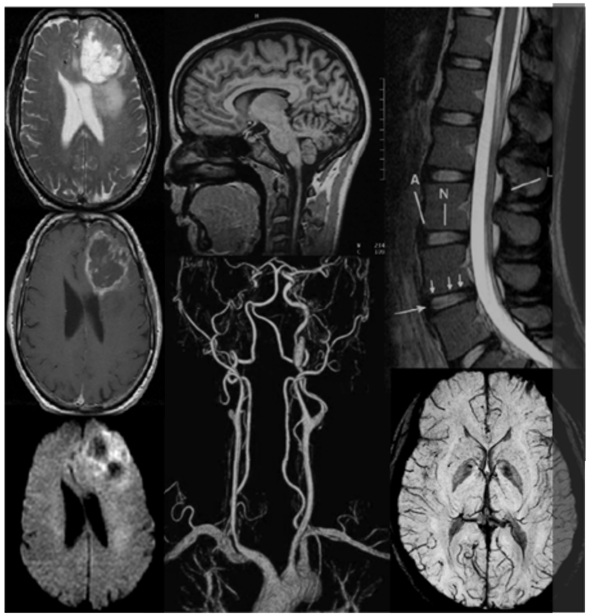

Magnetic Resonance in Medicine
Diffusion Weighted Imaging

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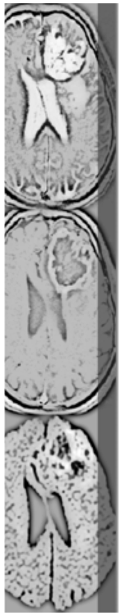
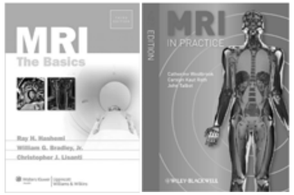


Content http://cflu.lab.nycu.edu.tw/

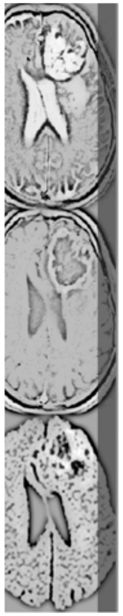
- **Principles of Diffusion Weighted Imaging (擴散權重造影)**
- **Applications of Diffusion Weighted Imaging**

- **MRI The Basics (3rd edition)**
  - Chapter 22: Echo Planar Imaging
- **MRI in Practice, (4th edition)**
  - Chapter 12: Functional Imaging Techniques



Principles of Diffusion Weighted Imaging

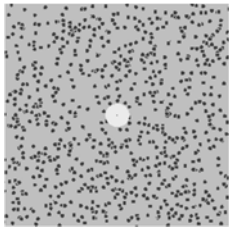
擴散權重影像原理



What is Diffusion?

- 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.
- Diffusion
  - Particles move randomly and spread out to fill the space around them until evenly spread.

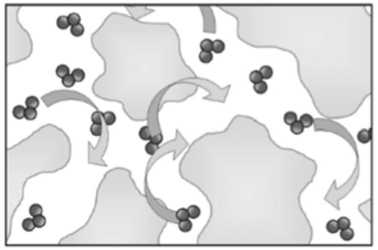
Robert Brown, 1827.
(pollen random motion)



https://www.youtube.com/watch?v=UC0bKzgQU9g
https://en.wikipedia.org/wiki/Brownian_motion

MR Diffusion

- MR Diffusion is a term used to describe the movement of molecules in the extra-cellular space due to random thermal motion.
- This motion can be restricted by boundaries such as ligaments, membranes, myelin, and macromolecules.

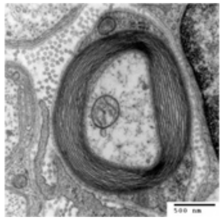


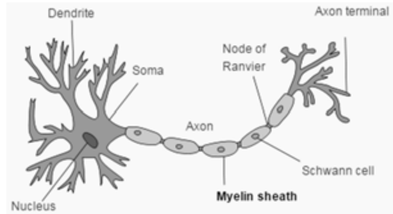
Myelin Sheath on Axon

- Myelin is a fatty white substance that surrounds the axon of some nerve cells, forming an electrically insulating layer.
- It is essential for the proper functioning of the nervous system.

https://en.wikipedia.org/wiki/Myelin

Transmission electron microscopy (TEM)



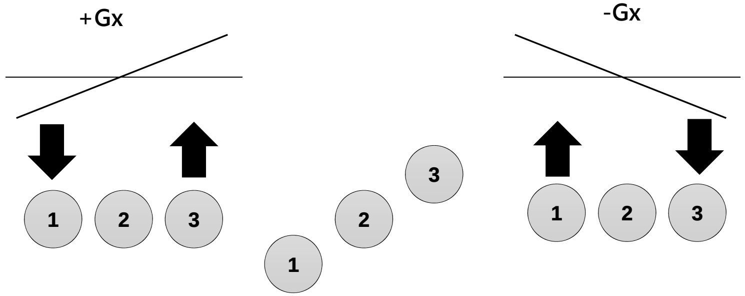


Diffusion Weighting

- Diffusion can be another type of weighting/contrast.
- As TR/flip angle controls T1 contrast;

  TE controls T2/T2* contrast.
- A diffusion factor, ***b***, controls diffusion contrast.
  - Generally, a larger b value results in a greater diffusion contrast.

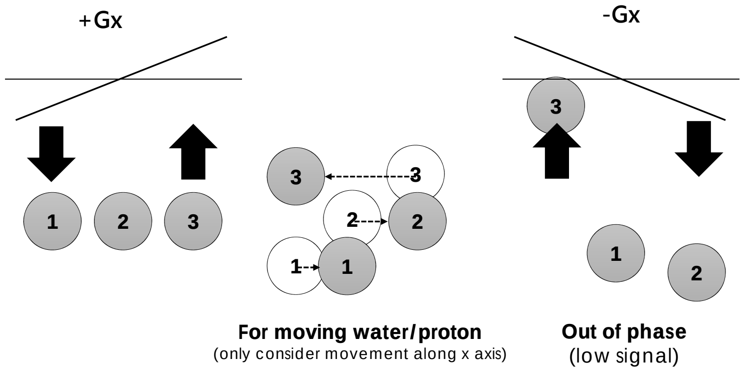
Diffusion gradient, an example



For fix water/proton

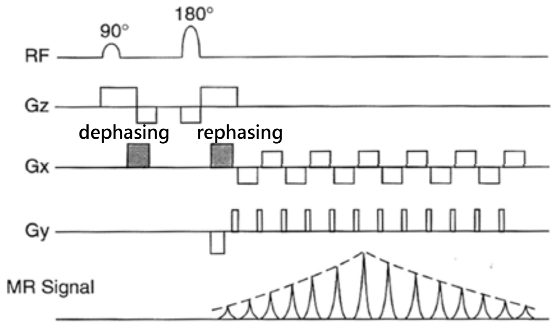
In phase
(high signal)

Diffusion gradient, an example

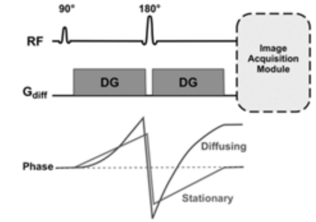


Diffusion Gradients

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



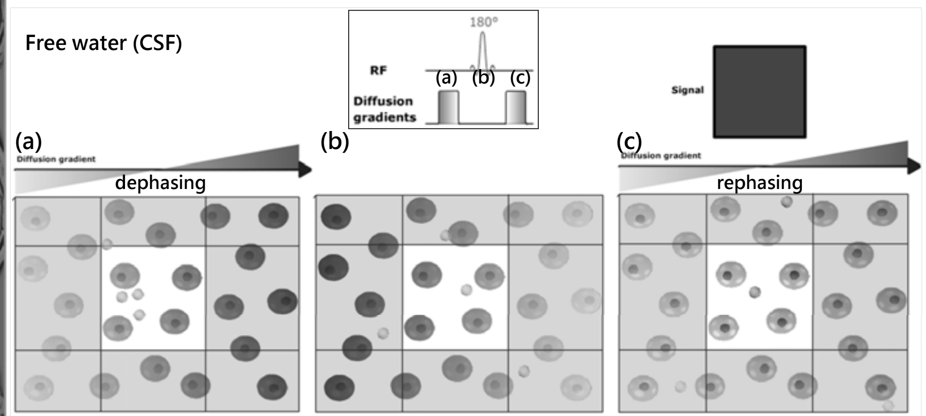
For a "fixed-position" proton, this pair of gradients won't cause dephasing.



Diffusion weighted imaging, DWI

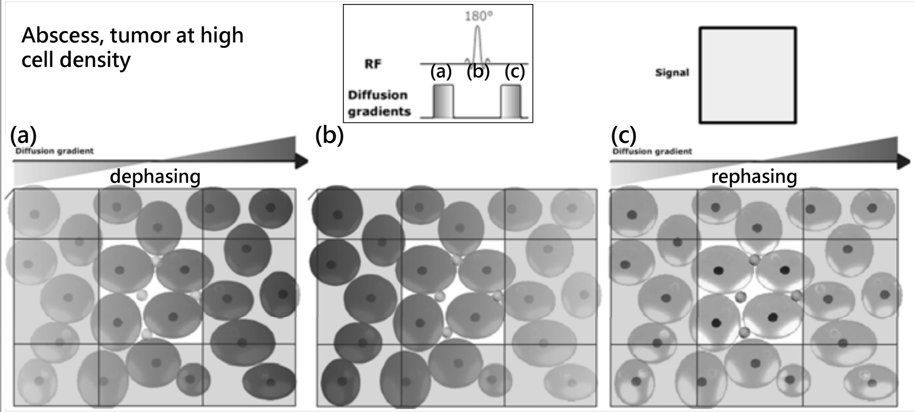
- Diffusion is defined as the process of random molecular thermal motion (Brownian motion)
  - High (free) diffusion along gradients → low signal
  - Low (restricted) diffusion along gradients → high signal
- DWI aims at highlighting the differences in water molecule mobility, irrespective of their direction of displacement.
  - Applying diffusion gradients in at least 3 spatial directions
  - Diffusion magnitude (trace image)
  - T2-weighted image

Diffusion gradient and motion



IMAIO 2014, http://www.imaios.com/en/e-Courses/e-MRI/Diffusion-Tensor-Imaging/diffusion-principles

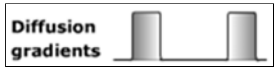
Diffusion gradient and motion



IMAIO 2014, http://www.imaios.com/en/e-Courses/e-MRI/Diffusion-Tensor-Imaging/diffusion-principles

Diffusion weighted imaging, DWI

- Diffusional signal loss by the gradient application
  - $\frac{S}{S_0} = e^{-\gamma^2 G^2 \delta^2 \left(\Delta - \frac{\delta}{3}\right) D} = e^{-bD}$



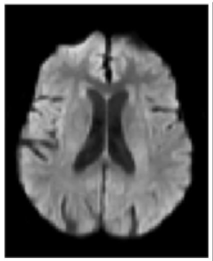
  - S_0 is the signal intensity without the diffusion weighting (no gradient application)
  - S is the signal with the gradient application
  - D is a diffusion constant
  - γ is the gyromagnetic ratio
  - G is the gradient strength
  - δ is the gradient duration
  - Δ is the time interval between dephasing and rephasing gradients

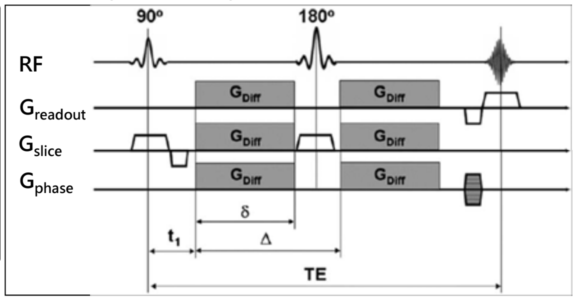
Unit
D: mm²/s
b: s/mm²

Diffusion weighted imaging, DWI

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

SE DWI





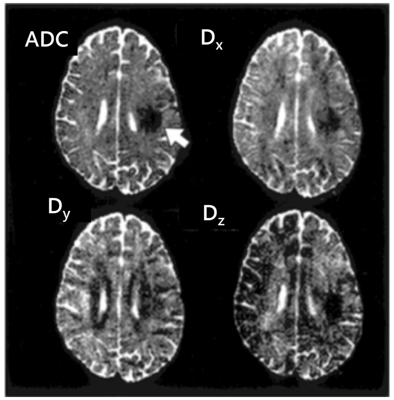
R. Bammer, EJR 45:169-184, 2003

Applications of Diffusion Weighted Imaging

擴散權重影像應用

Apparent Diffusion Coefficient, ADC

- Apply diffusion gradients along each orthogonal axis to obtain D_x, D_y, and D_z, respectively.
- $ADC = \frac{D_x + D_y + D_z}{3}$
- ADC is an isotropic (directional independent) map.
- ADC ↓ for acute stroke infarction

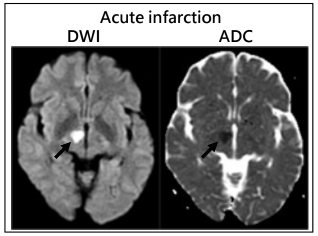


Mori et al. Anat Record 257:102-109, 1999.

DWI/ADC of stroke

Acute stroke
Sensitivity: 88~100%
Specificity: 86-100%

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



- http://radiopaedia.org/articles/diffusion-weighted-mri-in-acute-stroke-1
- http://www2.cmu.edu.tw/~cmcmd/ctanatomy/clinical/ischemicinfarction.html

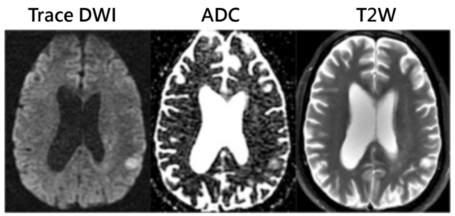
T2 effect in DWI

- The DWI signal intensity can be written as

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

- The TR used for most DWI sequences is extremely long (8-10 sec), so the ($1 - e^{-TR/T1}$) term may be disregarded.

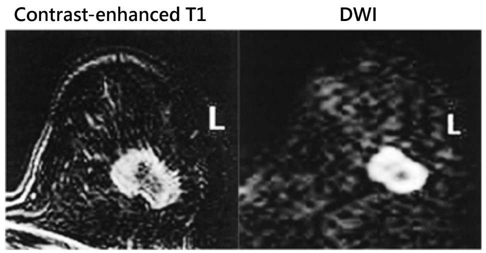
DWI ↑ may imply ADC ↓ or T2 ↑
If ADC is ↑ rather than ↓,
It indicates that T2 ↑ effect is larger then ADC effect → **T2 shine-through**



http://mri-q.com/t2-shine-through.html

Tumor imaging

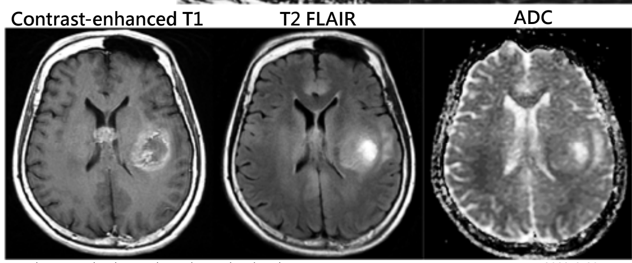
Invasive ductal carcinoma



b=600~700

Kuroki, 2004.

Glioblastoma



b=900~1000

THE END

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