Basic and advanced principles of Diffusion Weighted Images (DWI) - 1

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Date : 106.07.22

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Outline

- **Basic and advanced principles of Diffusion Weighted Images (DWI) - 1**
  1. Echo Planar Imaging **(EPI)**
  2. Diffusion weighted imaging **(DWI)**
- **Basic and advanced principles of Diffusion Weighted Images (DWI) – 2**
  1. Diffusion-weighted whole-body imaging with background body signal suppression **(DWIBS)**
  2. Intravoxel Incoherent Motion **(IVIM)**
- **Dynamic Contrast enhanced MRA**
- **Preliminary conclusions and discussion**

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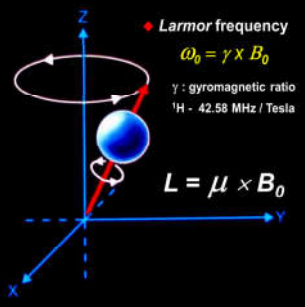
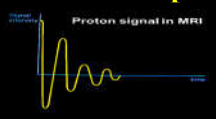
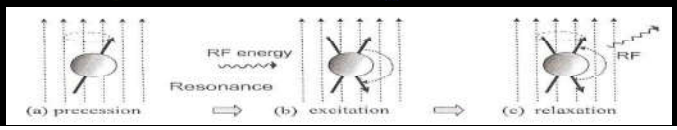
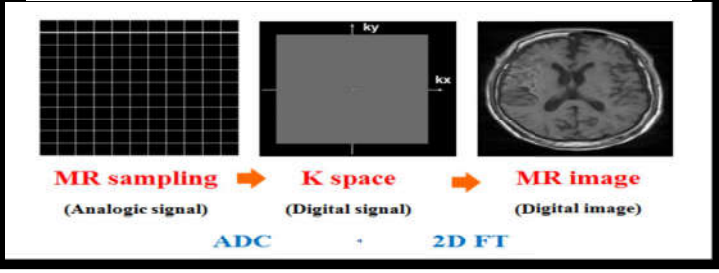
MRI
(magnetic resonance imaging)



What Happens After B_1 ?







Echo Planar Imaging
（回音平面造影）

1. EPI: the fastest MRI technique

- Complete k-space filling in a TR (during one T2* or T2 decay)

2. Applications

- Rapid acquisition for functional imaging
- Diffusion weighted imaging , Diffusion tensor imaging, perfusion imaging, functional MRI

Hardware requirements in EPI

1. High performance gradients

- Rapid on/off switching of the gradients
- Gradient strength of 20~100 mT/m
- Gradient rise time of less than 300μsec

>>>High slew rate (G-max/tR)

2. Fast computers

- Fast digital manipulations and signal processing

3. Fast computers

- Fast-sampling ADC $\frac{T_s}{Nx} = \frac{1}{BW}$, $T_s \downarrow \rightarrow BW \uparrow$ (in MHz) $\rightarrow$ SNR $\downarrow$

Types of EPI

1. Single-shot EPI

- Complete all lines in k-space after a single RF excitation (shot)

2. Multi-shot EPI

3. Constant vs. blipped phase encoding

Single-shot EPI

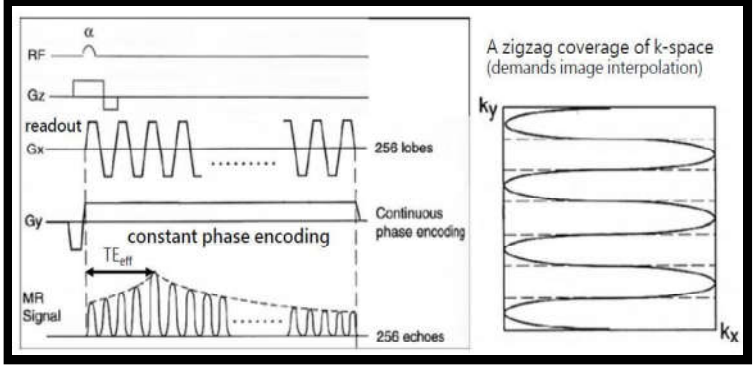
1. All the lines in k-space are filled by multiple gradient reversals, producing multiple gradient echoes in a single acquisition.

2. Readout (frequency-encoding) gradient

- reversed rapidly from maximum positive to negative Ny/2 times

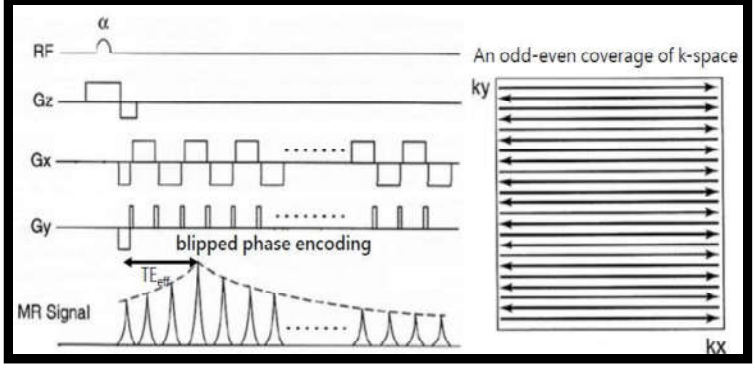
Single-shot EPI

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



Single-shot EPI

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

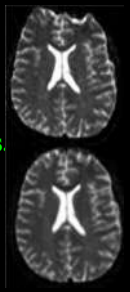


Single-shot EPI

1. Any phase error tends to propagate through the entire k-space.

2. one of the technical problems of single-shot EPI is magnetic susceptibility artifacts, particularly at air/tissue interfaces around the paranasal sinuses.

3. Chemical shift artifact in EPI is along the phaseencode axis.

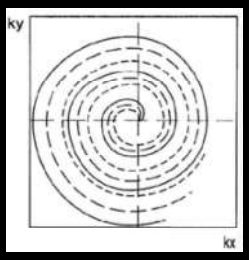


Multi-shot EPI

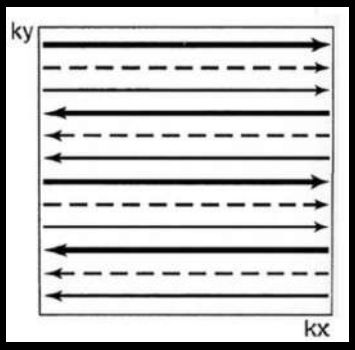
1. Also called segmental EPI

2. The readout is divided into multiple shots or segment (Ns)

A spiral coverage (using oscillating Gx and Gy)



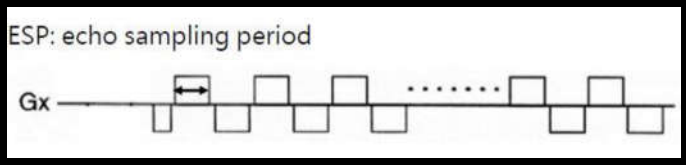
An interleaved coverage of k-space



Scan Time in EPI

1. Scan time

- T(single-shot EPI) = ESP x Ny x NEX
- T(multi-shot EPI) = TR x Ns x NEX
  = TR x (Ny/ETL) x NEX



Multi-shot vs. single-shot EPI

1. Advantages

- Less stress on the gradients (fewer duty cycles >>> better cooling)
- Less time to build up phase errors reducing susceptibility artifacts

2. Disadvantages

- Longer scan time
- More susceptible to motion artifacts

Contrast in EPI

1. Contrast in EPI depends on the "root" pulsing sequence

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

SE-EPI (90-180-EPI)

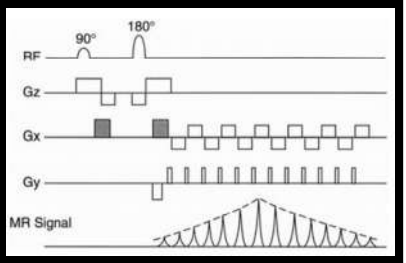
1. Eliminate Δbext

2. T1 and T2 weighting

3. Diffusion-weighted imaging

- Bipolar diffusion gradient

For a "fixed-position" proton, this pair of gradients won't cause dephasing.



GRE-EPI (α-EPI)

1. T2* weighting (lack of 180o pulse)

2. Faster imaging speed

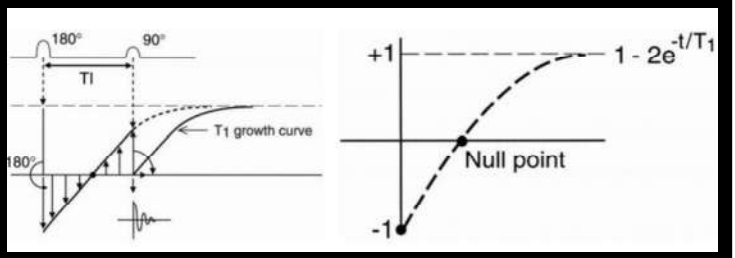
- Rapid acquisition for fu

3. Dynamic imaging

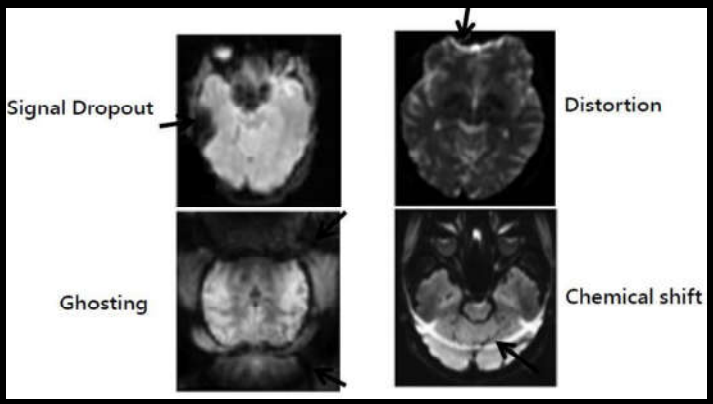
- Perfusion imaging
- cardiac cine imaging

IR-EPI (180-90-180-EPI)

1. Heavy T1 weighting
2. Suppression of tissue signal



Artifacts in EPI



Advantages of EPI

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

Disadvantages of EPI

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

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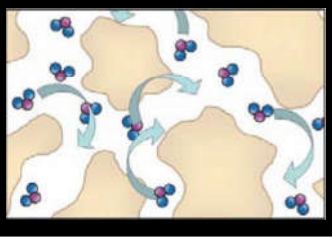
Principles of Diffusion Weighted Imaging

1. Particle theory & Brownian Motion
   - The particles are always moving.
   - The speed of movement depends on the temperature.
   - The speed of movement is inversely proportional to the mass of the particle.
2. Diffusion
   - Particles move randomly and spread out to fill the space around them until evenly spread.

MR Diffusion

1. MR Diffusion is a term used to describe the movement of molecules in the extra-cellular space due to random thermal motion.

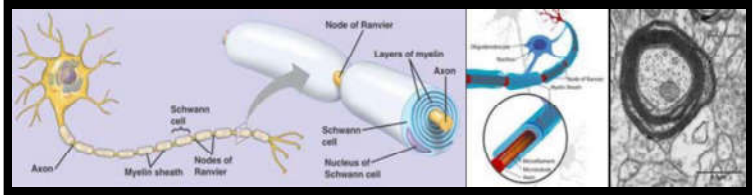
2. This motion can be restricted by boundaries such as ligaments, membranes, myelin, and macromolecules.



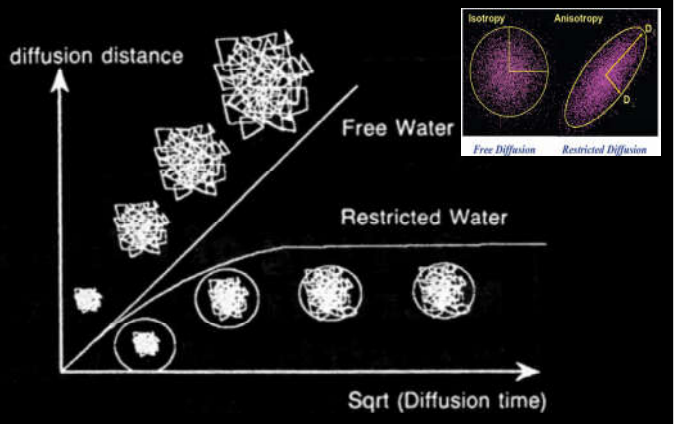
Myelin Sheath on Axon

1. Myelin is a fatty white substance that surrounds the axon of some nerve cells, forming an electrically insulating layer.

2. It is essential for the proper functioning of the nervous system.



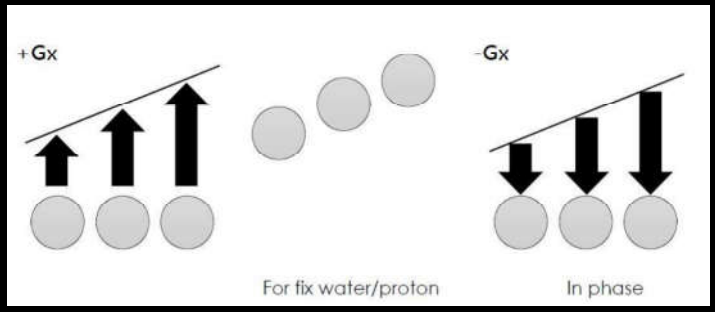
Principles of Diffusion Weighted Imaging



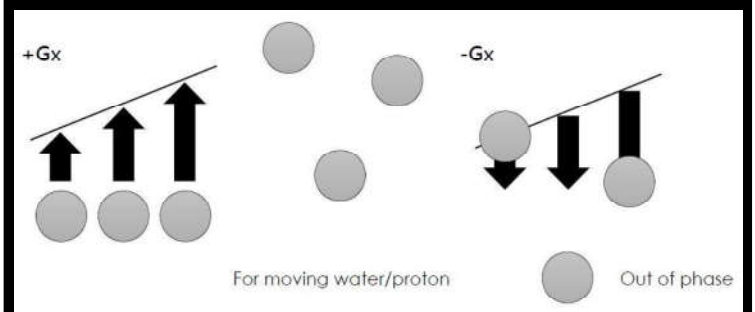
Diffusion Weighting

1. Diffusion can be another type of weighting/contrast.
   - As TR/flip angle controls T1 contrast
   - TE controls T2/T2* contrast
2. A diffusion factor, b, controls diffusion contrast.
   - Generally, a larger b value results in a greater diffusion contrast.

Diffusion gradient, an example

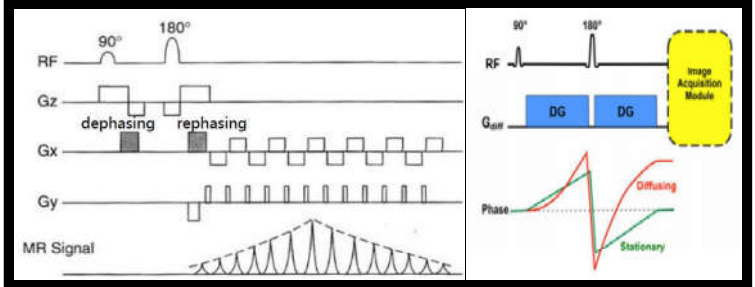


Diffusion gradient, an example



Diffusion Gradients

1. Apply a pair of diffusion gradients before and after the 180o RF pulse (SE-EPI)



Diffusion weighted imaging, DWI

1. Diffusion is defined as the process of random molecular thermal motion (Brownian motion)

- High (free) diffusion along gradients >>> low signal
- Low (restricted) diffusion along gradients >>> high signal

2. DWI aims at highlighting the differences in water molecule mobility, irrespective of their direction of displacement.

- Applying diffusion gradients in at least 3 spatial directions
- Diffusion magnitude (trace image)
- T2-weighted image

Hardware requirements in EPI

1. High performance gradients

- Rapid on/off switching of the gradients
- Gradient strength of 20~100 mT/m
- Gradient rise time of less than 300μsec

>>>High slew rate (G-max/tR)

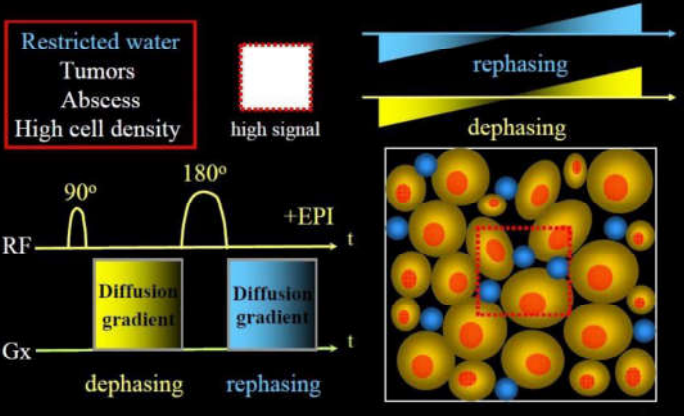
2. Fast computers

- Fast digital manipulations and signal processing

3. Fast computers

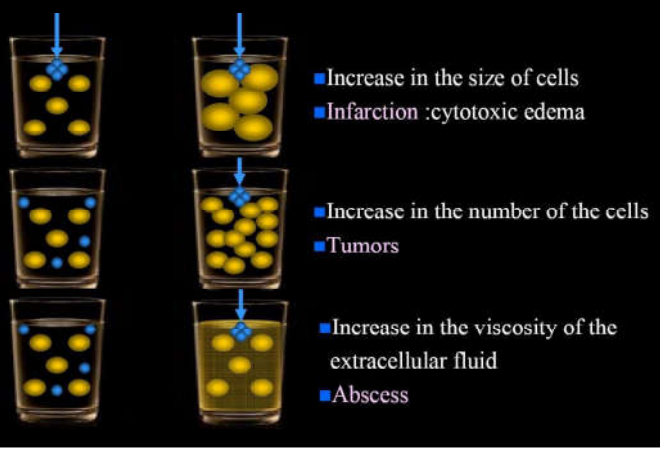
- Fast-sampling ADC $\frac{T_s}{Nx} = \frac{1}{BW}$, $T_s \downarrow \rightarrow BW \uparrow$ (in MHz) $\rightarrow SNR \downarrow$

Diffusion gradient and motion



Diffusion gradient and motion

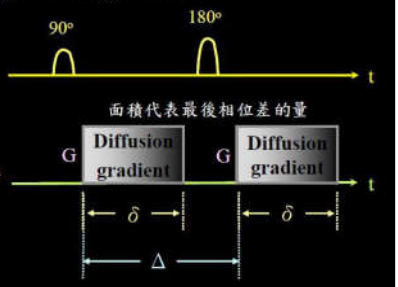
Diffusion weighted imaging, DWI



Diffusion weighted imaging, DWI
Diffusion factor = b factor

- Diffusion signal loss by the gradient application

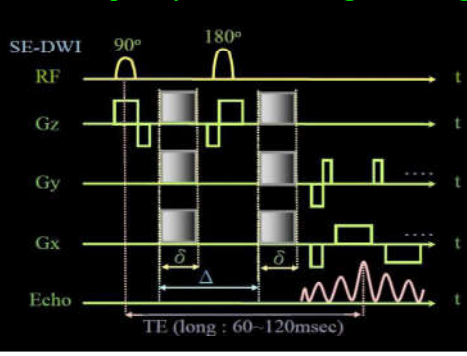
$$\frac{S}{S_0} = e^{-\gamma^2 G^2 \delta^2 (\Delta - \delta/3) D} = e^{-b D}$$



S =signal with the gradient application
S_0 =signal no gradient application
D =diffusion constant
γ =gryomagnetic ratio
G =gradient strength
δ =gradient duration
Δ =time interval between dephasing and rephasing gradients

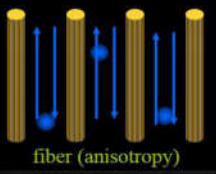
Diffusion weighted imaging, DWI

1. Apply diffusion gradients along each orthogonal axis simultaneously.
2. Isotropically diffusion-weighted images



Applications of Diffusion Weighted Imaging
Apparent Diffusion Coefficient, ADC

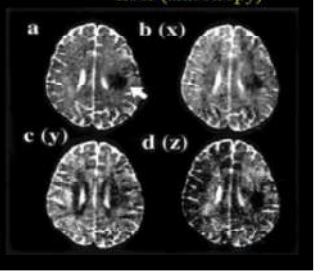
- Restricted diffusion & anisotropy
- 擴散在同一點內隨方向而不同
- DWI:梯度三個方向都開，各別取得Dx、Dy、Dz
- ADC is isotropic map (無關方向性)
- ADC ↓ for acute stroke infarction.


fiber (anisotropy)

$$ADC = \frac{Dx+Dy+Dz}{3}$$

$$\frac{S}{S_0} = e^{-b D}$$

S =signal with the gradient application
S_0 =signal no gradient application
D =diffusion constant b =diffusion weighting

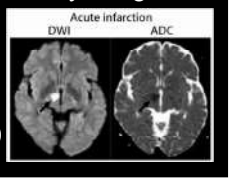


DWI/ADC of stroke

1. Acute (0~7 days)
- ADC ↓ (hypo-intensity), maximal signal reduction at 1~4 days
- DWI ↑ (hyper-intensity)
- Ischemia >> cytotoxia edema(intact BBB) >> restricted extracelluar space

2. Subacute (1~3 weeks)
- ADC return to near baseline (~2 weeks)
- DWI ↑ (hyper-intensity), due to high T2 signal caused by vasogenic edema (disrupted BBB)
- Irreversible tissue necrosis

3. Chronic (>3 weeks)
- ADC ↑ (hyper-intensity), DWI ↓ (hypo-intensity)



T2 shine through effect

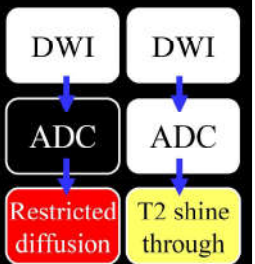
- *TR* value DWI sequences is long (8-10 sec) , so $(1-e^{-TR/T1})$ term may be disregarded.
- DW images both T2 and diffusion weighted (long TE: 60~120msec)
- Long T2 lesions can increase DWI signal mimicking restricted diffusion
- Clarified by reviewing ADC images

$$S_{DWI} = k[H] \cdot (1-e^{-TR/T1}) \cdot e^{-TE/T2} \cdot e^{-b \cdot ADC}$$

- K: is a scaling constant,
- *TR*, *TE*, and *b* are operator-selected parameters
- [*H*] is spin density
- ADC is the apparent diffusion coefficient (顯示純擴散訊息)

T2 shine through effect

1. DWI ↑ may imply ADC↓ or T2 ↑
   If ADC is ↑ rather than ↓ ,
   It indicates that T2↑ effect is larger then ADC effect >>> T2 shine-through



擴散加權造影應用
Application of Diffusion Weighted Imaging (DWI)

- Ischemic stroke
- 偵測體內腫瘤
- 區別腫瘤的特性，以區別可能的病理型態
- 區別器官內腫瘤以及非腫瘤的區域
- 全身性擴散權重影像

Thank you for your attention