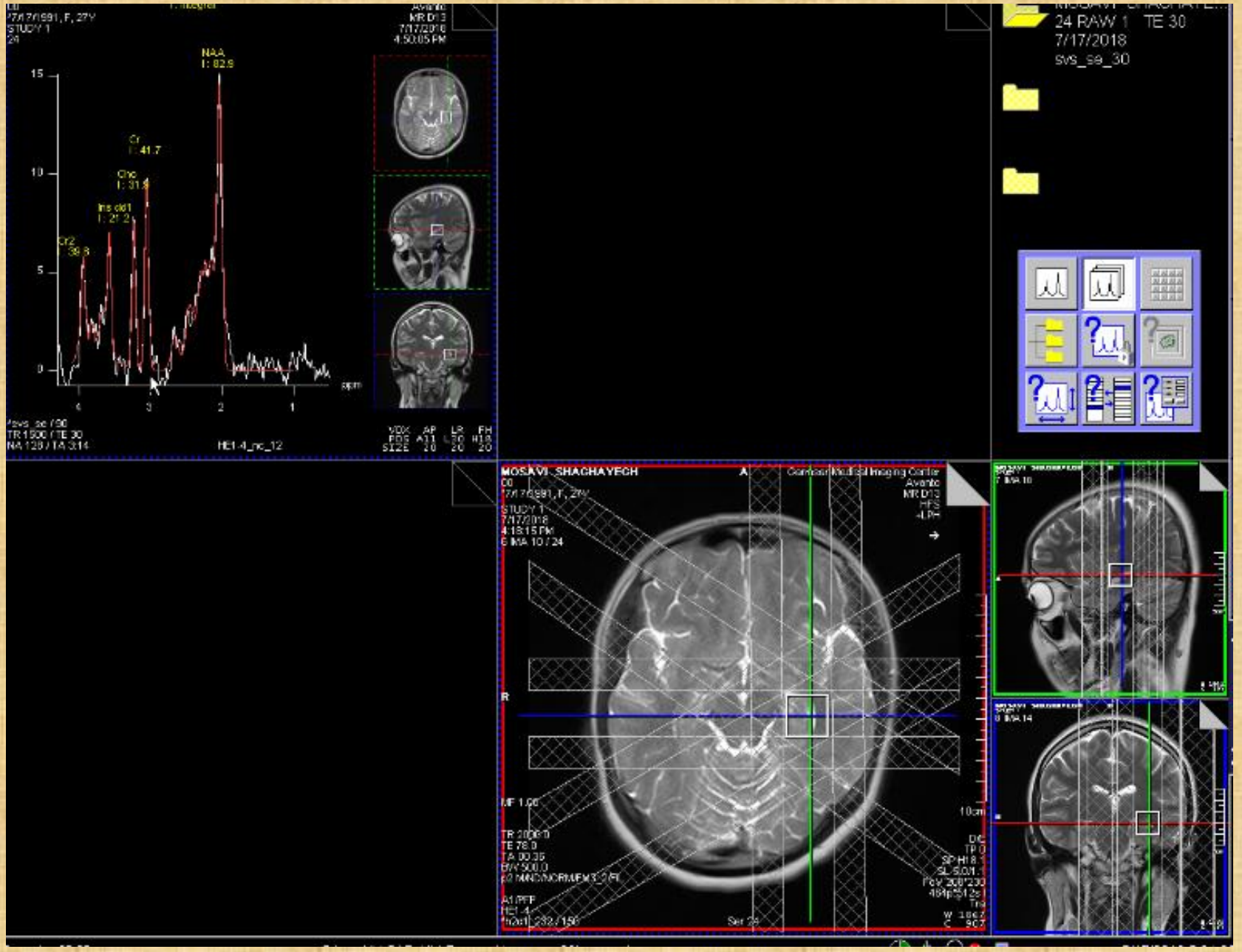
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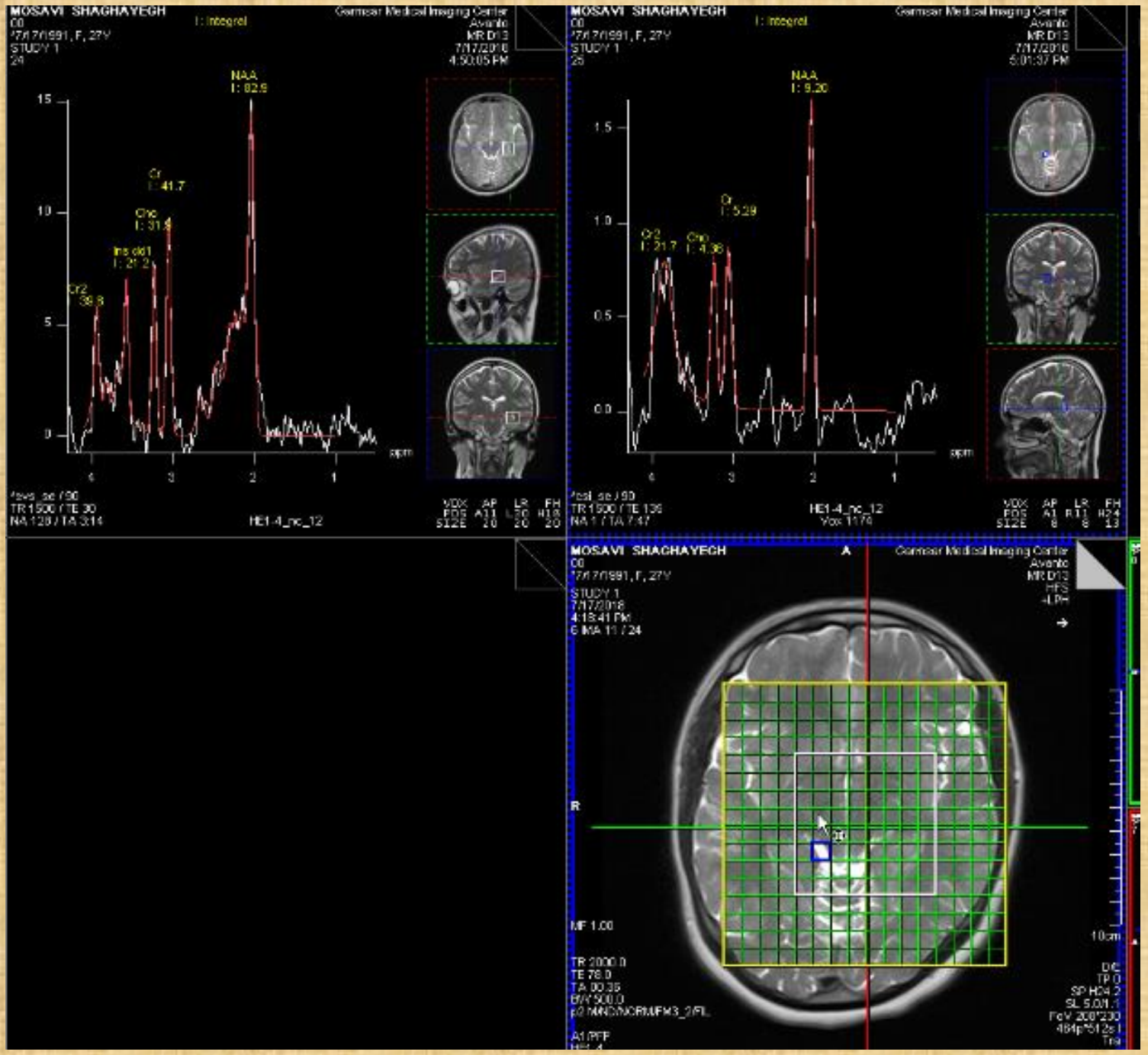
Cr
Cho
Ins old
Cr2
24 RAW 1 TE 30
7/17/2018
svs_se_30
MOSAVI^SHACHAYEH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Germain Medical Imaging Center
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Cr
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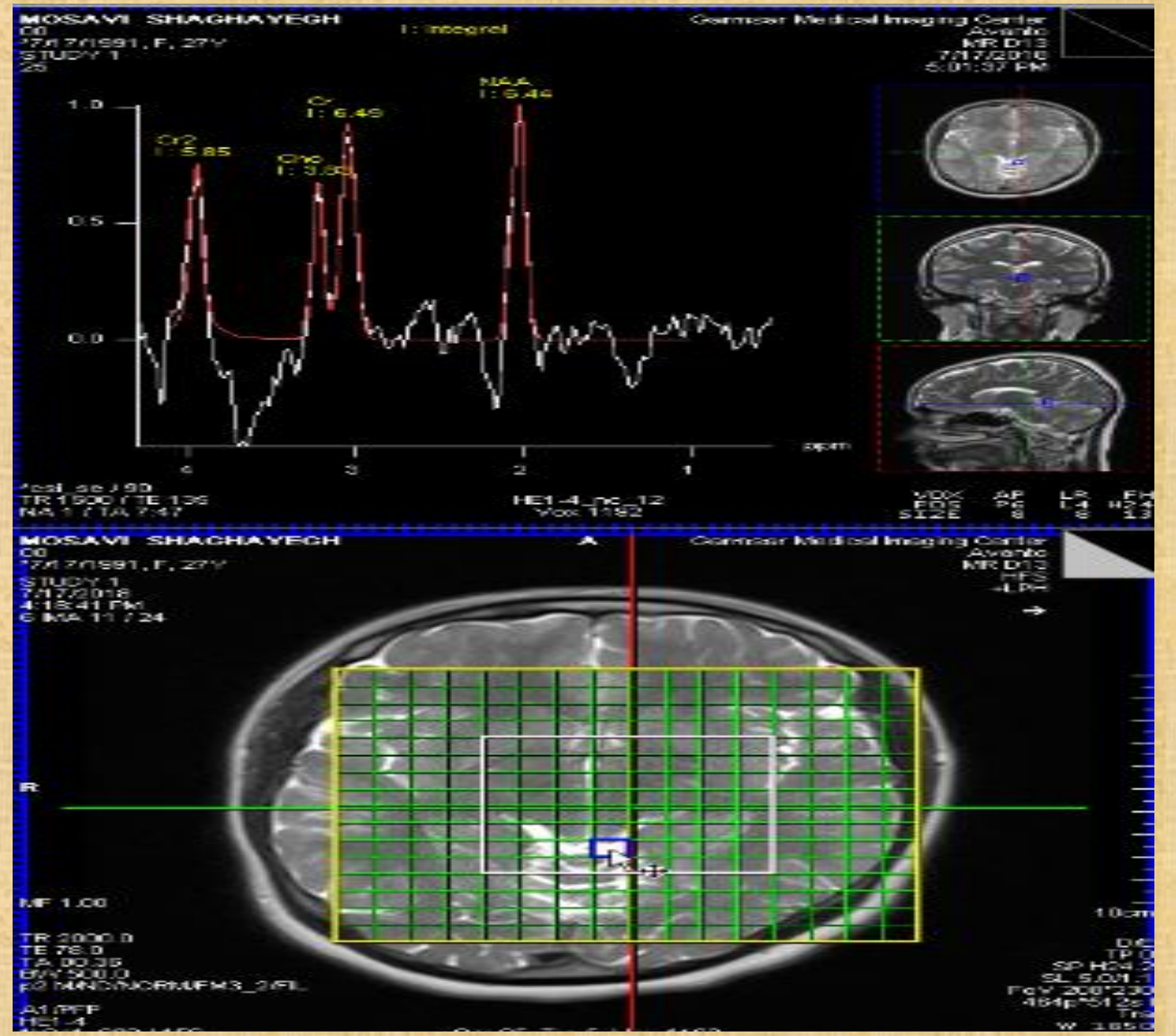
Cho
I: 31.9
Ins old
I: 21.2
Cr2
39.8
ppm
MOSAVI SHAGHAYEGH
Germain Medical Imaging Center
NAA
I: 9.20
Cr
I: 5.29
Cr2
I: 21.7
Cho
I: 4.86
ppm
MOSAVI SHAGHAYEGH
Germain Medical Imaging Center
R
MF 1.00
10cm


MOSAVI SHAGHAYEGH
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Cr
I: 6.49
Cr2
I: 5.85
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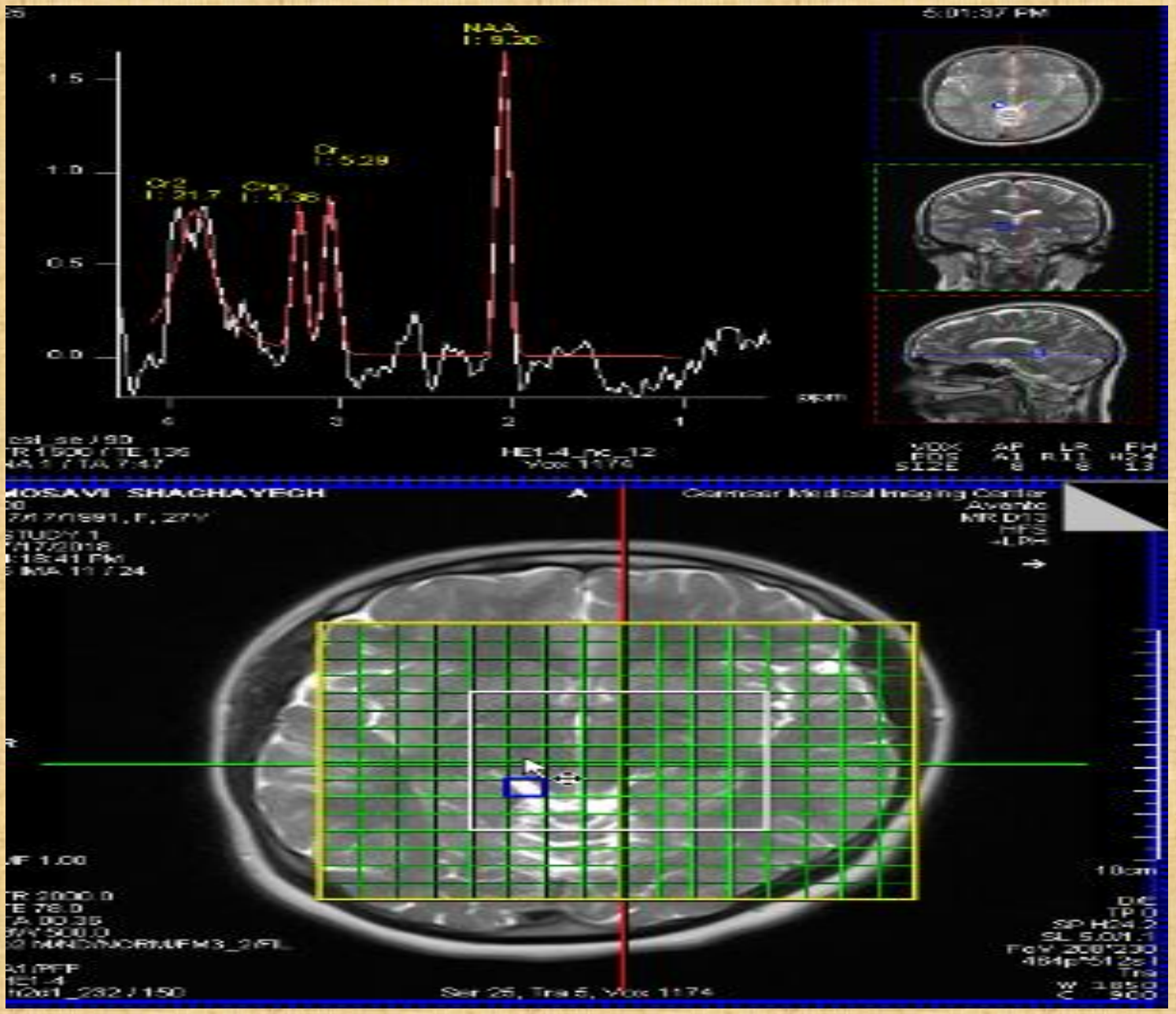
0.0
ppm
MOSAVI SHACHAYEGH
Gamsar Medical Imaging Center
R
10cm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Cr
I: 5.29
Cr2
I: 3.17
Cho
I: 4.36
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6
5
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PPM
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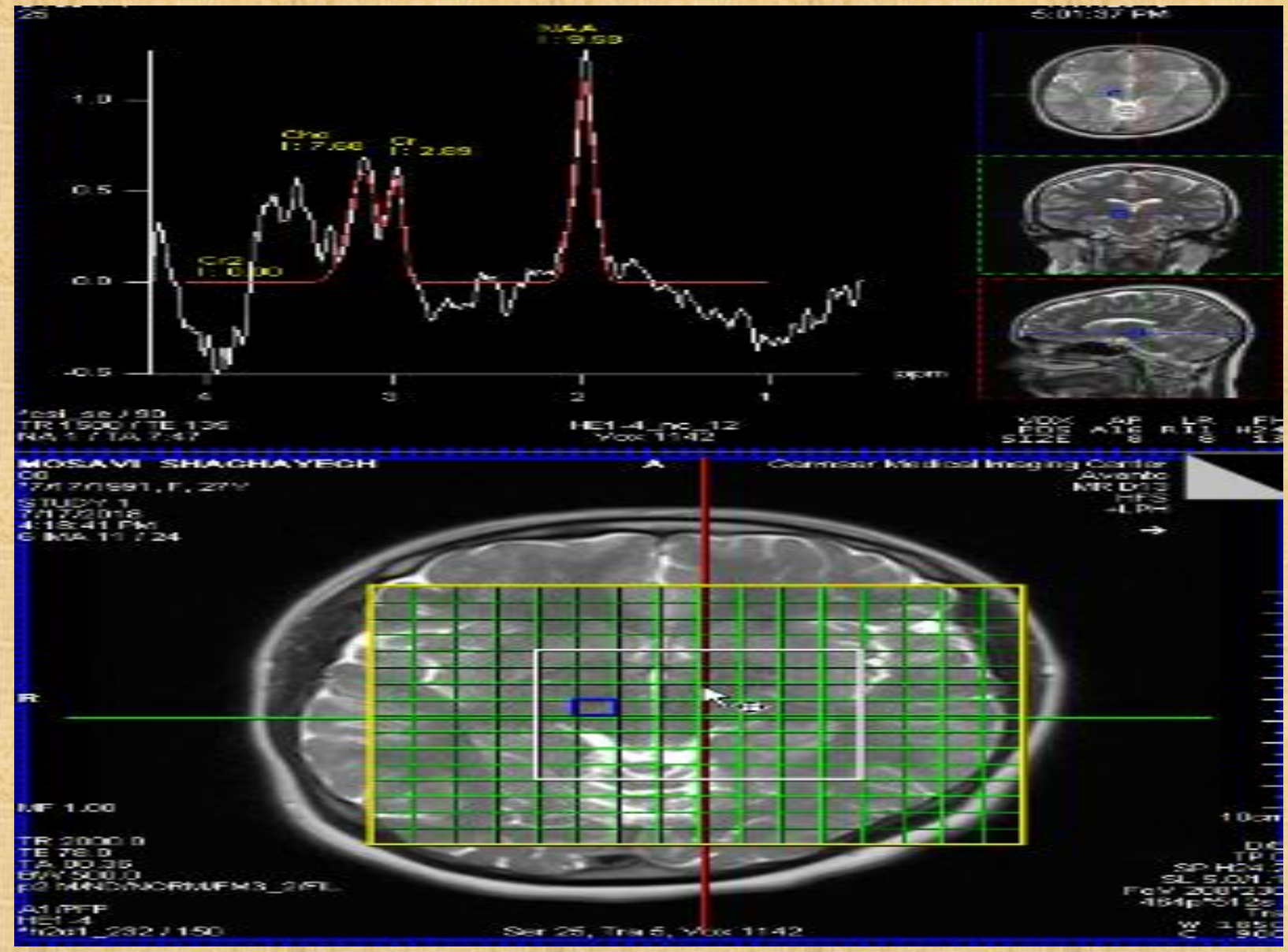
HE1-4_pc_12
Vox: 1174
Ser 25, Tra 5, Vox: 1174
10cm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Cr2
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ppm
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Cancer Medical Imaging Center
STUDY 1
7/17/2018
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TR 2000.0
TE 78.0
TA 00:35
BW 90.0
Ser 25, Tra 5, Vox 1142


ACT
AX FLAIR FS
Ax T2 FSE
Ax T1 memp
Ax DWI 1000b *OPTIO...
Sag T1 CD+
COR T1 fatsat CD+
Ax T1 CD+
PROBE-SV 144
PROBE-SV 35
PROBE-SV 144
PROBE-SI 144
Setup
Add Task
View
Run
Auto Scan
Scan
Save Rx
Head First, Supine
Imaging Options...
2D T2flair
EDR, TRF, Fast, ARC
Coil: 8HRBRAIN
AX FLAIR FS
GRx
2:43
Scan Plane
Freq. FOV
Phase FOV
Slice Thickness
Spacing
S/I
L/R
P/A
Start
End
Chem SAT
Contrast
1:48 PM


Done
1 3-Plane Loc
2 Calibration
ACT
AX FLAIR FS
RxD
Ax T2 FSE
RxD
Ax T1 memo
InRx
Ax DWI 1000b *OPTI...
Sag T1 CD+
COR T1 fatsat CD+
Ax T1 CD+
PROBE-SV 144
PROBE-SV 3S
PROBE-SV 144
PROBE-SI 144
02:43
01:23
01:49
01:00
02:43
04:20
Setup
View
Add Task
Run
Auto Scan
Scan
Save Rx
Head First, Supine
Imaging Options...
2D Spin Echo
EPI, DIFF, Asset
Coil: 8HRBRAIN
Ax DWI 1000b *OPTION*
GRx
Scan Plane
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Freq FOV
26.0
Phase FOV
1.00
Slice Thickness
5.0
Spacing
2.0
1:00
R/L
A/P
S/I
Start
End
Chem SAT
None
Contrast
1:48 PM


3-Plane Loc
2 Calibration
3 Ax FLAIR FS
4 Ax T2 FSE
5 Ax T1 memo
6 Ax DWI 1000b *OP...
Sag T1 GD+
COR T1 fatsat GD+
Ax T1 GD+
PROBE-SV 144
PROBE-SV 35
PROBE-SV 144
PROBE-SI 144
Done
Done
Done
Done
ACT
RxD
RxD
02:09
01:57
03:04
Setup


10
11
12
13
Ax T1 GD+
PROBE-SV 144
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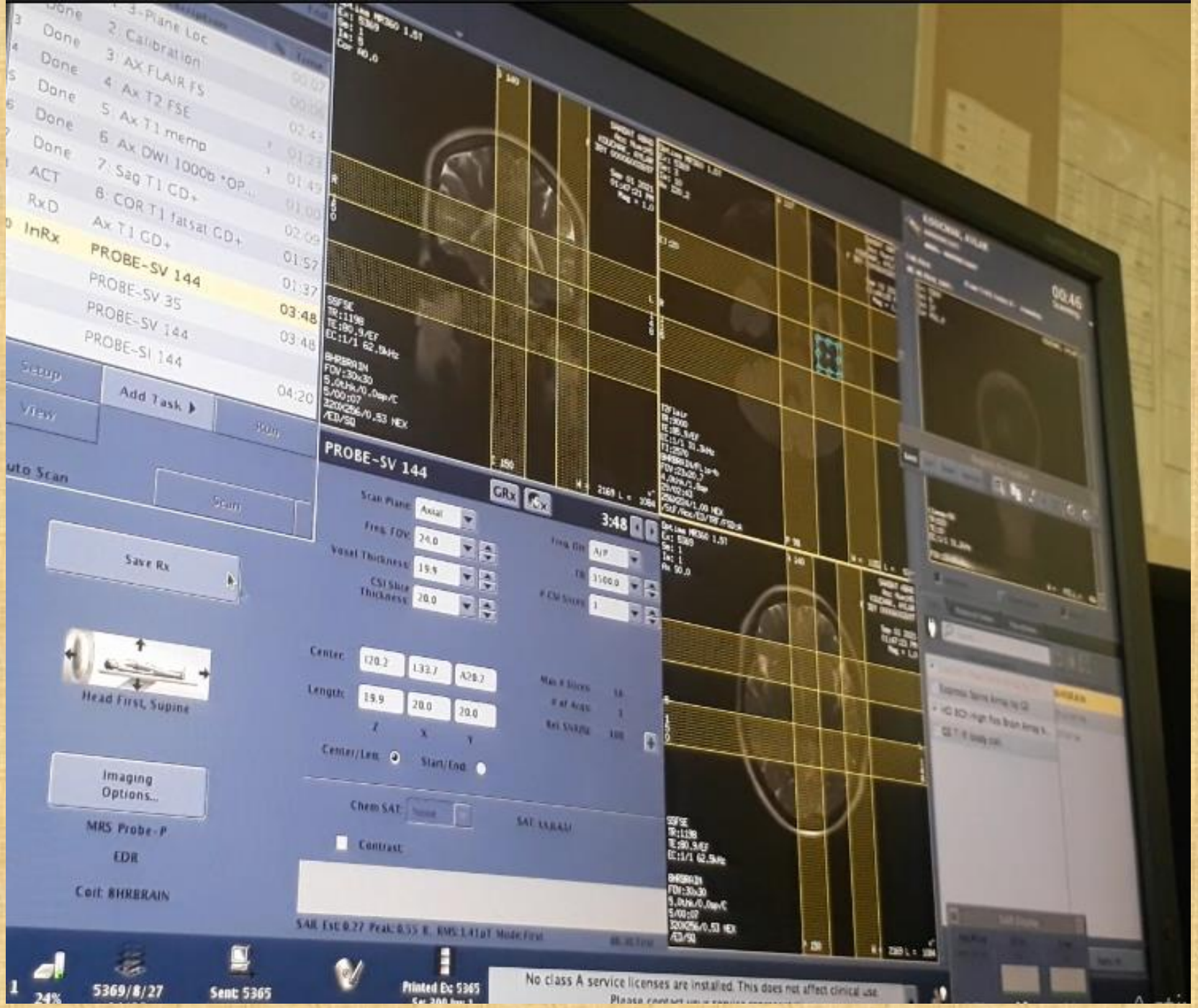
03:04
04:20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Done 3: AX FLAIR FS
Done 4: Ax T2 FSE
Done 5: Ax T1 memp
Done 6: Ax DWI 1000b *OP...
ACT 7: Sag T1 CD+
RxD 8: COR T1 fatsat CD+
InRx Ax T1 CD+
PROBE-SV 144
PROBE-SV 35
PROBE-SV 144
PROBE-SI 144
Setup
Add Task
View
Auto Scan
Scan
Save Rx
Head First, Supine
Imaging Options...
MRS Probe-P
EDR
Coil: 8HKBRAIN
PROBE-SV 144
GRx
3:48
Scan Plane
Axial
Center
Length
Center/Len
Start/End
Chem SAT
Contrast
5369/8/27
Sent: 5365
No class A service licenses are installed. This does not affect clinical use.


Done 2: Calibration
Done 3: AX FLAIR FS
Done 4: Ax T2 FSE
Done 5: Ax T1 memo
Done 6: Ax DWI 1000b *O...
Done 7: Sag T1 GD+
Done 8: COR T1 fatsat GD+
Done 9: Ax T1 GD+
Done 10: AX T2* GRE
11 InRx PROBE-SI 144
PROBE-SV 144
PROBE-SV 35
PROBE-SV 144
04:20
Setup
Add Task
View
Run
Auto Scan
Scan
Save Rx
Head First, Supine
Imaging Options...
MRS Probe-P
EDR
Coil: BHRBRAIN
PROBE-SI 144
GRx
4:20
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Freq FOV: 19.0
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CSI Slice Thickness: 20.0
S/I R/L A/P
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End
Chem SAT: None
Contrast
2:08 PM
September 1
24%
5369/10/21
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