Chapter 8.5, 10.5, 17
MR Spectroscopy, Chemical shift and Water/Fat Separation

Yongquan Ye, Ph.D.
Radiology, Wayne State Univ

- **Previous sessions**
  - Larmor frequency, chemical shift intro (Chap. 1)
  - FID (Chap. 8)
  - Fourier Transform (Chap.9)

- **Today's session**
  - Spectroscopy and Chemical Shift
  - Chemical shift imaging
  - Water/fat imaging and separation

Spectroscopy and Chemical Shift (CS)

- Revisit FID signal (w/o spatial encoding)

$$S_j(t) \propto S_{0,j} e^{i(\Omega - \omega_{0,j})t},\ \omega_{0,j} = \gamma_j B_0$$

$$S_{FID} \propto \sum S_j(t)$$

- γ_j is determined by nucleus types (e.g. $^{1}H(42.58)$, $^{23}N_a(11.27)$,$^{31}P(17.25)$), micro chemical/ molecular environment (e.g. H_2O/CH_2+CH_3, thus the term chemical shift)

- B_0 inhomogeneity also affects FID frequency component, thus highly uniform B_0 is required for MRS

Spectroscopy and Chemical Shift (CS)

- CS implies frequency shift, can be described by the shielding constant σ

$$B_{shifted}(j) = (1 - \sigma_j)B_0$$

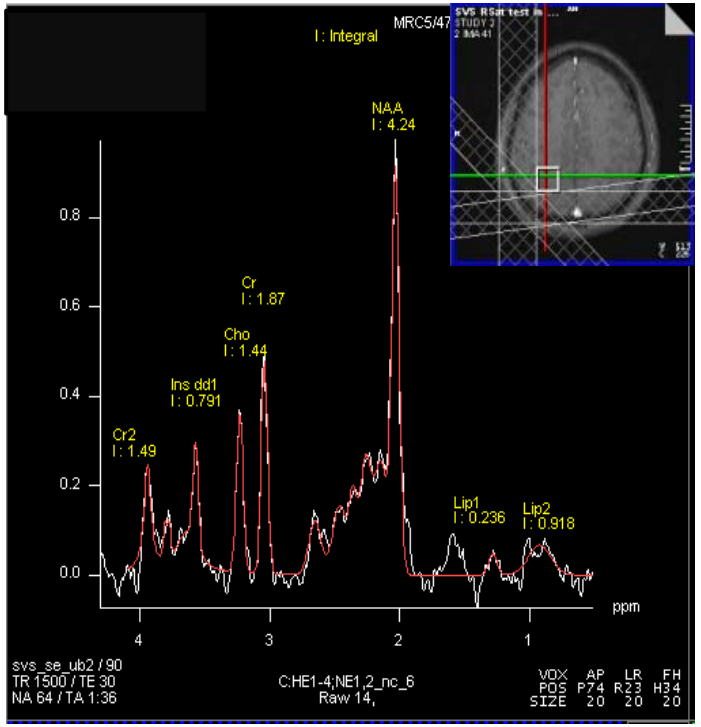
- CS is practically expressed in ppm unit, taking Larmor frequency as reference (e.g. $CS_{water/fat}$ 3.35ppm)
- MR Spectroscopy (MRS) determines the abundance of different molecules spectrally rather than spatially, i.e. non spatial selective
- MR Spectroscopy Imaging (MRSI) incorporates limited spatial selection

MRS

- Collects FID w/o spatial encoding, then directly do 1D FT
- Practically, excitation is spatial selective
- Multiple acquisition is needed for sufficient SNR

$$\sigma = \sigma_m / \sqrt{N_{acq}}$$

- Tissue and molecular of interest
  - Water/fat, choline(Cho), creatine (Cr/Cr2), n-acetyl aspartate (NAA), lactate, acetate



Chemical shift imaging (CSI)

- CSI selectively image one nuclei (usually ^{1}H) with different chemical shift/frequency/ magnetic shielding

- CSI methodologies
  - Additional CS dimension (MRSI)
  - Selective excitation/suppression
  - Selective saturation of water and fat
  - Multi-point (in-/oppose-phase) acquisition

MRSI

- CS dimension definition

$$\sigma = -\Delta\omega/\omega_0 \text{ , in ppm}$$

- 4D (x,y,z, CS) signal

$$s(\vec{k},t) = \int d^3 d\sigma \rho(\vec{r},\sigma) e^{-i2\pi(\vec{k}\cdot\vec{r}-\sigma f_0 t)}$$

- Fourier pairs: k-r and f-t

- CS dimension, instead of the frequency encoding dimension as in 3D imaging, becomes the new 'Read' dimension, while all 3 spatial dimensions act as 'phase encode'

2D+CS sequence

- Looks like 3D diagram, but
  - Still 2D slice selection
  - No gradient during readout
  - PE steps along x/y instead of y/z
  - MRS analysis for each voxel
  - Or multiple images, each represent the spin density at any CS

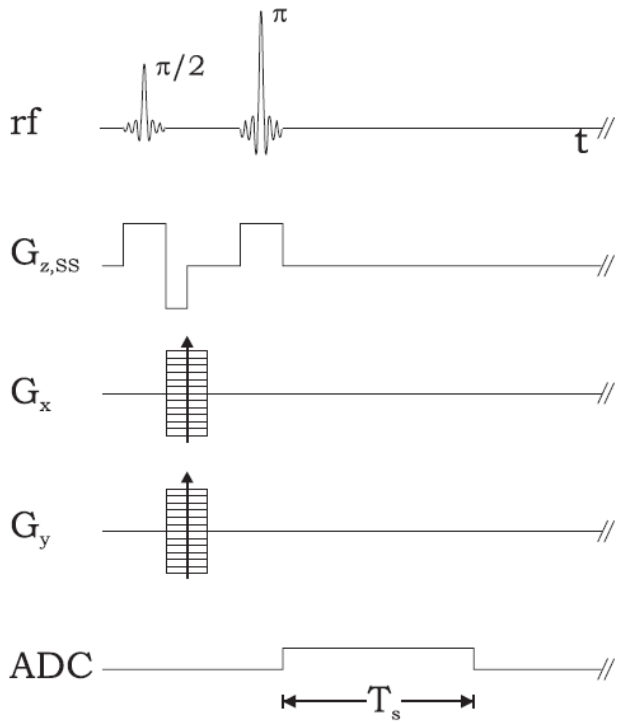


Fig. 10.21

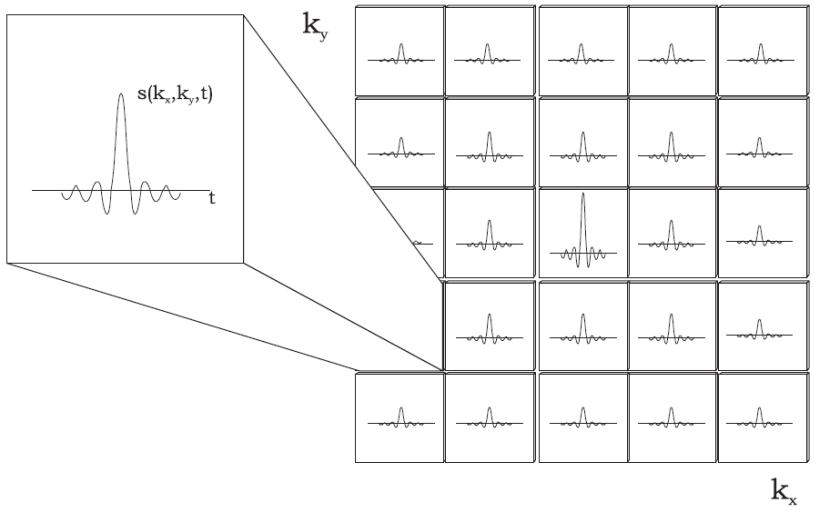


Fig. 10.22

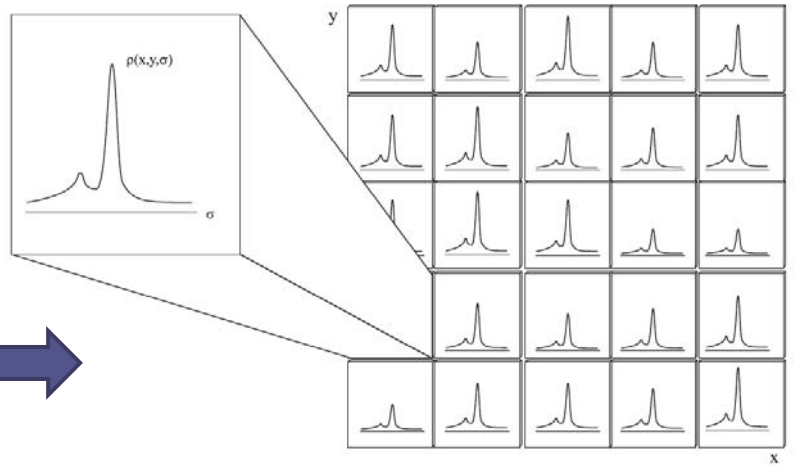


Fig. 10.23

2D MRSI (2D+CS)

- Considerations
  - $T_{acq}=N_{acq}N_xN_yTR$
  - Minimal receiver bandwidth
  - Reduce N_xN_y (fixed L_x/L_y) for high SNR (8x8~32x32)
  - Increase N_{acq} for high SNR (>64)
  - Long TR to reduce T1W (1-2s)
  - Require very high field homogeneity

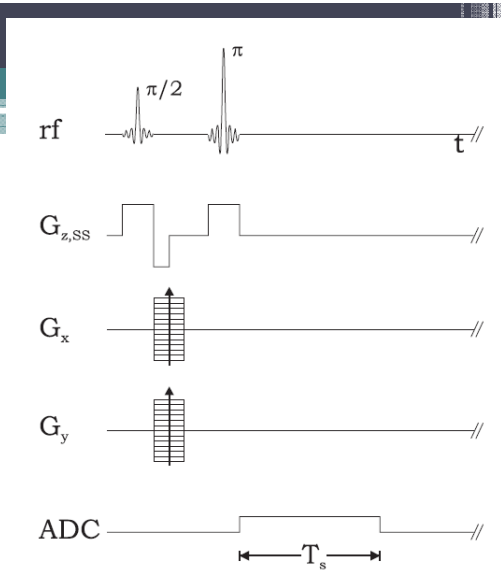
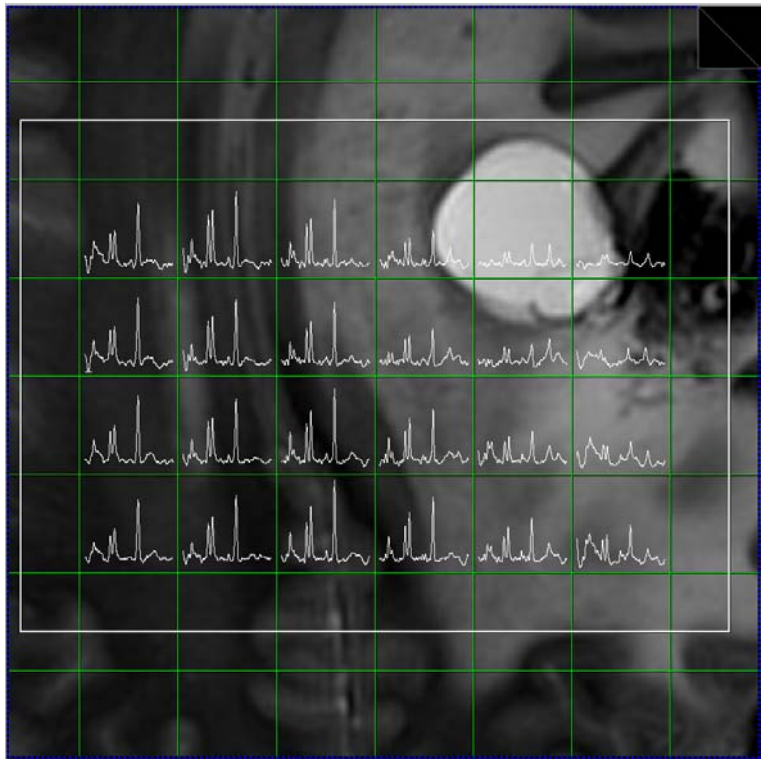


Fig. 10.21



3D MRSI (3D+CS)

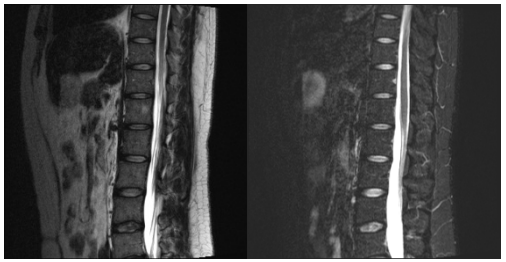
- Similar to 2D+CS, only that slice selection replaced by another phase encoding
- $T_{acq}=N_{acq}N_xN_yN_zTR$
- More stringent requirement on field homogeneity
- Usually too long to be applicable

Why separating water and fat?

- Fat shift artifacts:
  both partial volumed and non-partial volumed voxels

- Signal contamination (beat pattern as function of TE), introducing false contrast:
  Partial volumed voxels only

- Fat signal is bright in T2W images



T2W Fat nulling,T2W

Fat shift artifact

- CS_{fw} 3.35ppm -> Δf_{fw} 214Hz@1.5T
- Along any direction, the fractional number of voxel the fat is shifted is

$$N_{shift} = \Delta f_{fw} / \Delta f_{voxel}$$

- In Read direction

$$\Delta f_{voxel,x} = \not{\gamma} G_x \Delta x = 1/T_s$$

- In in-plane PE direction (EPI)

$$\Delta f_{voxel,y} \cong 1/N_y T_s$$

$$\Delta f_{voxel,y} \approx \Delta f_{voxel,x} / N_y$$

Fat shift artifact

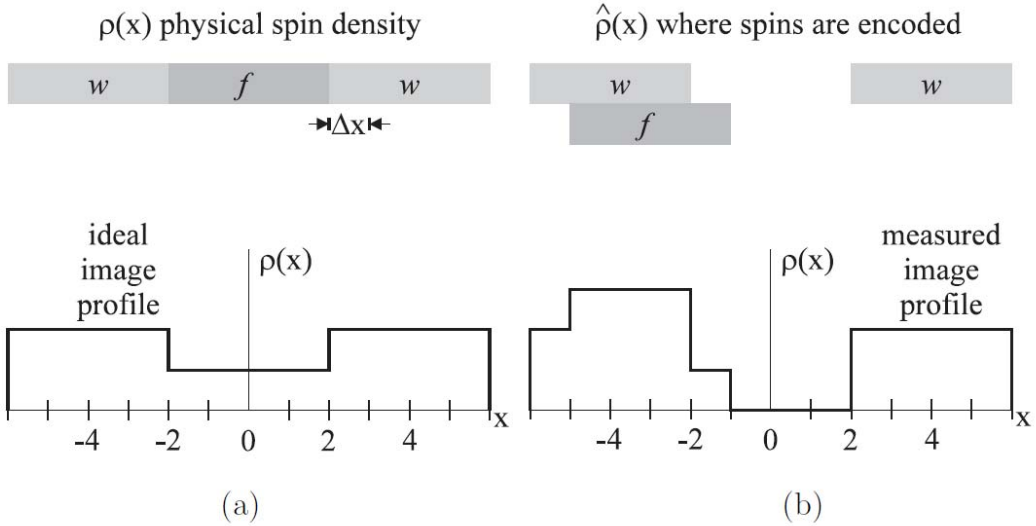
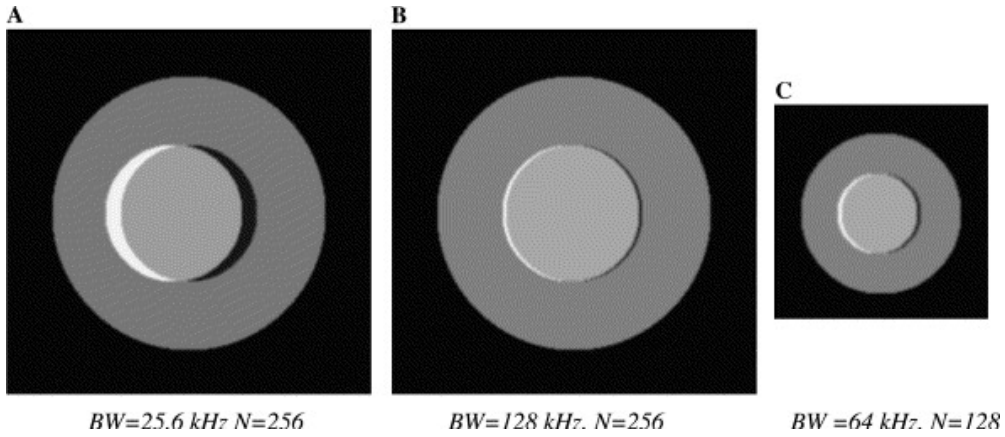


Fig. 17.3

$$\omega_f = -\gamma G x + \Delta\omega_{fw}$$
$$= -\gamma G(x - \Delta\omega_{fw}/\gamma G)$$
$$= -\gamma G x'$$

$$\Delta x_f = \Delta f_{fw}/\not{\gamma} G$$
$$= \Delta x \cdot \Delta f_{fw}/\mathrm{BWpx}$$



Benoit-Cattin, JMR, 2005

Signal with beat pattern as a function of TE

- In a water-fat partial volumed voxel

$$\hat{\rho}(TE) = \hat{\rho}_w(TE) + \hat{\rho}_f(TE)$$

- Assume water has a zero phase, then

$$\hat{\rho}(TE) = \hat{\rho}_{w,m} + \hat{\rho}_{f,m} e^{-i2\pi\Delta f_{fw} TE}$$

- In-phase and oppose-phase scenarios

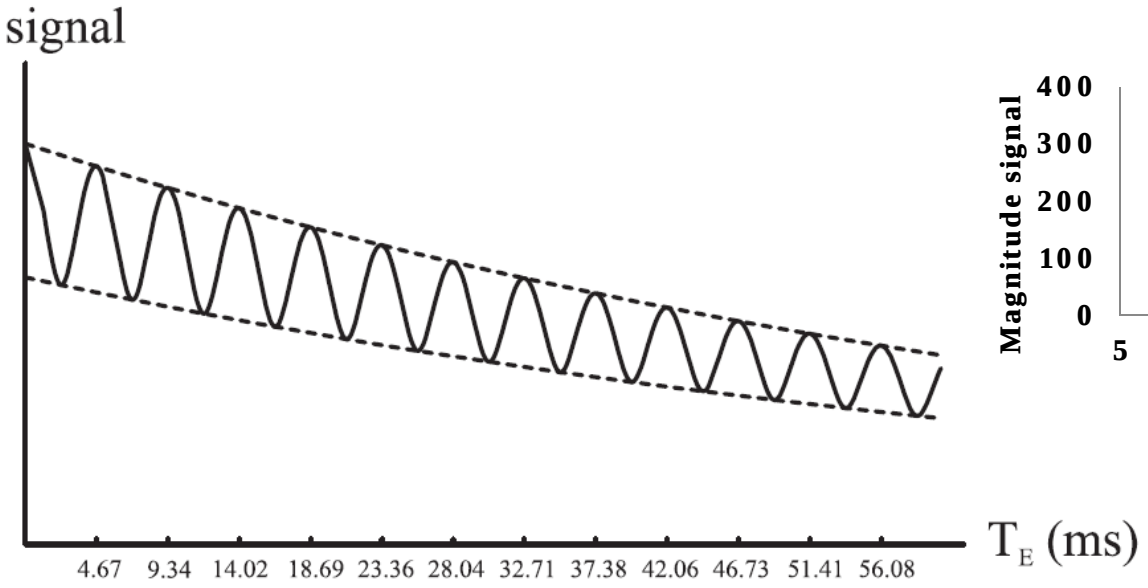
$$-i2\pi\Delta f_{fw} TE_{in}(n) = 2n\pi$$

$$-i2\pi\Delta f_{fw} TE_{op}(n) = (2n+1)\pi$$

n=0,1,2…

Signal with beat pattern as a function of TE

- Edge enhancement/ reduction artifacts
- Inaccuracy in T2* estimation



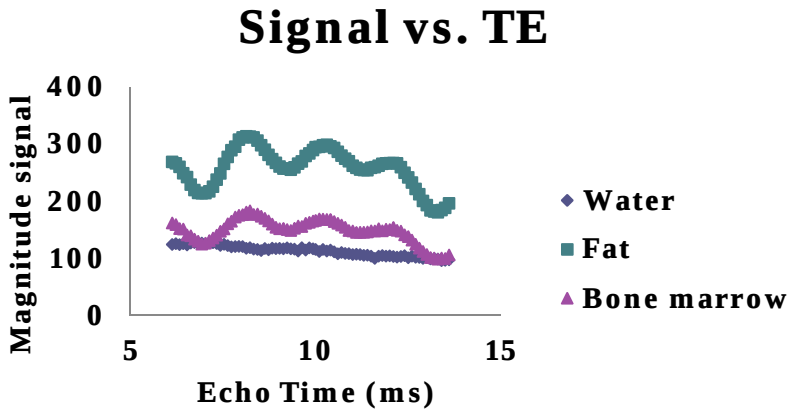
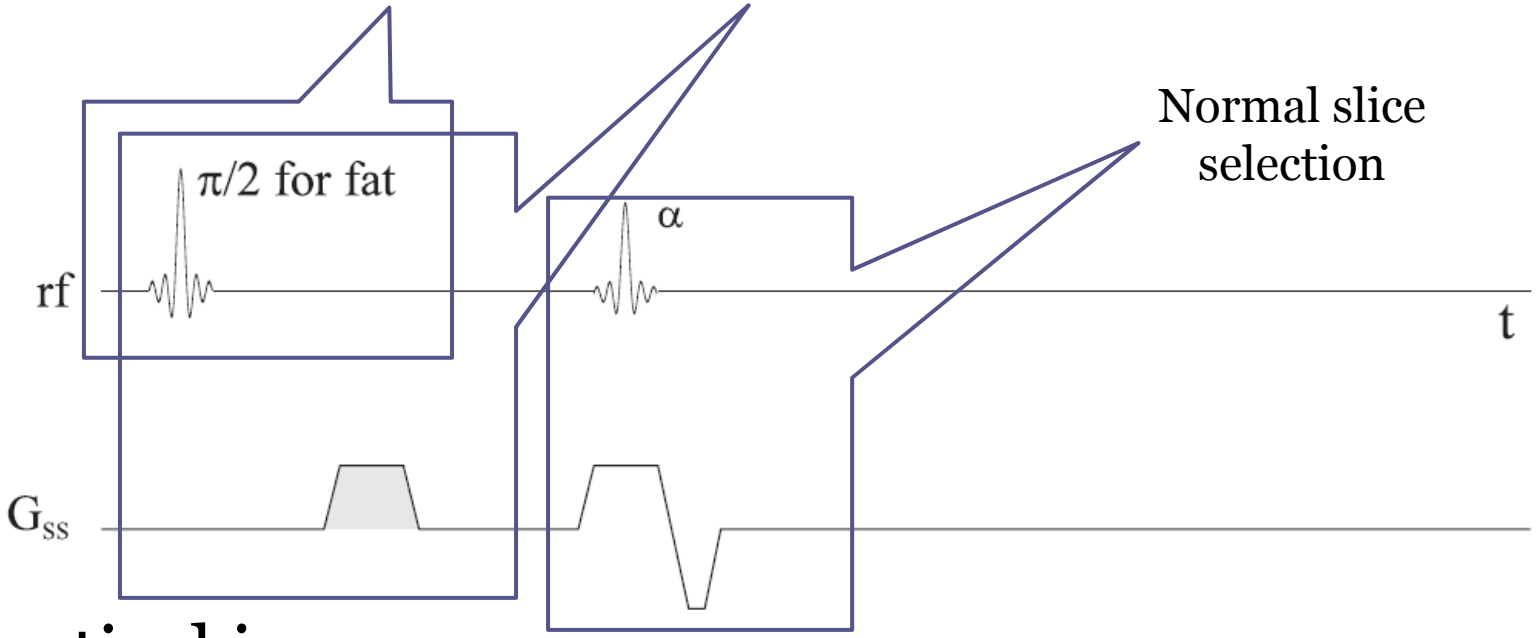


Fig.17.8, and remember Fig. 8.1

Separating water and fat

- Selective excitation and saturation



- Practical issues:
  - Long RF pulse duration for narrow RF bandwidth
  - Fat selective pulse may also excite water due to field inhomogeneity, or too small Δf_{fw} at low fields
  - Field inhomogeneity also widens fatty peaks

Separating water and fat

- Inversion recovery

$$T_{1,fat} < T_{1,GM/WM/muscle}$$

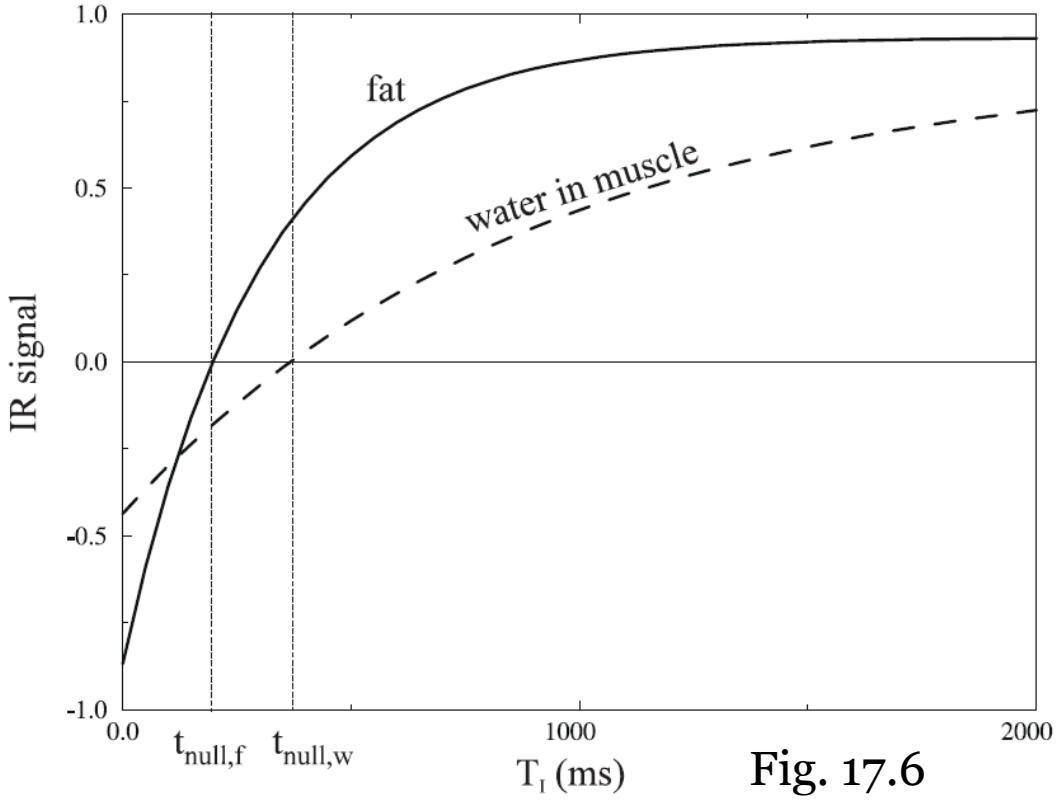


Fig. 17.6

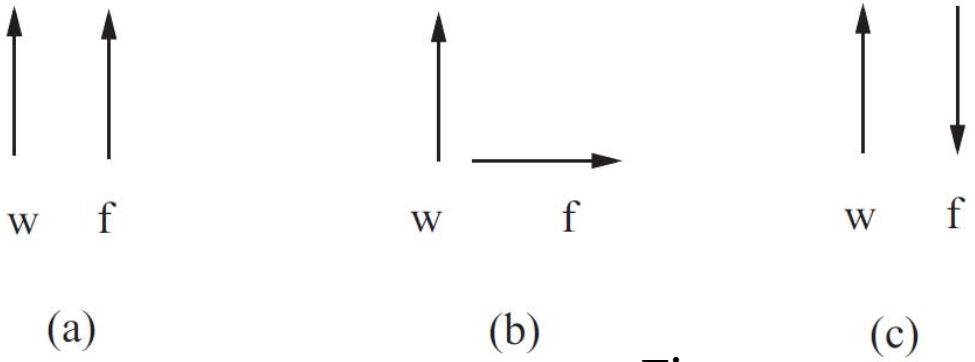
Separating water and fat

- Multipoint acquisition
  - Known water/fat chemical shift
  - Adapting a simple partial volume model (Chap. 15)
  - Utilize phase information

- Methods
  - Single echo complex separation
  - Two-/three-point Dixon method
  - Multi-point Dixon method (for more accurate results or extra species such as silicon)

Separating water and fat
Multipoint acquisition (Dixon method)

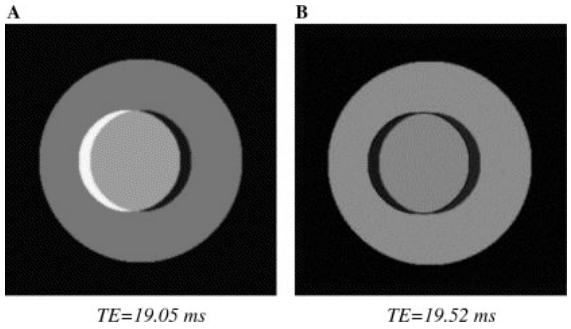
$$\hat{\rho}(TE) = \hat{\rho}_{w,m} + \hat{\rho}_{f,m} e^{-i2\pi\Delta f_{fw} TE}$$



$TE_{op} = (2n+1)/2\Delta f_{fw}$

$TE_{in} = n/\Delta f_{fw}$

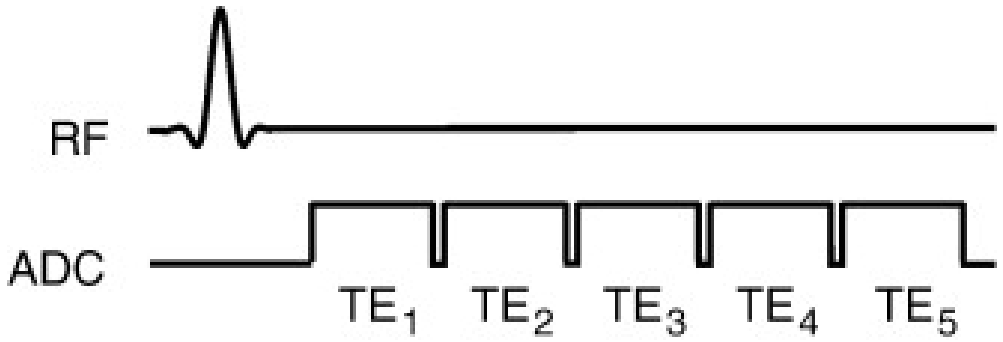
Fig.17.9



Benoit-Cattin, JMR, 2005

1.5T:
TE_{op} =2.34/7.01/11.69…ms
TE_{in} = 4.67/9.35/14.02…ms
3T:
TE_{op} =1.17/3.51/5.84/8.18…ms
TE_{in} =2.34/4.67/7.01/9.35…ms

GE and SE



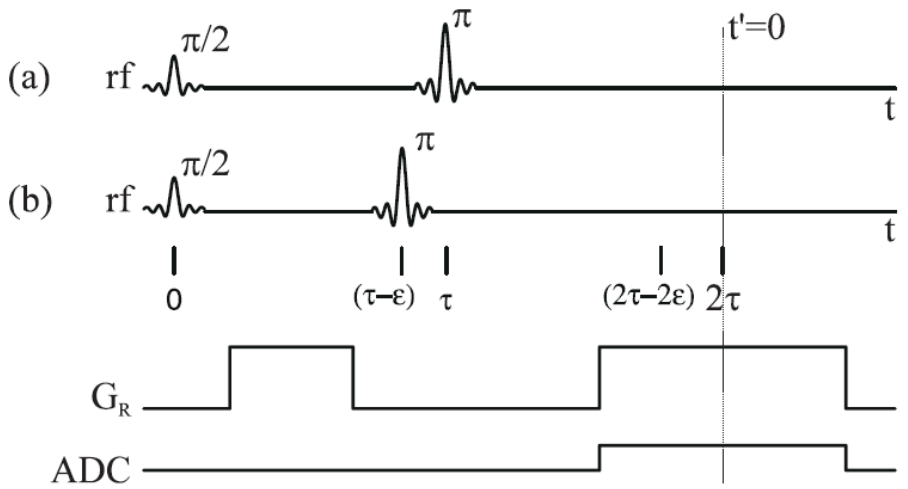
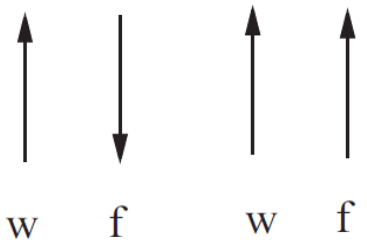


Fig. 17.13

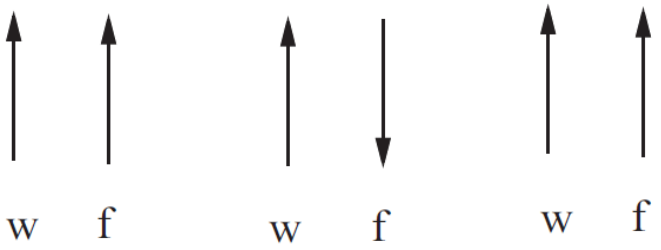
2-/3-/multi-point Dixon

2-point Dixon



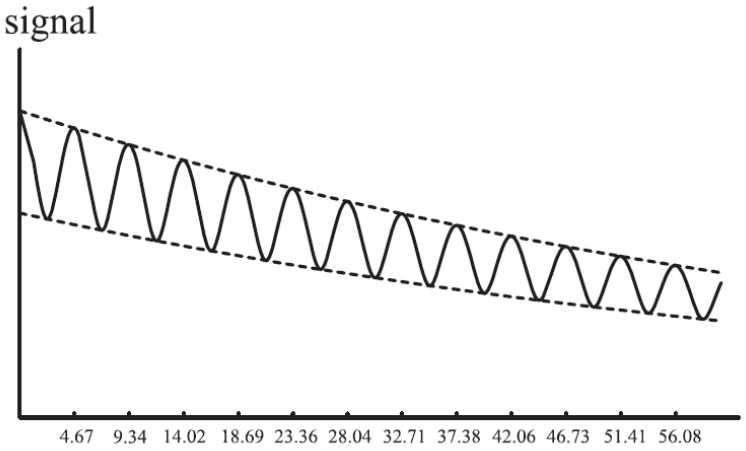
- Easy to understand
- Susceptible to field inhomogeneity

3-point Dixon



- 2 in-phase can determine ΔB

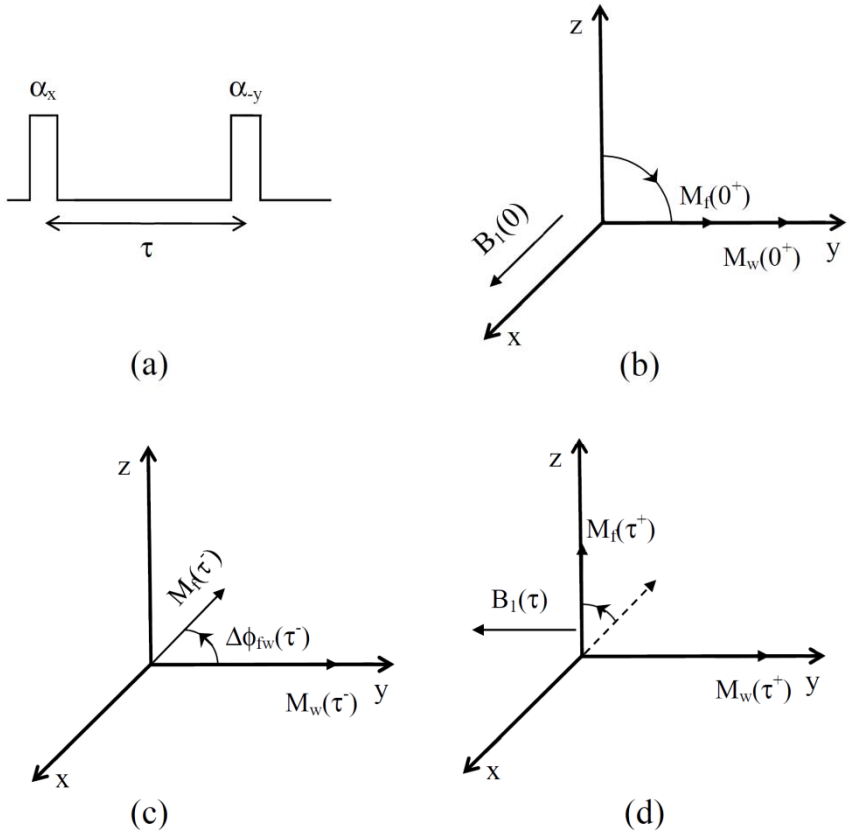
Multi-point Dixon



- Use multi point regression and phase information

Fig.17.8

Separating water and fat Spatial-Spectral (SPSP) pulses



Homeworks

- Probs 17.1-17.4

Next Class

Chapter 18, by Dr. Neelavalli