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.
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.

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 fixed water/proton:
  - $+G_x$
  - $-G_x$
- In phase
Diffusion gradient, an example

-\( G_x \)  
  \[ \uparrow \quad \downarrow \]
  For moving water/proton  
  Out of phase

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  \( \rightarrow \) low signal
  - Low (restricted) diffusion along gradients  \( \rightarrow \) 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 weighted imaging, DWI

- Diffusional signal loss by the gradient application
  \[ \frac{S}{S_0} = e^{-\gamma^2 G^2 \delta^2 \Delta} = e^{-bD} \]
  - $S_0$ is the signal intensity without the diffusion weighting (no gradient application)
  - $S$ is the signal with the gradient application
  - $D$ is a diffusion constant
  - $\gamma$ is the gyromagnetic ratio
  - $G$ is the gradient strength
  - $\delta$ is the gradient duration
  - $\Delta$ is the time interval between dephasing and rephasing gradients

Unit
- $D$: mm$^2$/s
- $b$: s/mm$^2$

Applications of Diffusion Weighted Imaging

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


DWI/ADC of stroke

- Acute (0~7 days)
  - ADC ↓ (hypo-intensity), maximal signal reduction at 1~4 days
  - DWI ↑ (hyper-intensity)
  - Ischemia → cytotoxic edema (intact BBB) → restricted extracellular 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)

T2 effect in DWI

- The DWI signal intensity can be written as
  $$S_{DWI} = k[H] \cdot (1 - e^{-\frac{TR}{T1}}) \cdot e^{-\frac{TR\cdot T2}{T1}} \cdot e^{-BADC}$$
- The TR used for most DWI sequences is extremely long (8-10 sec), so the $(1 - e^{-TR/T1})$ term may be disregarded.

T2 shine-through

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

Tumor imaging

- Contrast-enhanced T1, T2 FLAIR, ADC

THE END

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