Easy Understanding of MR Spectroscopy

Practical Considerations

이 정 희 Ph.D.
자기공명연구실, 아산생명과학연구소

1. Introduction

Localized *in vivo* ^{1}H MR spectroscopy (^{1}H MRS) has gained an increasing attention from clinicians as well as physicists over last few years. Recent development in MR hardwares and softwares has made ^{1}H MRS practical for users by providing the automatic adjustment of the acquisition parameters (1). More demands on clinical evaluation of patients are expected. I will briefly review the techniques of ^{1}H MRS emphasizing on the selection of the pulse sequence and the acquisition parameters in a user's standpoint.

2. Pulse Sequences

The following pulse sequences are generally used for localized *in vivo* ^{1}H MR spectroscopy. These pulse sequences restrict data acquisition to a rectangular volume, or voxel (Fig. 1). Each pulse sequence has own characteristics, therefore, it is advisable to select the pulse sequence for a demand of a spectroscopy exam for patient's evaluation.

a) STEAM (STimulated Echo Acquisition Mode)

The sequence acquires a stimulated echo from a localized volume. It consists of three slice selective 90-degree RF pulses, and a set of crusher gradients (Fig. 2). The STEAM sequence provides accurate voxel localization, water suppression methods, and relatively short echo times. However, a stimulated echo has an inherently lower SNR than a spin echo (2,3). This is a choice of short echo times (20 ~ 40 msec) and relatively large volumes (> 8 ml). This sequence is usually used for the adult size heads when the partial volume effect is not critical with a large voxel size.

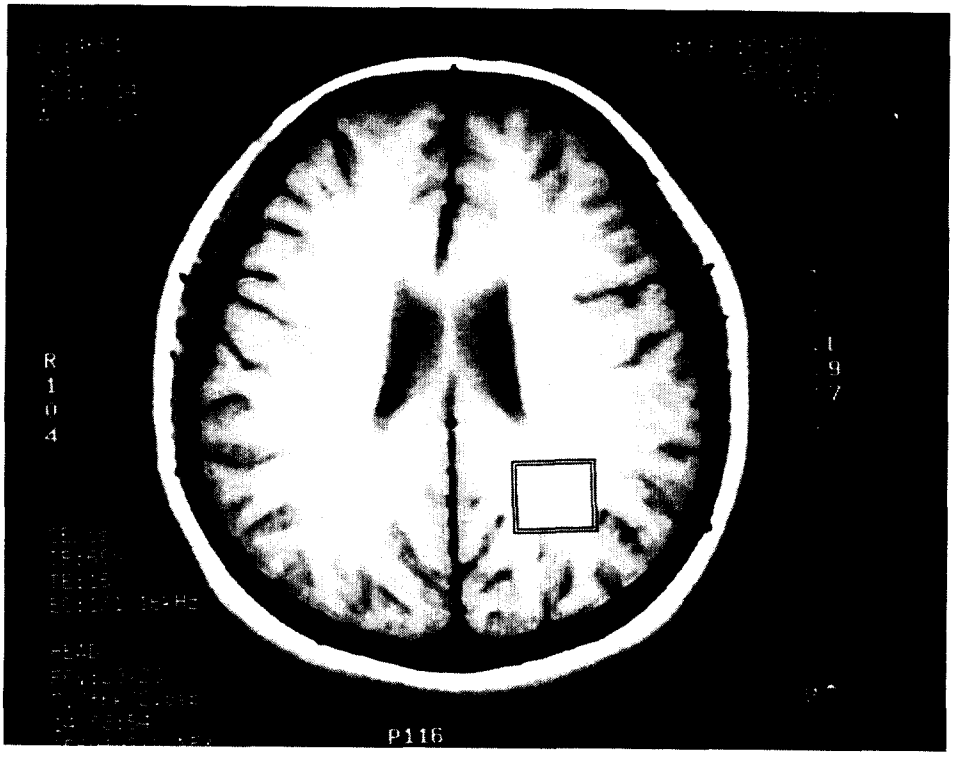
b) PRESS (Point RESolved Spectroscopy)

The sequence acquires a spin echo from a localized volume. It consists of three slice-selective RF pulses (of 90-, 80-, 180- degree flip angle), and two sets of crusher gradients (Fig. 3). The PRESS sequence provides accurate

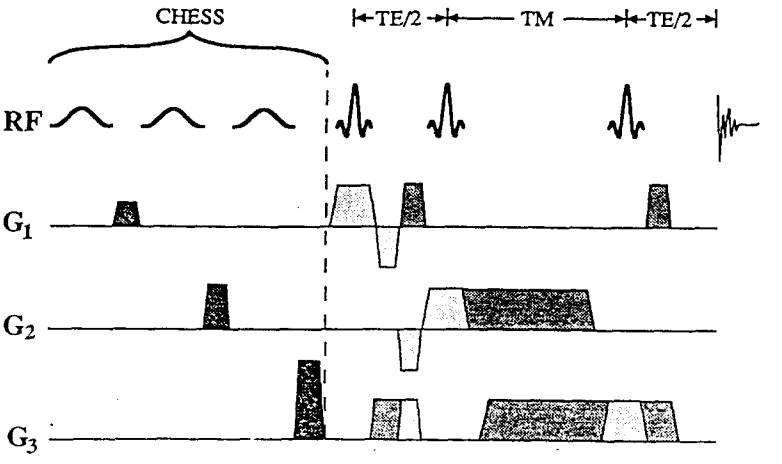
voxel localization, but has relatively long echo times compared with the STEAM sequence. However, the use of a spin echo rather than a stimulated echo gives PRESS a twofold SNR advantage over STEAM (4). Therefore, this is a choice of long echo times (> 60 msec) and relatively small volumes (minimum voxel size > 1 ml). This sequence is usually used for infants and for adults when the spectrum of a single focal region is required (e.g. hippocampus).

c) ISIS (Image Selected In-vivo Spectroscopy)

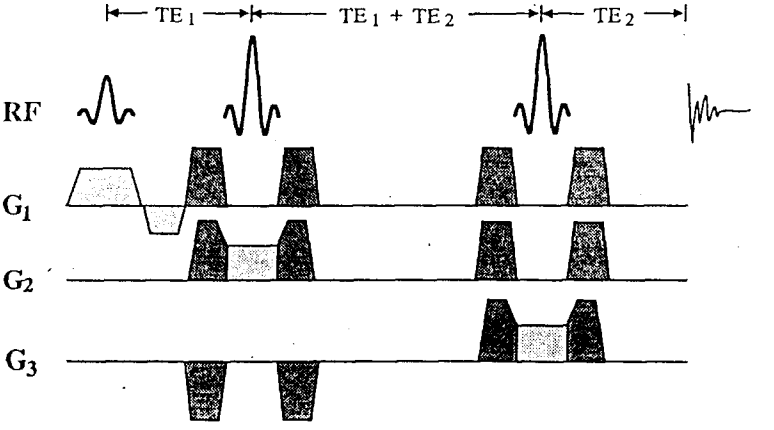
In the ISIS sequence, a FID is generated by a single 90 - degree excitation RF pulse that is preceded from zero to three slice-selective 180 - degree inversion RF pulses (Fig. 4). Up to 8 different FIDs can be acquired from the active region of the NMR coil. By the appropriate addition and subtraction of a set of FIDs acquired with different inversion pulses, you can acquire a signal from a slice, a column, or a localized volume (5). The ISIS sequence offers the best means of localizing very short T_2 species. This sequence is generally used for ^{31}P MR spectroscopy.



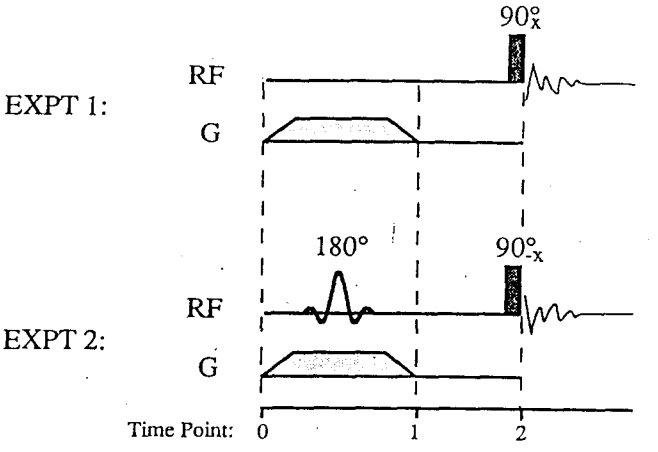
[Fig. 1] Localization of a voxel on the transaxial human brain image.



[Fig. 2] The STEAM sequence with water suppression sequence (CHESS).



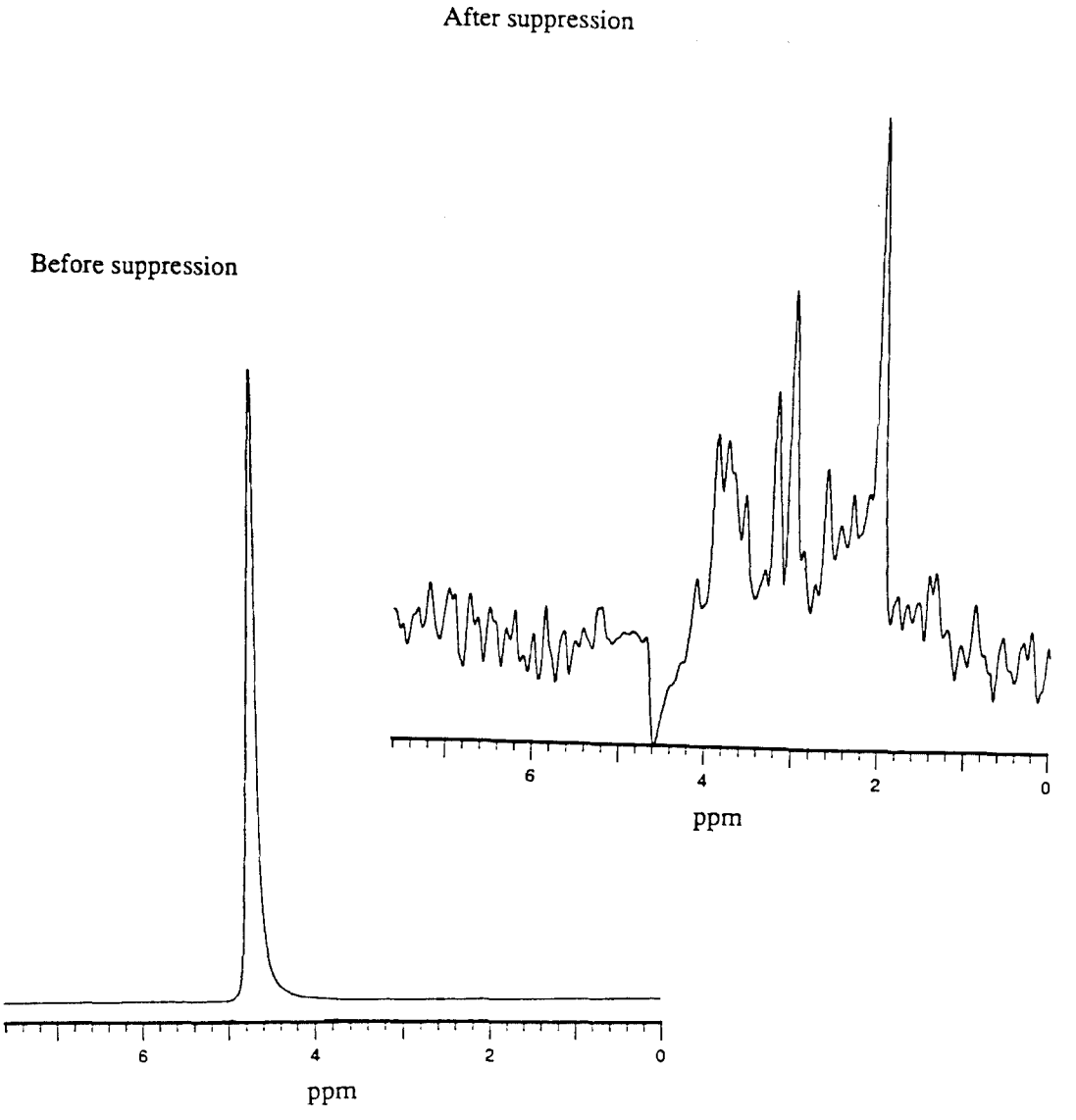
[Fig. 3] The PRESS sequence.



[Fig. 4] The ISIS sequence for initial two FID acquisition.

3. Water Suppression Scheme

The *in vivo* concentration of water is generally 35 ~ 45 M, and that of major brain metabolites is in the range of ~10 mM. Therefore, without removing water signal in *in vivo* ^{1}H MR spectroscopy, signals from other metabolites are usually subsided under the water signal (Fig. 5). Therefore, the efficiency of water suppression in the pulse sequence determines the overall quality of the ^{1}H spectrum. Various water suppression pulse sequences can be combined with the above pulse sequences. Among those, 3-pulse CHESS sequence was incooperated with the STEAM and PRESS sequences (6-7).



[Fig. 5] Spectrum before and after water suppression.

4. Data Acquisition Parameters

a) SF (Spectral Frequency), SW (Spectral Width) and SI (Data Size)

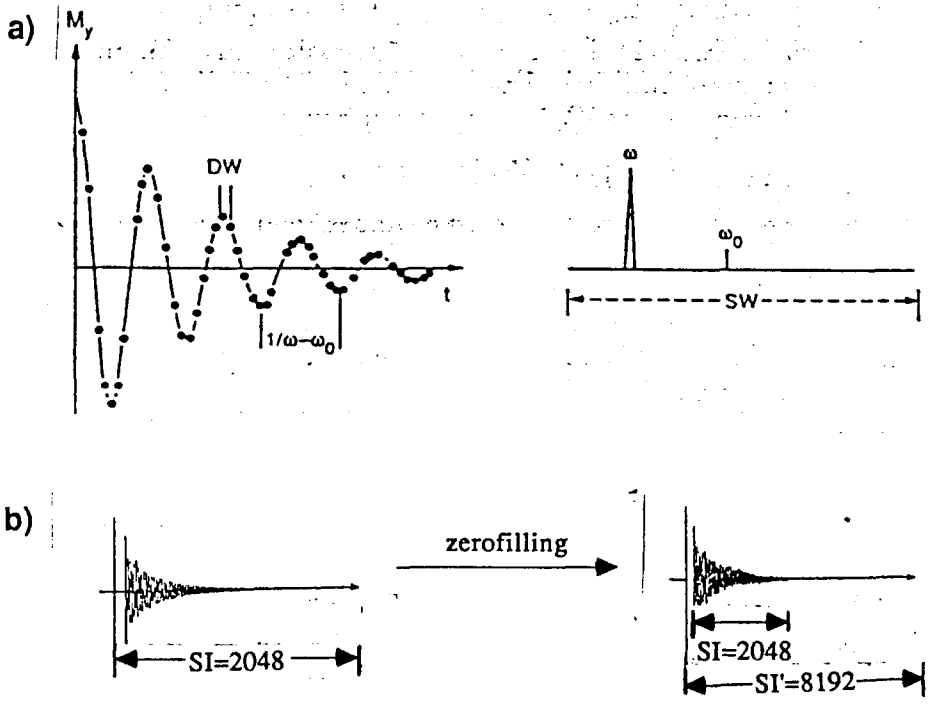
Spectral frequency of ^1H nuclei in 1.5T MRI / MRS system is 64.86 MHz. It can be varied ±10 Hz from exam to exam, thus, is required to set on resonance for every exam for a good SNR. The major human brain metabolites are observed within 0 ~ 4.5 ppm, therefore, spectral width is set up between 2000 ~ 2500 Hz to avoid the aliasing effect. Data acquisition time (ACQ) is as expressed as:

$$ACQ = SI \times DW = SI / SW = 1 / DR.$$

where DW = dwell time and DR = digital resolution. Thus,

$$DR = SW / SI \text{ (Hz / Pts)}.$$

In order to increase the digital resolution, the size of the data can be as large as possible. However, the large size also pays off the large disk space. Therefore, it is advisable to collect raw data with a small size and increase the size by zerofilling when post-processing. Currently, we collect the raw data with 2048 points and increase to 8192 points by zerofilling (Fig. 6).



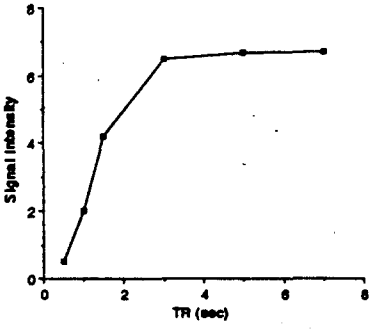
[Fig. 6] a) Spectroscopic parameters and b) zerofilling.

b) TR (Pulse Repetition Rate)

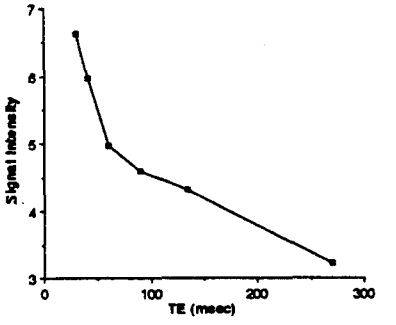
This value is usually 5 times of T_1 (spin-lattice relaxation time) to obtain the fully saturated signal. A saturation curve can be obtained and a proper choice of TR can be determined from the curve (Fig. 7). It is important for accurate data analysis and quantification.

c) TE (Echo Delay)

A choice of this value determines the signal intensity. The smaller this value, the more information you can get from the spectrum. However, this value is effected by a choice of the pulse sequence with a support of the MR hardware. For STEAM, short echo times of 20 ~ 40 msec can be used without much difficulties. With PRESS, it is much easier to use longer echo times of > 60 msec, however, in order to use short echo times, the strength of the spoiler gradients should be adjusted. For short echo PRESS spectroscopy, outer volume contamination and water suppression failure often occur. T_2 decay curves of the major brain metabolites can be obtained, from which the T_2 (spin-spin relaxation time) values of the metabolites can be calculated. For the data analysis, the signal intensity is corrected according to this value (Fig. 8).



[Fig. 7] T_1 saturation curve of the human brain metabolite.



[Fig. 8] T_2 decay curve of the human brain metabolite.

d) Shimming (Homogeneity Adjustment)

Homogeneity, the uniformity of the static magnetic field, is adjusted by shimming the magnet. It is enhanced, or adjusted by means of current offsets on the primary x, y, z gradients. A good shimming effects the resolution and sensitivity of the resulting spectrum. Good line shape and width should be obtained by shimming, and FWHM of the water signal is usually in the range of 1 ~ 4 Hz in our system.

e) RF Power

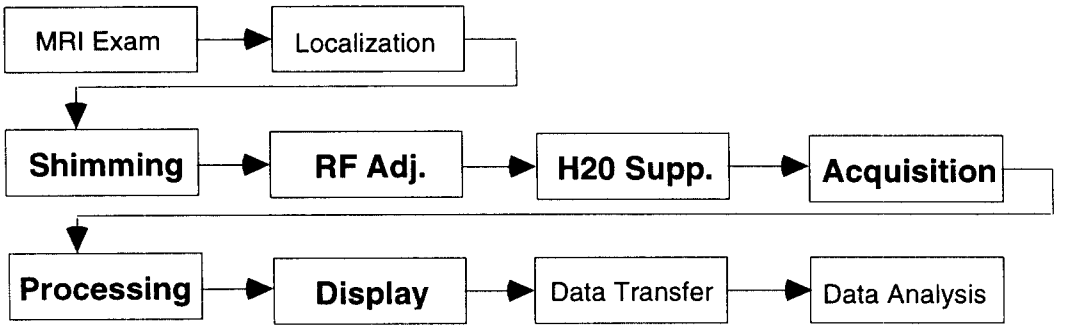
RF powers of transmitter and receiver should be adjusted. The transmitter power is affected by a size of the object in the center of the RF coil. The maximum power output is important for good spectral sensitivity and water suppression performance.

f) Water Suppression

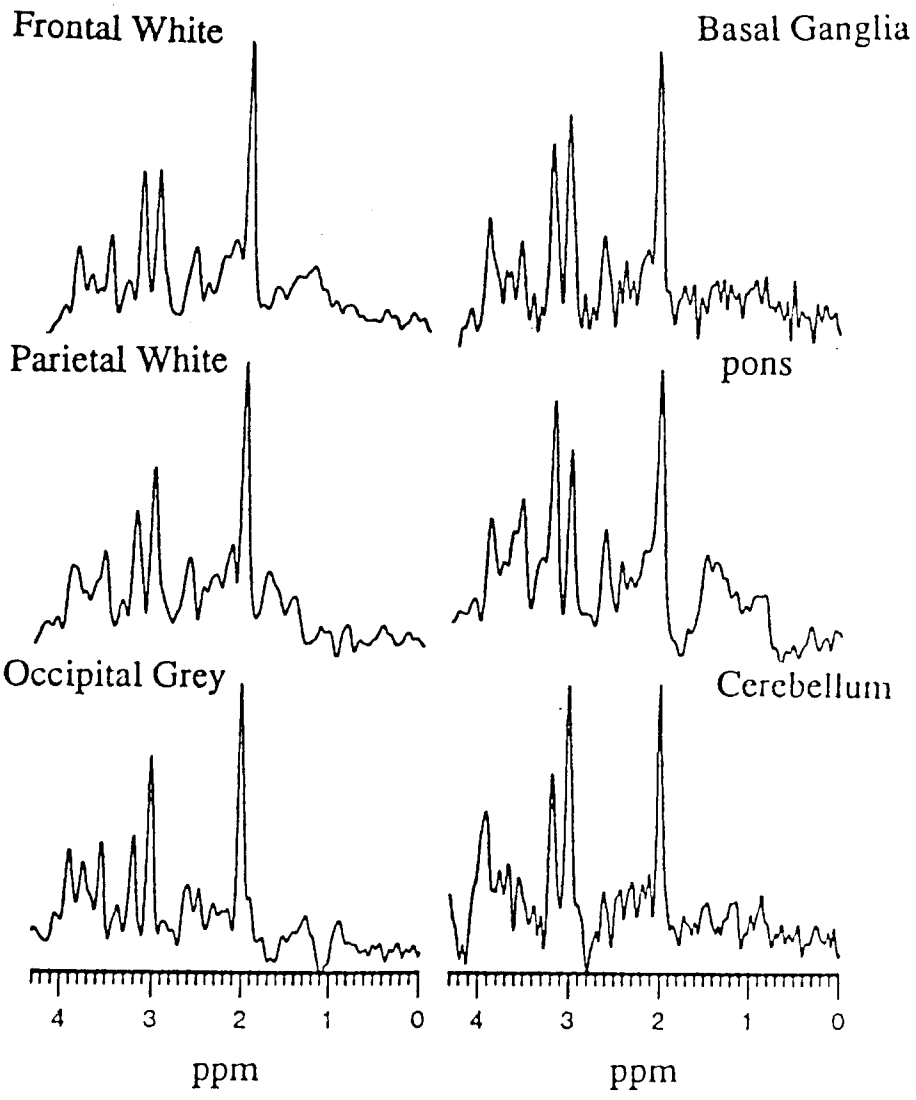
Water suppression is usually performed after adjusting all the above parameters. It requires an accurate adjustment of the spectral frequency of the water signal, an efficient RF power performance, and an accurate timing of the suppression sequence itself with the mother pulse sequence. It is certainly one of the most elaborative steps for ^{1}H MR spectroscopy along with shimming.

g) Acquiring Spectrum

^{1}H MR spectroscopy is performed as shown in the diagram (Fig. 9). With a proper combination of TR and TE, the parameter adjustment can be done either manually or automatically. There are advantages and disadvantages for each method. It is operator independent if done automatically. However, the automatic method are often failed, especially for difficult regions (highly heterogeneous region due to anatomic abnormalities, and regions of increased susceptibility due to the surrounding tissues, air canals, and blood flows). In these cases, you can obtain spectra by manually adjusting the parameters, even though some sacrifice on the resolution is sometimes inevitable. However, it is still better to obtain a spectrum than no spectrum. Example spectra of regions of the human brain are shown in Fig. 10.



[Fig. 9] A schematic diagram of ^{1}H MR spectrum acquisition. Procedures written in bold letters can be done either manually or automatically.



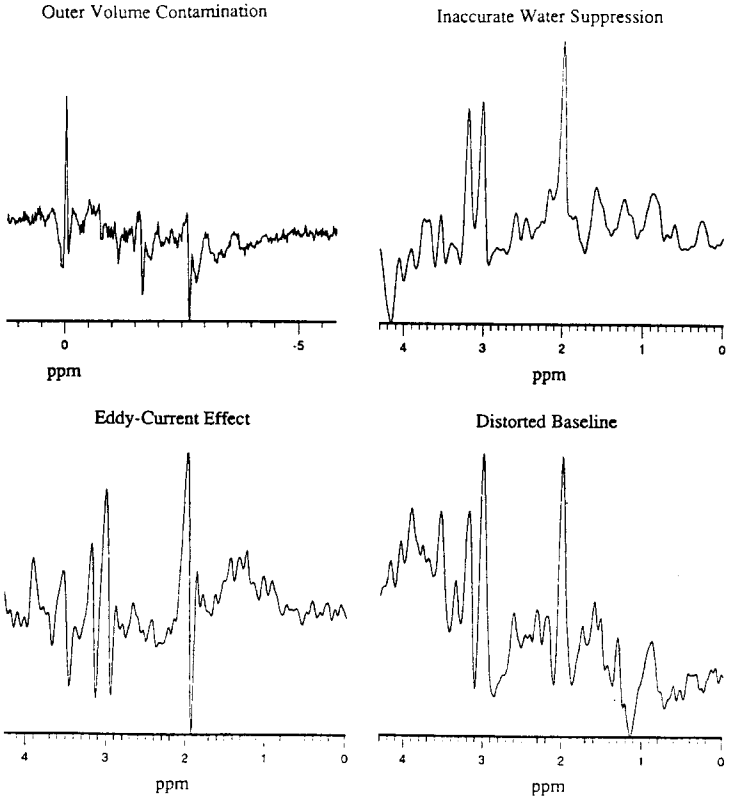
[Fig. 10] ^{1}H MR Spectra of six selected regions of the human brain.

5. Data Analysis

Spectral Data analysis is done on an independent computer (e.g. Sun Sparc 10 workstation) which is connected to MR spectrometer via ethernet. Raw data are transferred to the computer equipped with spectral data analysis softwares. The area under the peak is theoretically proportional to the concentration of the metabolite in that frequency. The area is usually calculated by Lorenzian-Gaussian fitting of the peak. Relative ratios of the metabolites to creatine are calculated. In order to determine the absolute concentrations of the metabolites in the unit of mmoles / kg of body tissue, rigorous quantification methods are needed.

6. Quality Control

Eddy current effect, inappropriate water suppression, outer volume contamination, and baseline distortion often effect the overall spectral quality, and those resulting spectra are often of no use. Examples of unacceptable spectra are shown in Fig. 11. In order to minimize those artifacts, a good maintenance of the MR system is required.



[Fig. 11] Examples of unacceptable quality spectra.

7. References

1. Webb PG, Sailasuta N, Kohler SJ, Raidy T, Moats RA, Hurd RE.Automated single-voxel proton MRS: Technical development and multisite verification, *Magn Reson Med* 1994;**31**:365-373.
2. Frahm J, Merboldt K, Hanicke W, Localized proton spectroscopy using stimulated echoes. *J. Magn. Reson.* 1987;**72**:502-508.
3. Moonen CTW, van Zijl PCM, Highly effective water suppression for in vivo proton NMR spectroscopy (DRY STEAM). *J. Magn. Reson.* 1990;**88**:28-41.
4. Kimmich R, Hoepfel D, Volume selective multipulse spin-echo spectroscopy. *J. Magn. Reson.* 1987;**70**:488-192.
5. Keevil SF, Porter DA, Smith MA, Experimental characterization of the ISIS technique for volume selected NMR spectroscopy. *NMR in Biomed.* 1992;5:200-208.
6. Haase A, Frahm J, Hanicke W, Mattaei, 1H NMR chemical shift selective (CHESS) imaging. *Phys. Med. Biol.* 1985;*30*:431.
7. Doddrell DM, Galloway G, Brooks W, Filed J, Bulsing J, Irving M, Baddeley H, Water signal elimination in vivo, using suppression by mistimed echo and repetive gradient episodes. *J. Magn. Reson.* 1986;**70**:176-180.