H_2O and fat imaging

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Chemical Shift (Review)

- Atomic nuclei are surrounded by electrons, which can shield the main magnetic field B_0 and reduce the net magnetic field experienced by nuclear spins. With chemical shift, the resonant frequency becomes

$$u = g(1 - s)B_0$$

- The actual chemical shift ($du = -gsB_0 = -su_0$) is proportional to the applied magnetic field

Chemical Shift (Review)

- σ is the dimensionless shielding constant
- By convention, zero chemical shift (σ =0) is arbitrarily assigned to the protons in tetramethyl saline, $Si(CH_3)_4$. The chemical shift of other protons is calculated from their resonant frequency with:

$$s\ [ppm] = \frac{u - u_{TMS}}{u_{TMS}} \times 10^6$$

where v_{TMS} is the resonant frequency of $Si(CH_3)_4$.

Chemical Shift (Review)

- Why assigned $Si(CH_3)_4$?

  It is chosen because it is highly diamagnetic, and has a ^{13}C peak. Also note, water is slightly paramagnetic comparing with fat.

  And σ_{wf} is around 3.5ppm.

Chemical Shift Misregistration Artifacts (CSMAs)

- It is caused by the frequency (chemical) shift between water and fat resonance
- CSMA – Frequency Encoding

$$\Delta x / dx = (du / BW) N_x$$

- CSMA – Slice Selection

$$\Delta z / dz = du / BW$$

Chemical Shift Misregistration Artifacts (CSMAs)

- CSMA – Phase Encoding
  Almost no effect
- Reason
  The frequency of the chemical shift affects the measured signal during the time-dependent measurement of the magnetic resonance. So the chemical shift effects only the signal measured during the read-out interval, AT. The chemical shift does not contribute in the phase encode direction because the phase encoding is applied during a fixed time interval, τ, in which the chemical shifted frequencies contribute a constant amount of phase shift at each phase encode step and this does not affect the spatial information.

Factors decide the CSMA

- Strength of magnetic field
- Bandwidth of the slice-selective pulses
- Strength of the magnetic field gradient
- Data-sampling bandwidth
- Voxel dimensions
- The chemical shift itself

H_2O/Water Signal Separation

- Frequency-selective pulse
- Tissue nulling with inversion recovery
- Dixon method

The first 2 methods were introduced in last lecture.

Selective excitation of the fat

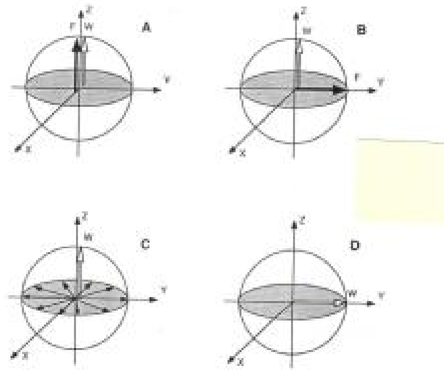


Figure 16-29. Frequency-selective excitation. **A,** Fat and water magnetizations are initially polarized along the direction of the external magnetic field *(Z)*. **B,** The selected spectral component (in this case fat) is rotated into the transverse plane by an RF pulse in the absence of a gradient. **C,** The magnetization is then dephased by a spoiler gradient such that the transverse magnetization of fat averages to zero. **D,** A slice-selective pulse next rotates the other component (in this case water) into the transverse plane for imaging.

Frequency-selective pulse

- Limitation

  Rely on the well-defined frequency separation (e.g. Δf_{wf} is only about 70Hz at 0.5T)

  Sensitive to both B_1 nonuniformity and B_0 inhomogeneity

Tissue Nulling with Inversion Recovery

- Invert the water and fat magnetization. Because water has longer T1 than fat, the longitudinal magnetization of water is negative but nonzero at the time of the RF excitation pulse. The transverse magnetization and signal that result are primarily from water

Tissue Nulling with Inversion Recovery

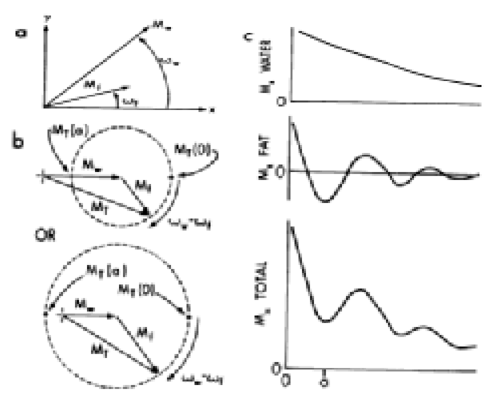
- Limitation

  sensitive to B1 nonuniformity, prolongs scan time and reduces the signal from other tissues in the process of nulling fat

Dixon method

- First introduced in “Dixon WT: Simple proton spectroscopic imaging. Radiology 153: 189, 1984”

Dixon method



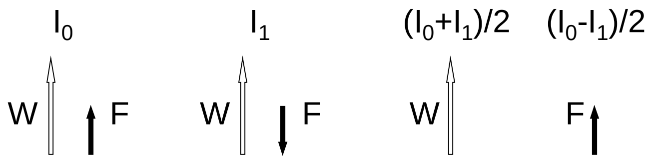
Transverse magnetization following a 90° pulse. The volume element contains both water and fat. M_w = water magnetization; M_f = fat magnetization; ν_w and ν_f = Larmor frequencies of water and fat ($\omega = 2\pi\nu$).

a. Laboratory frame.

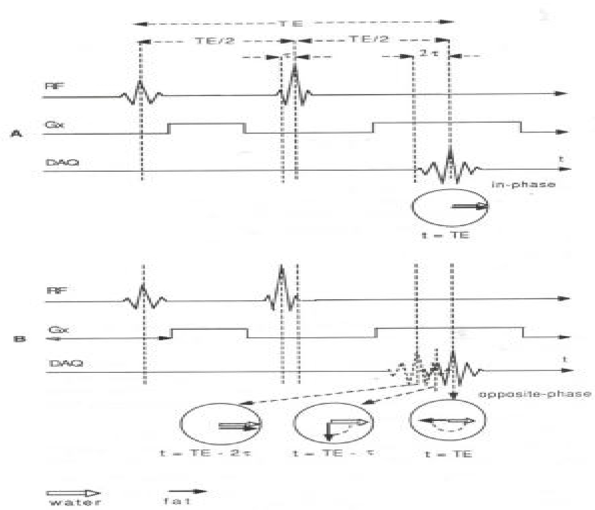
b. Rotating frame, top $|M_w| > |M_f|$, bottom $|M_f| > |M_w|$.

c. Typical FID.

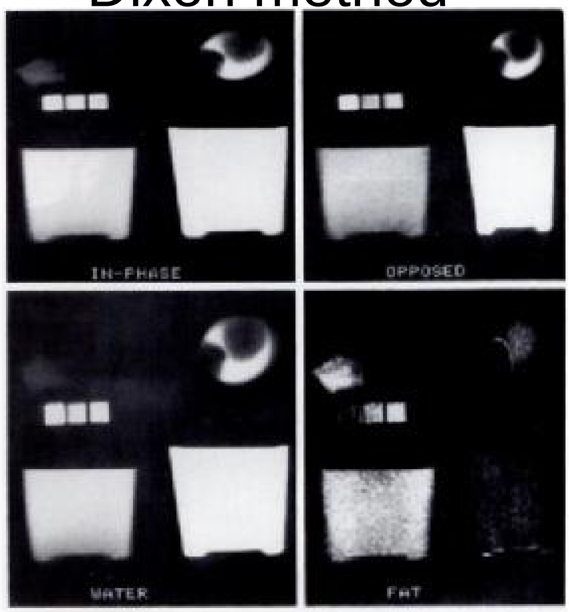
Dixon method



How to use Dixon method in Pulse Sequence?



Dixon method



Dixon method

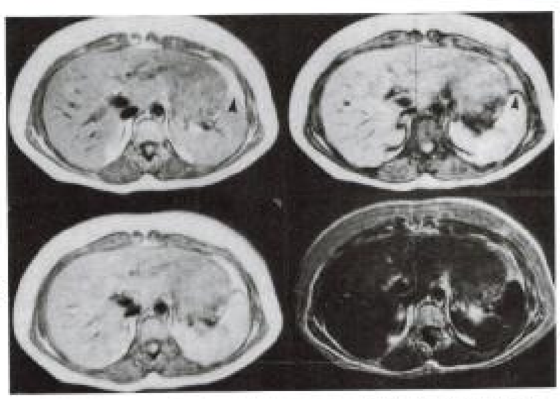


Figure 16-24. Phase-contrast imaging of the liver in a normal volunteer. **A,** Conventional in-phase SE 1500/30 image shows the spleen to have a slightly higher signal intensity than liver. **B,** Opposite-phase SE 1500/30 image again shows the spleen to have a slightly higher signal intensity than the normal, nonfatty liver. A dark band of low signal intensity (*arrowhead*) demarcates interfaces between water-containing viscera and fat-containing adipose tissue. **C,** Calculated "water-only" image is derived by adding images **A** and **B**. This image is similar to the in-phase image (**A**), indicating that all the liver and spleen signal intensities are from water. **D,** Calculated "fat-only" image is derived by subtracting image **B** from image **A**. The absence of signal from the spleen and liver indicates that neither tissue contains MR-observable fat. The ambiguous appearance of subcutaneous fat results from the magnitude reconstruction, as explained in Figure 16-23 (Courtesy D Stark.)

Dixon method Disadvantages

- Necessity for image postprocessing required after acquisition of two independently acquired scans
- Prolong the scan time
- What's the other one?

  Patient motion between each acquisition causes the image artifacts

Conclusion

- Used in tissue engineering such as the characterization of engineered adipogenic constructs
- Fat/water CSI had its origins as early as 1982, with clinical applications for studies of bone marrow, orbit, fatty infiltration of the liver and so on
- Some advantages and some disadvantages

Fat/water CSI Advantages

- By eliminating the strong fat signal components of images, more efficient use of the full dynamic range of the gray scale for image filming and display on an MR monitor
- As to T2-weighted imaging, the contribution of fat is not insignificant. And T2-weighted sequence is used specifically to detect abnormalities based on the increased T2 of water
- Improve T1 and T2-weighted sequences, since it can alter tissue contrast
- Minimize the CSMA for sure

Fat/water CSI Disadvantages

- The major disadvantages are mainly from the methods we use to do the Fat/Water image such as motion artifacts, increasing the scan time, reduce some signal and so on

Reference

- David D.S. et al: Magnetic resonance imaging (Second Edition), 1992
- Haacke E.M. et al: Magnetic resonance imaging physical principle and sequence Design
- Dixon WT: Simple proton spectroscopic imaging. Radiology 153: 189, 1984
- Haase A: H NMR chemical shift selective (CHESS) imaging. Phys. Med. Biol., 1985, Vol. 30, No. 4, 341-344.
- Xu H, Hong L, Othman S F, et al. MR Characterization of Tissue-Engineered Contructs. 45th ENC, Asilomar, California

HW 1

- Assume that a voxel centered at x_0 with width Δx contains both water and fat uniformly distributed throughout the voxel

a) How large must the read gradient G_R be so that 80% of the fat lies within the same voxel as the water when Δx =1mm? Assume that all the fat sits at one frequency with =3.35ppm and B0=1.0T.

b) In what direction along x is fat shifted

Hw 2

- Derive the equation of the correct timing offset τ of the 180 degree pulse to create an opposite-phase image