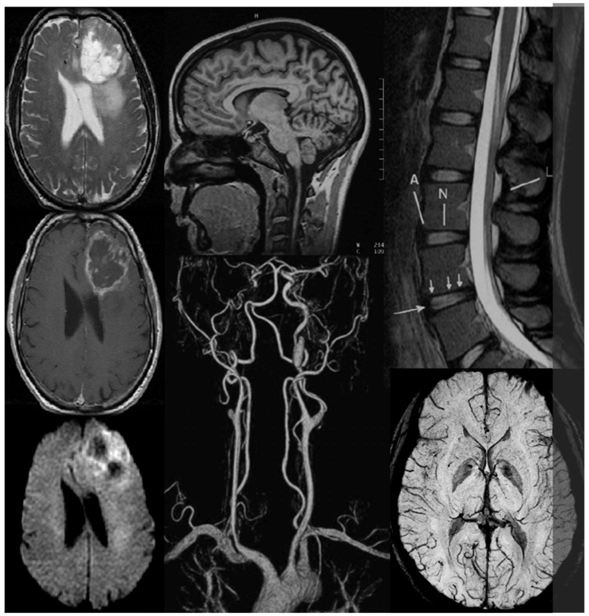

磁振影像學MRI
Echo Planar Imaging

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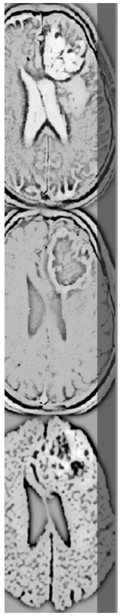
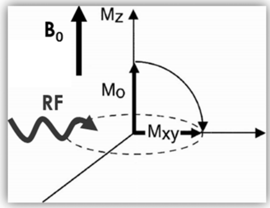
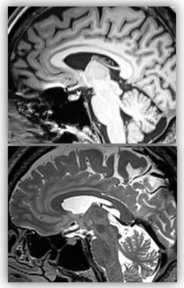
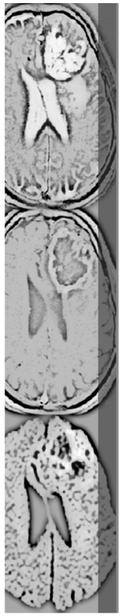


Procedure of MRI



- Alignment (magnetization) B_0
- Precession $\omega_0 = \gamma B_0$
- Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
- MR signal (EMF, relaxation time)
- Imaging (Pulse sequencing: SE, GRE, EPI)
  - Tissue Contrast: Image weighting
  - Spatial localization: Slice selection & Spatial Encoding
  - Data space/K space

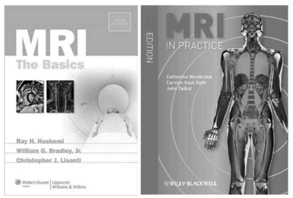




本週課程內容 http://cflu.lab.nycu.edu.tw

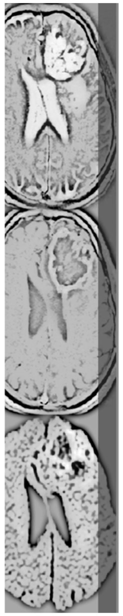
- 回音平面造影

- MRI The Basics (3rd edition)
  - Chapter 22: Echo Planar Imaging
- MRI in Practice, (4th edition)
  - Chapter 5: Pulse sequences



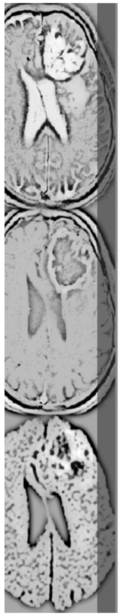
回音平面造影

Echo Planar Imaging



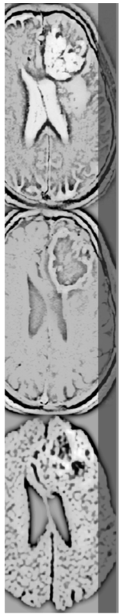
Echo Planar Imaging, EPI

- **EPI**: the fastest MRI technique
  - Complete k-space filling in a TR (during one T2* or T2 decay)
- Applications
  - Rapid acquisition for functional imaging
  - Diffusion tensor imaging, perfusion imaging, functional MRI



Hardware requirements in EPI

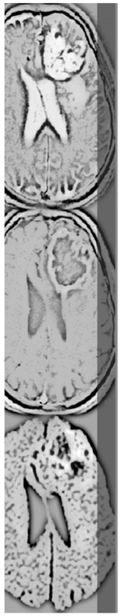
- High performance gradients
  - Rapid on/off switching of the gradients
  - Gradient strength of 20~100 mT/m
  - Gradient rise time of less than 300 μsec
  - ➔ High slew rate (G_{max}/t_R)
- Fast computers
  - Fast digital manipulations and signal processing
- Fast-sampling ADC
  - $\frac{T_s}{Nx} = \frac{1}{BW}$, T_s ↓ → BW ↑ (in MHz) → SNR ↓



Types of EPI

- Single-shot EPI
  - Complete all lines in k-space after a single RF excitation (shot).
- multi-shot EPI

- Constant phase encoding
- blipped phase encoding



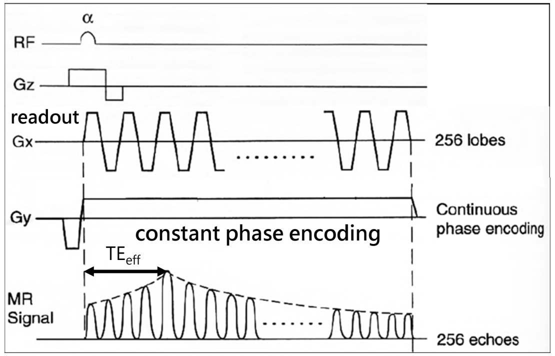
Single-shot EPI

- All the lines in k-space are filled by multiple gradient reversals, producing multiple gradient echoes in a single acquisition.

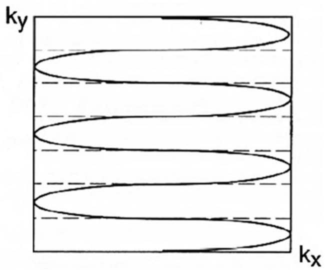
- Readout (frequency-encoding) gradient
  - reversed rapidly from maximum positive to negative Ny/2 times

Single-shot EPI

- Each lobe of the readout gradient above or below the baseline corresponds to a separate k_y line in k-space.

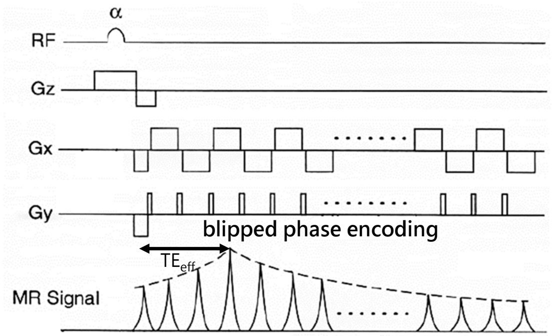


A zigzag coverage of k-space
(demands image interpolation)

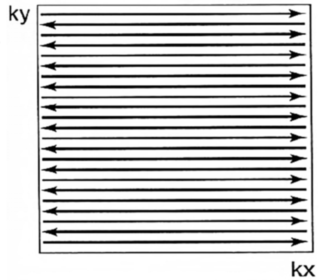


Single-shot EPI

- The phase-encode gradient is subsequently applied briefly during the time when the readout gradient was zero (200 μsec).

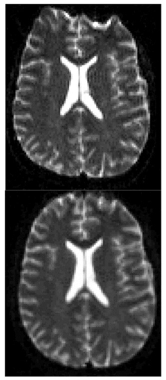


An odd-even coverage of k-space



Single-shot EPI

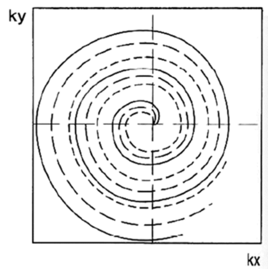
- Any phase error tends to propagate through the entire k-space.
- one of the technical problems of single-shot EPI is magnetic susceptibility artifacts, particularly at air/tissue interfaces around the paranasal sinuses.
- chemical shift artifact in EPI is along the phase-encode axis.



www.humanconnectome.org

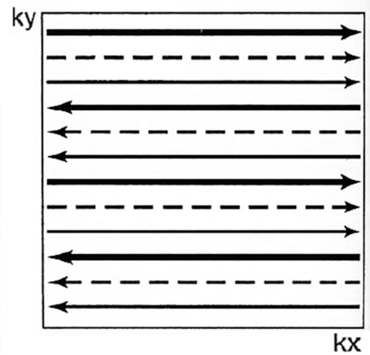
Multi-shot EPI

- Also called segmental EPI
- The readout is divided into multiple shots or segment (N_s)
  - $N_y = N_s \times ETL$



A spiral coverage (using oscillating G_x and G_y)

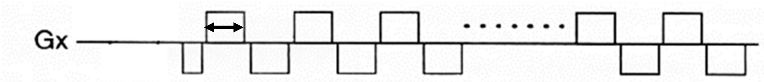
An interleaved coverage of k-space



Scan Time in EPI

- Scan time
  - T(single-shot EPI) = ESP x N_y x NEX
  - T(multi-shot EPI) = TR x N_s x NEX
    = TR x N_y/ETL x NEX

ESP: echo sampling period



Multi-shot vs. single-shot EPI

- Advantages
  - Less stress on the gradients (fewer duty cycles → better cooling)
  - Less time to build up phase errors→ reducing susceptibility artifacts
- Disadvantages
  - Longer scan time
  - More susceptible to motion artifacts

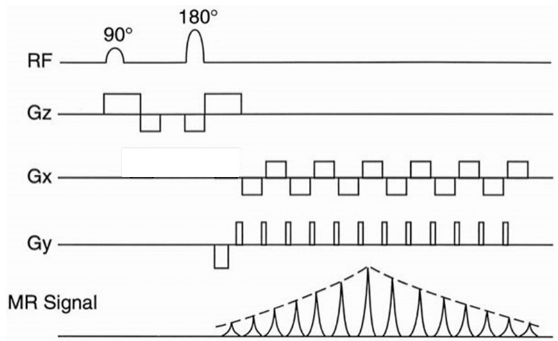
Contrast in EPI

- Contrast in EPI depends on the "**root**" pulsing sequence

- SE-EPI (90^o-180^o-EPI)
- GRE-EPI (α^o-EPI)
- IR-EPI (180^o-90^o-180^o-EPI)
  - inversion-recovery (IR)

SE-EPI (90^o-180^o-EPI)

- Eliminate ΔB_{ext}
- T1 and T2 weighting

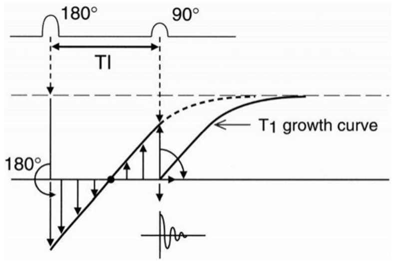


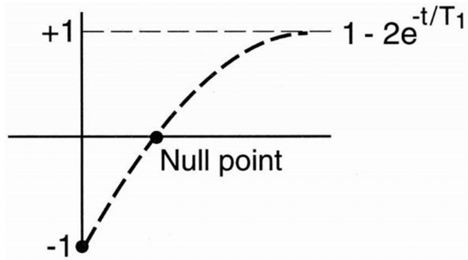
GRE-EPI (α°-EPI)

- T2* weighting (lack of 180° pulse)
- Faster imaging speed
- Dynamic imaging
  - Perfusion imaging
  - cardiac cine imaging

IR-EPI (180°-90°-180°-EPI)

- Heavy T1 weighting
- Suppression of tissue signal

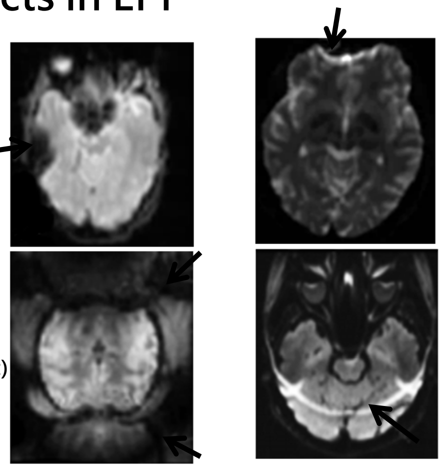




Artifacts in EPI

Signal Dropout

Distortion

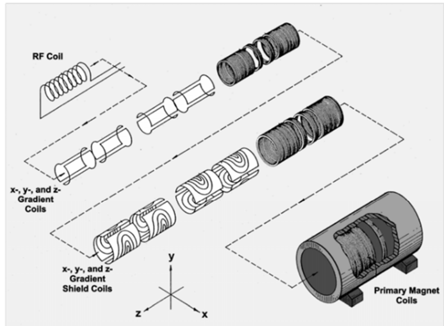


Ghosting
(eddy current artifact)

Chemical shift

Actively Shielded Gradients

- **An additional set of nested coils placed between gradient coils and magnet.**
- **Opposing currents driven through shield coils minimize stray gradient fields.**



Design using actively shielded gradients. The gradient shields are slightly larger in diameter than the primary gradient coils and generate a counter magnetic field to reduce eddy currents induced in the magnet structure.

https://mriquestions.com/active-shielded-gradients.html

Advantages of EPI

- Scan time is approximately 100 msec or less (32~50 msec).
- Cardiac and respiratory motion won't pose problems.
- PD, T1, and T2 weighted images free of motion artifacts can be achieved.
- It allows the functional studies rather than the mere depiction of anatomy.
- Resolution can be improved due to fast scanning speed.

Disadvantages of EPI

- Fat suppression with presaturation techniques is always required (to cancel fat-water chemical shift artifacts).
- Rapid on/off switching of the gradients ➔ possible "electric shock" in the subject
- Potential for phase error (less effect for multi-shot EPI)
- Intrinsic non-uniformities in B0 and susceptibility effects (less effect for multi-shot EPI)

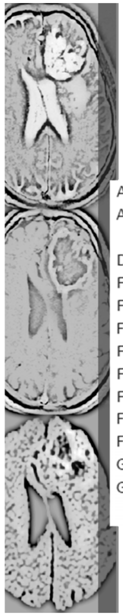
Comparisons

Table 5.3 Single and multi-shot methods.

	Sequence	Readout	Time
FSE	90/180	multiple SE	min/sec
GRASE	90/180	GE	min/sec
SE-EPI	90/180	GE	sec/sub sec
GE-EPI	variable flip	GE	sec/sub sec
IR-EPI	180/90/180	GE	sec/sub sec

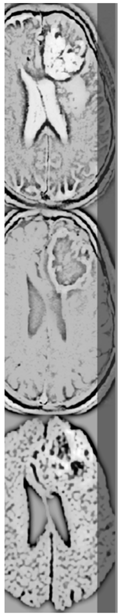
Sequence list

	GE	Philips	Siemens
Spin echo	SE	SE	SE
Fast spin echo	FSE	TSE	TSE
Inversion recovery	IR	IR	IR
Short tau inversion recovery	STIR	STIR	STIR
Fluid attenuated inversion recovery	FLAIR	FLAIR	FLAIR
Coherent gradient echo	GRASS	FFE	FISP
Incoherent gradient echo	SPGR	T1FFE	FLASH
Balanced gradient echo	FIESTA	BFFE	True FISP
Steady state free precession	SSFP	T2 FFE	PSIF
Fast gradient echo	Fast GRASS/SPGR	TFE	Turbo FLASH
Echo planar	EPI	EPI	EPI
Parallel imaging	ASSET	SENSE	iPAT
Spatial pre-saturation	SAT	REST	SAT
Gradient moment rephasing	Flow comp	Flow comp	GMR
Signal averaging	NEX	NSA	AC
Anti-aliasing	No phase wrap	Foldover suppression	Oversampling
Rectangular FOV	Rect FOV	Rect FOV	Half Fourier imaging
Respiratory compensation	Resp comp	PEAR	Resp trigger
Driven equilibrium	FR-FSE	DRIVE	RESTORE



Sequence Abbreviations

AC	number of acquisitions	iPAT	integrated parallel acquisition technique
ASSET	array spatial and sensitivity encoding technique	MP RAGE	magnetization prepared rapid gradient echo
DRIVE	driven equilibrium	NEX	number of excitations
FFE	fast field echo	NSA	number of signal averages
FIESTA	free induction echo stimulated acquisition	PEAR	phase encoding artefact reduction
FISP	free induction steady precession	PSIF	mirrored FISP
FLAIR	fluid attenuated inversion recovery	REST	regional saturation technique
FLASH	fast low angled shot	RESTORE	restore turbo spin echo
Flow comp	flow compensation	SENSE	sensitivity encoding
FR-FSE	fast recovery fast spin echo	SPGR	spoiled GRASS
FSE	fast spin echo	SSFP	steady state free precession
GMR	gradient moment rephasing	STIR	short tau inversion recovery
GRASS	gradient recalled acquisition in the steady state	TFE	turbo field echo
		TSE	turbo spin echo
		Turbo FLASH	magnetization prepared sub second imaging



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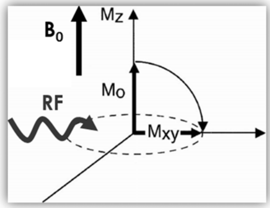

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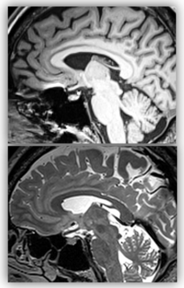

THE END

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