脈衝程序與空間編碼
A Course of MRI

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本週課程內容

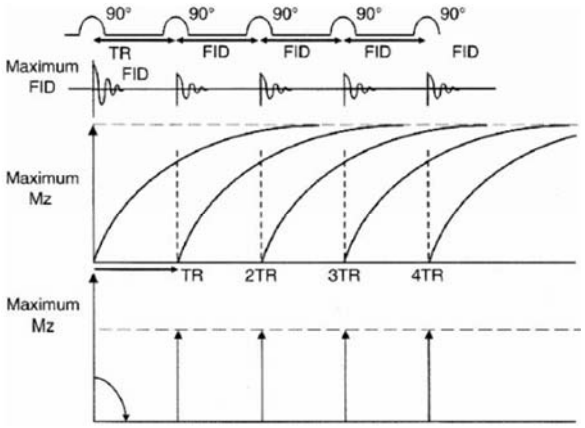
- 脈衝程序(Pulse sequences)
  - Partial saturation, saturation, inversion recovery
  - Spin Echo
- 空間編碼(Spatial encoding)
  - Slice selection (G_z)
  - Frequency encoding (G_x)
  - Phase encoding (G_y)

脈衝程序

Pulse Sequences

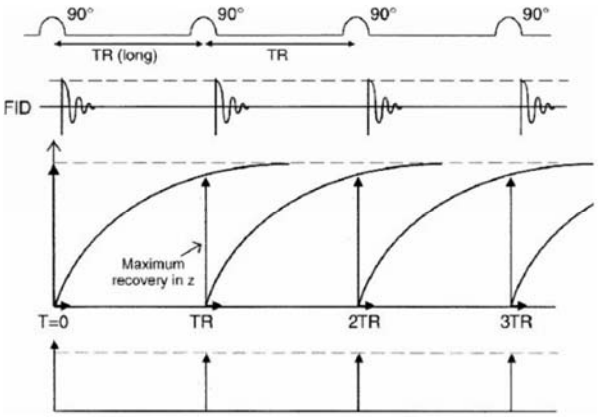
Partial Saturation Pulse Sequence

- TR is short and TE is minimal: T1-weighted image



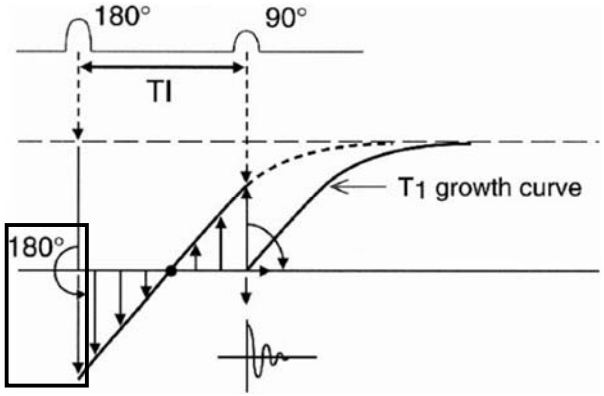
Saturation Recovery Pulse Sequence

- TR is long and TE is minimal: proton-density weighted image



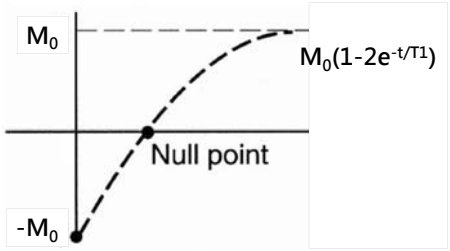
Inversion Recovery Pulse Sequence

- The inversion time (TI): the interval between 180° and 90° RF pulses



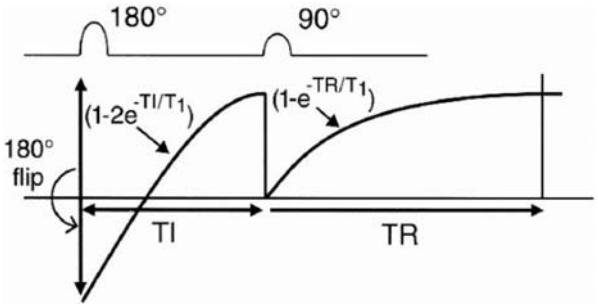
Null Point (S=0)

- After the 180° RF pulse, the magnetization starts to recover from $=M_0$ instead of zero.
- Signal intensity (S) = 0 = $1\text{-}2e^{-TI/T1}$
- TI(null) = ($ln2$)T1 ≒ **0.693 T1.**



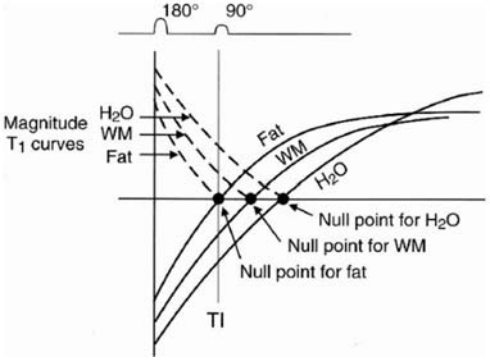
Two Recovery Curves

- Recovery after the 180° RF pulse
- Recovery after the 90° RF pulse



Tissue Suppression: STIR & FLAIR

- STIR: Short TI inversion recovery, fat suppression
- FLAIR: Fluid attenuated inversion recovery, water suppression



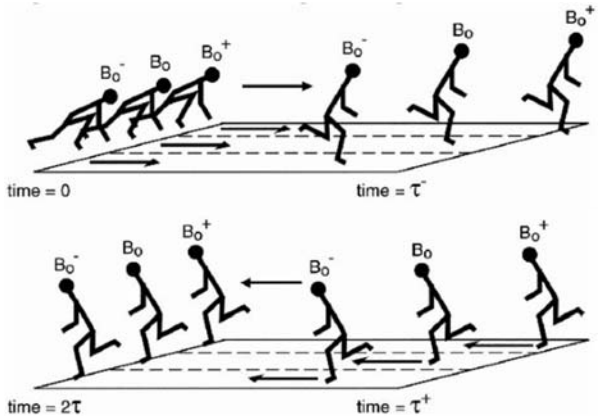
< STIR >
For 1.5T, TI = 140 ms
For 1.0T, TI = 100 ms

Magnitude Reconstruction

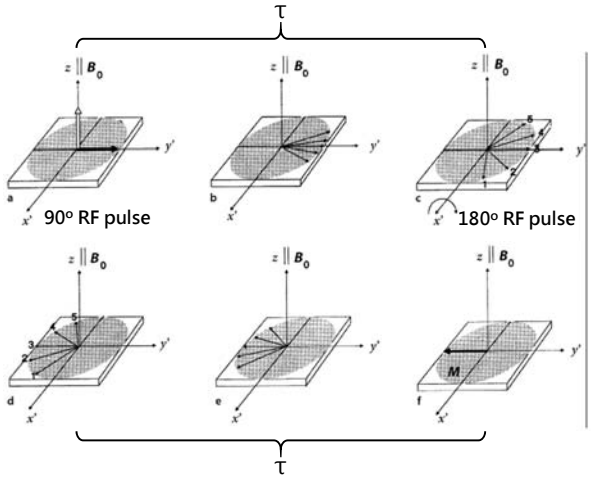
- We can add the x and y coils together to increase the SNR by a factor of $\sqrt{2}$ (increase about 40%).
- The root mean square (rms) = $\sqrt{S_x{}^2 + Sy^2}$
  - The magnitude image is always positive.
  - Its dynamic range is less than the original, i.e., 0 to M_0 vs. $-M_0$ to M_0
- Magnitude reconstruction ➔ higher SNR
- Phase reconstruction ➔ greater contrast

The Concept of Rephasing

- Dephasing due to the external magnetic field inhomogeneities.

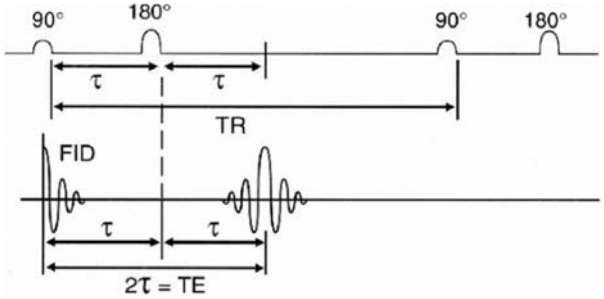


The Concept of Rephasing



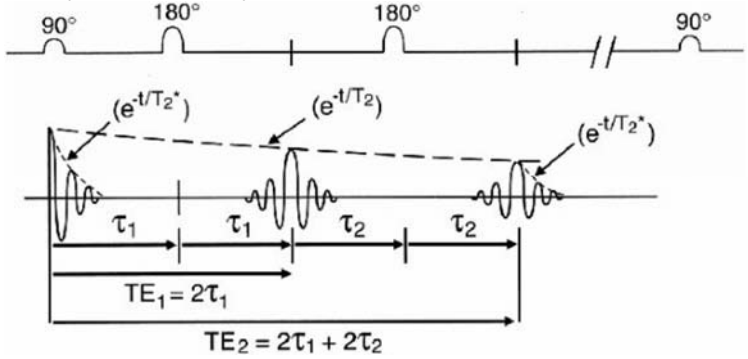
Spin Echo Pulse Sequence

- Time τ is the time from 90° RF pulse to the 180° RF pulse.
- Time τ is also the time from 180° RF pulse to the point of maximum rephasing, i.e., the echo.
- We call 2τ the echo delay time (time to echo) – TE.



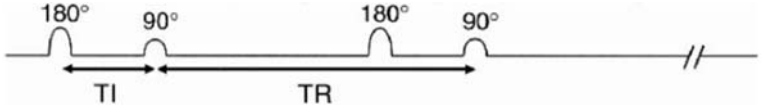
Multiple Spin Echos

- We can eliminate the fixed external magnetic field inhomogeneities (ΔB_{ext}), but not spin-spin interactions (ΔB_{int}).
- T2* decay → T2 decay

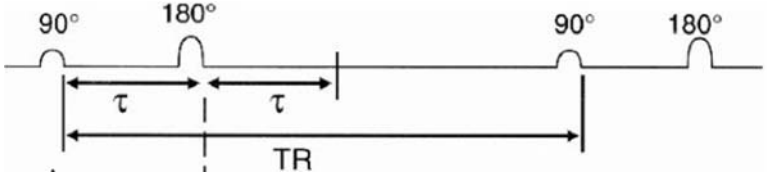


Combination of 90° and 180° pulses

Inversion recovery



Spin echo



空間編碼

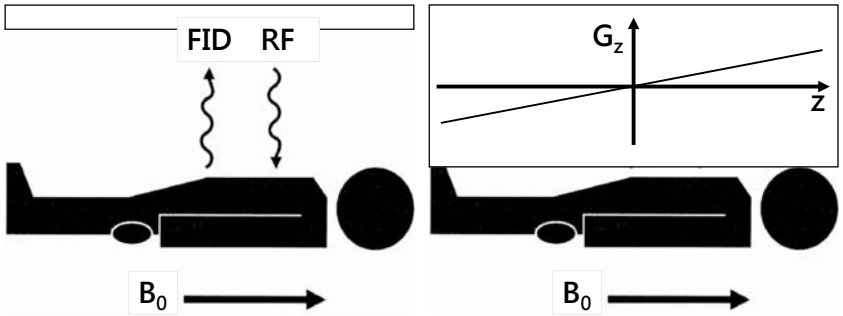
Slice Selection and Spatial Encoding

Gradients

- A gradient is simply a magnetic field that changes from point to point – usually in a *linear* fashion.
  - The slice-select gradient
  - The readout or frequency-encoding gradient
  - The phase-encoding gradient
- An image = slice selection + in-plane spatial encoding

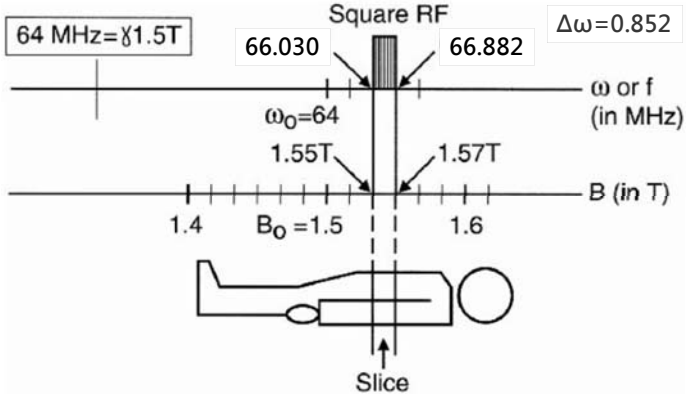
How to Select a Slice

- Create a variation in the field along the z-axis in linearly increasing or decreasing by G_z.



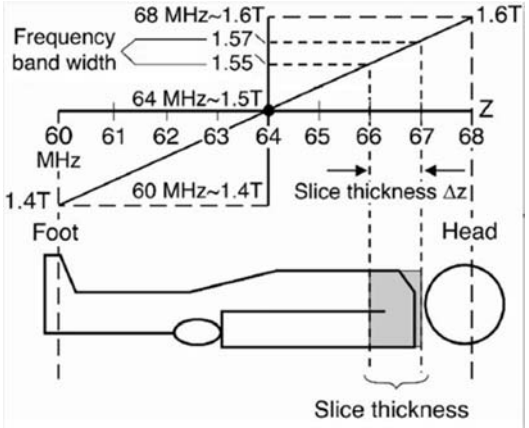
Field Strength and Larmor Frequency

- Larmor frequency: $\omega(z)=\gamma(B_0+G_z \cdot z)$



Bandwidth of RF Pulse

- We can excite one slice by an RF pulse with a specific frequency range.
- This range of frequencies determines the slice thickness and is referred to as the bandwidth.



Slice-Select Gradient (G_z)

- We transmit an RF pulse with a bandwidth that has the appropriate center frequency.
- This gradient is turned on only when we transmit the RF pulses.
- When we transmit the 180° pulse (*rephasing pulse*) for the same slice, we activate the same gradient.

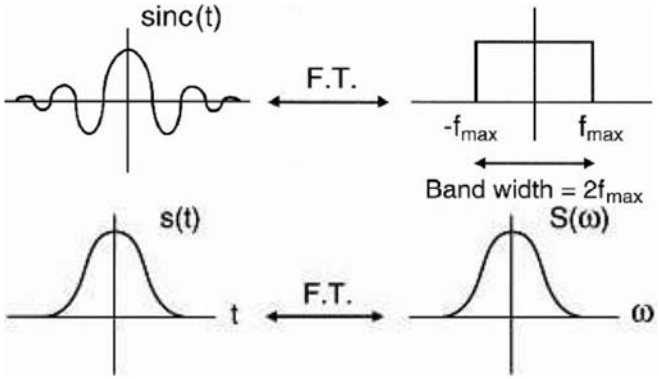
Two types of RF pulses

- Slice-selective
  - This RF pulse will select only a certain slice of the body.
  - Used in two-dimensional (2D) imaging
- Non-selective
  - A non-selective RF pulse excites every part of the body that is in the coil.
  - Used in three-dimensional (3D) imaging

Fourier Transform (FT)

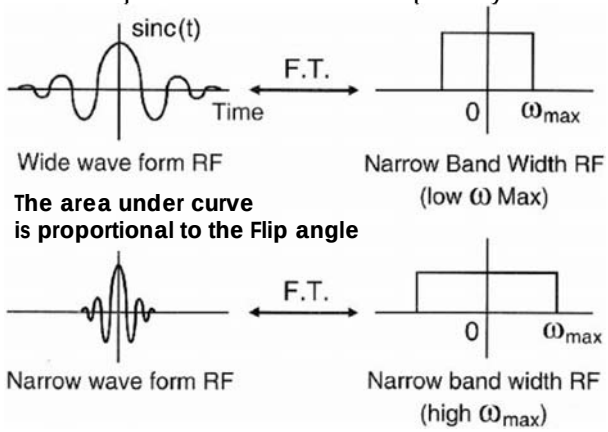
- Time domain ⇔ Frequency domain

sinc(t)=sin(t)/t



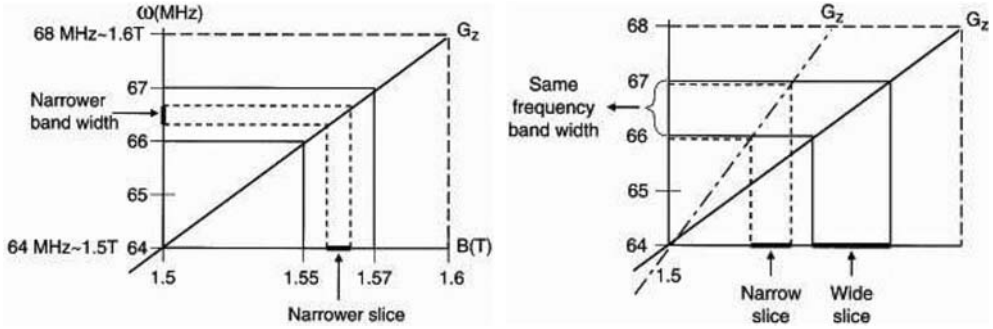
Waveform and Bandwidth

- A narrower RF pulse ➔ a wider frequency bandwidth



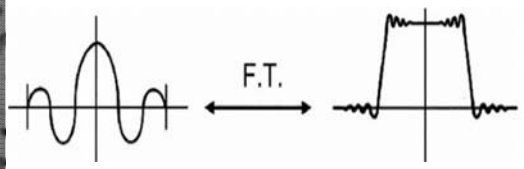
Slice Thickness

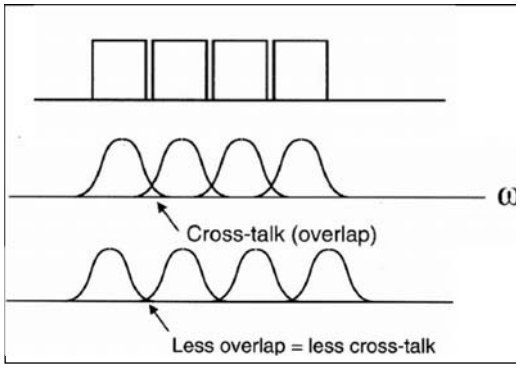
- Two ways to reduce the slice thickness
  - Use a narrow bandwidth
  - Increase the slope of the magnetic field gradient (G_z)



Contiguous Slices Cross Talk

- Ideally, the contiguous slices are right next to each other and the Fourier transform has a rectangular shape.
- In reality, the frequency spectrum of the RF pulse does not have a rectangular shape.





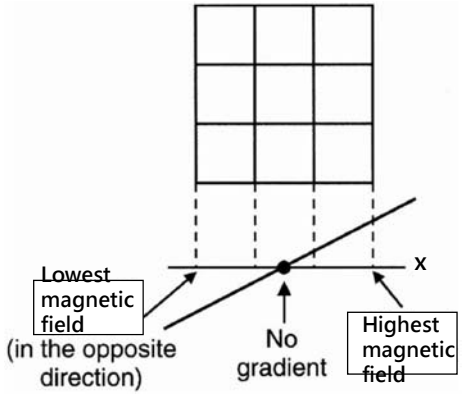
In-plane Spatial Encoding

- The spatial information regarding each slice
  - Frequency encoding
  - Phase encoding

0	$\cos\omega_0 t$	$\cos\omega_0 t$	
$\cos\omega_0 t$	$2\cos\omega_0 t$	0	$\rightarrow 8\cos\omega_0 t$
$2\cos\omega_0 t$	0	$\cos\omega_0 t$	

Frequency Encoding

- The frequency-encoding gradient (G_x) is applied during the time of echo is received, i.e., during readout.



Frequency Encoding

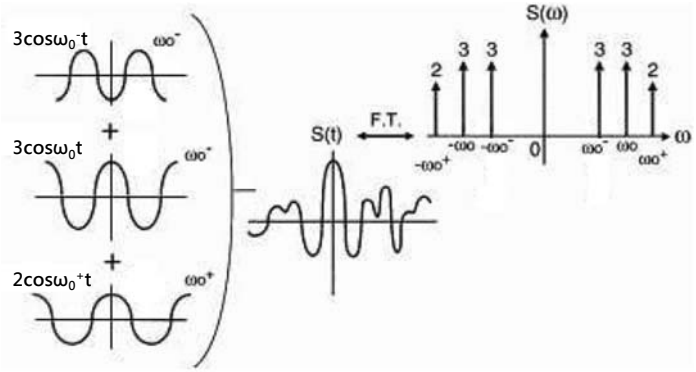
- The center frequency comes from each column differs from each other.

0	$\cos\omega_0 t$	$\cos\omega_0^+ t$
$\cos\omega_0^- t$	$2\cos\omega_0 t$	0
$2\cos\omega_0^- t$	0	$\cos\omega_0^+ t$

$\rightarrow 3\cos\omega_0^- t + 3\cos\omega_0 t + 2\cos\omega_0^+ t$

Frequency Encoding

- We can analyze the magnitude of each frequency component using FT (Fourier transform).



Phase Encoding

- We usually turn on the phase-encoding gradient (G_y) between the 90° and the 180° RF pulses or between the 180° pulse and the echo.

0	$\cos\omega_0 t$	$\cos\omega_0 t$
$\cos\omega_0 t$	$2\cos\omega_0 t$	0
$2\cos\omega_0 t$	0	$\cos\omega_0 t$

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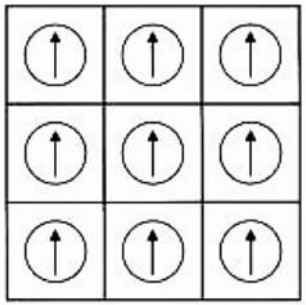
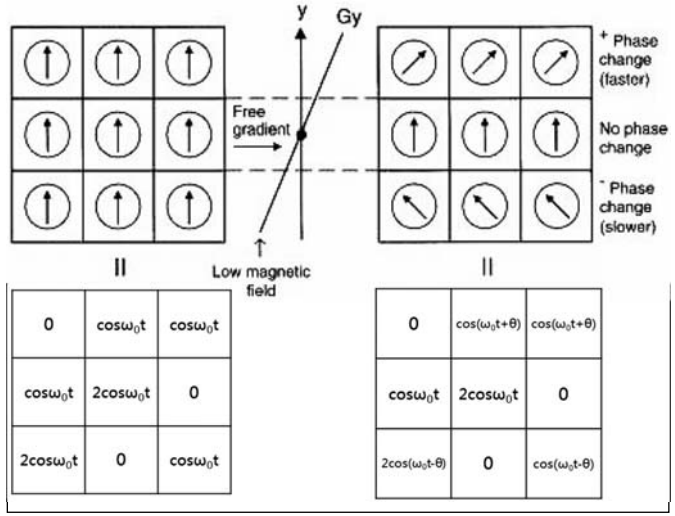
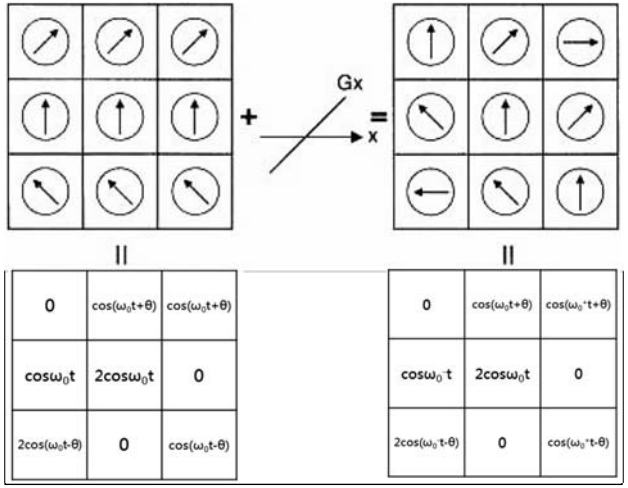


Phase Encoding



Spatial Encoding

- The protons in each pixel have a distinct frequency and a distinct phase, which are unique and encode for the x and y coordinates for that pixel.



THE END

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