MRI for Radiotherapy: MRI Basics

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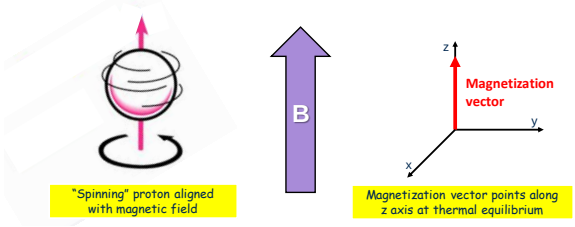
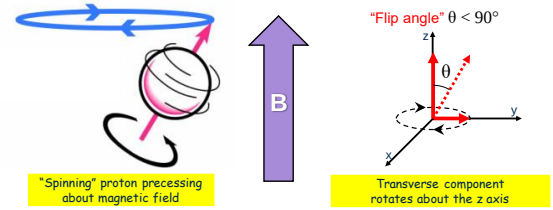
Nuclear Magnetic Resonance

Magnetic resonance images are created using the magnetic resonance (MR) properties of hydrogen nuclei in fat and water.



Nuclear Magnetic Resonance

When the spins are tipped away from the longitudinal (z) direction by a radiofrequency (RF) electromagnetic pulse, they begin to precess about the z axis at the "Larmor" frequency (f = 128 MHz at 3 Tesla).



Nuclear Magnetic Resonance

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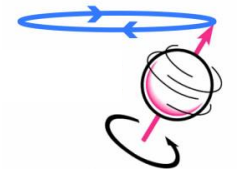
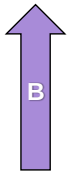
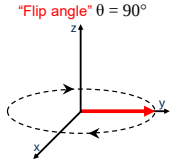


"Spinning" proton precessing about magnetic field



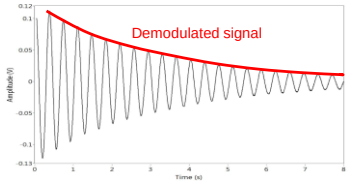
"Flip angle" θ = 90°



Transverse component rotates about the z axis

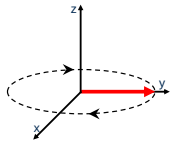
Nuclear Magnetic Resonance

The rotating transverse component of the magnetization induces an oscillating signal in a nearby RF receiver coil.



The signal amplitude is proportional to the transverse magnetization.

"Flip angle" θ = 90°

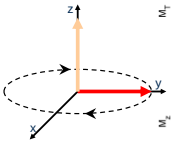


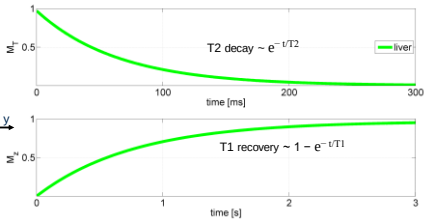
Transverse component rotates about the z axis

T1 and T2 relaxation

An "excitation" RF pulse converts longitudinal magnetization into transverse magnetization, which then decays with time constant T2. The longitudinal magnetization regrows toward thermal equilibrium with time constant T1.

After 90° RF pulse





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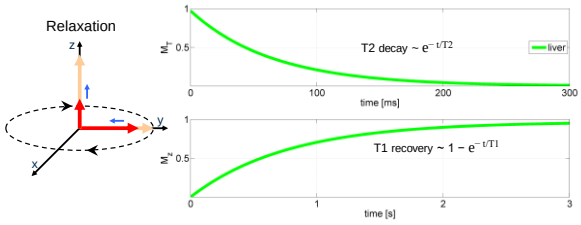
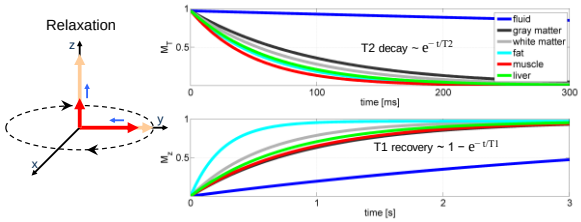


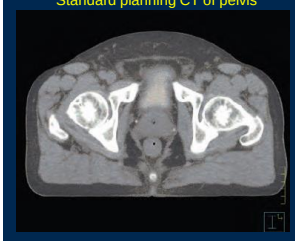
T1 and T2 relaxation

T1 and T2 vary widely across different tissue types, which contributes to the excellent soft tissue contrast offered by MRI.

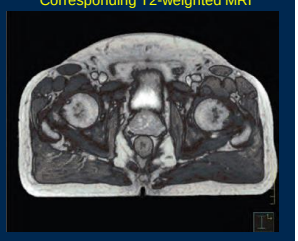


CT vs. MRI

Standard planning CT of pelvis



Corresponding T2-weighted MRI

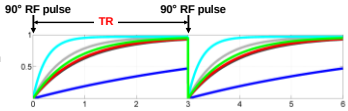


T Koch et al, in MReadings: MR in RT. siemens.com/magnetom-world-rt

Contrast Manipulation: TR and TE

- The repetition time TR is the time between excitation RF pulses.

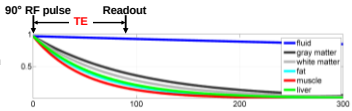
Longitudinal magnetization vs. time [s]



TR controls T1 weighting

- The echo time TE is the time between the excitation RF pulse and signal acquisition.

Transverse magnetization vs. time [ms]

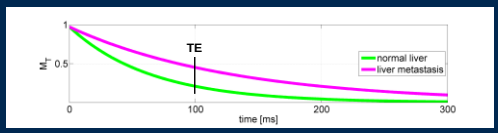


TE controls T2 weighting

T2-weighted MRI

- Use TR >> T1, TE ~ T2
- Signal intensity stratifies according to T2
  - Longer T2 → brighter on image

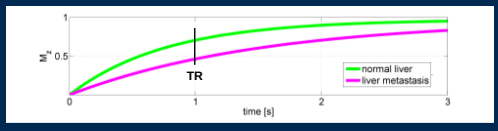
T2 is generally elevated in cancerous tissue



T1-weighted MRI

- Use TR < T1, short TE. Inherently faster than T2-w MRI.
- Signal intensity stratifies according to T1
  - Shorter T2 → brighter on image

T1 is also generally elevated in cancerous tissue



T1 and T2 weighted MRI of Liver

- Liver metastases appear dark on T1 weighted MRI and bright on T2 weighted MRI
- Unrecognizable on CT (in this particular case)

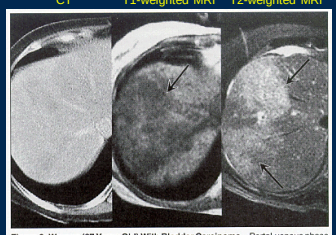
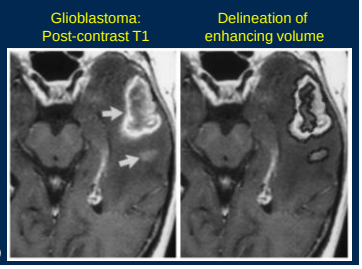


Figure 3: Woman (67 Years Old) With Bladder Carcinoma—Portal-venous phase helical CT (left), T1-weighted MRI (center), and T2-weighted MRI (right). The MRIs depict diffuse metastatic tumor (arrows) replacing much of the liver parenchyma. Hepatic metastases were not prospectively identified on the CT scan.

RN Low, Oncology (Williston Park), 14(6 Suppl 3):5-14; 2000.

Contrast-Enhanced MRI

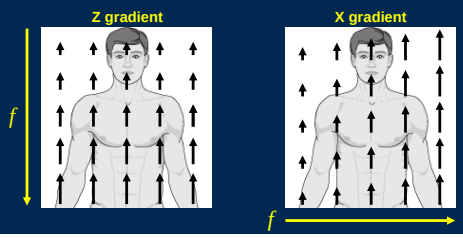
- Gadolinium-based contrast agents shorten T1
  - Results in bright signal on T1-weighted MRI
- Especially useful in the brain
  - Leaky vasculature in high-grade gliomas
  - T2-weighted MRI can be used for non-enhancing (usu. low grade) gliomas



BN Joe et al, Radiology 212:811-816 (1999)

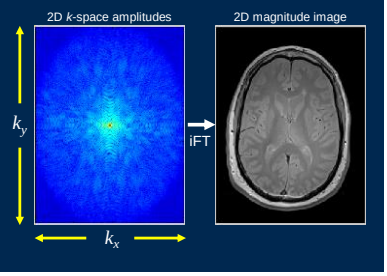
Magnetic Resonance Imaging

Spatial localization is accomplished by using linearly varying magnetic fields ("gradients") to map position to resonance frequency.



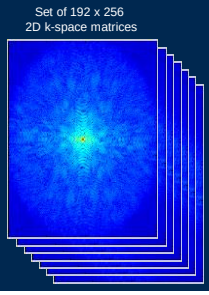
Magnetic Resonance Imaging

- We sample the NMR signal in the presence of magnetic field gradients, in order to measure the "spatial frequency" components of the magnetization distribution in "*k* space".
- Then reconstruct the image by applying the inverse discrete Fourier transform to the *k*-space data matrix.



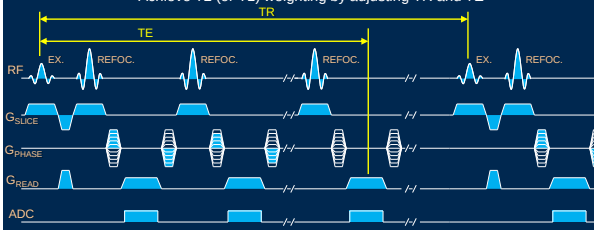
MRI Pulse Sequences

- An MRI pulse sequence is the set of instructions given to the scanner, to tell it when to apply the RF pulses, when to turn magnetic field gradients on and off, and when to read out the MR signal, in order to accumulate the *k*-space data needed to construct an image.
- Main pulse sequences used for radiotherapy applications:
  - Fast spin echo: T2 weighted MRI
  - Spoiled gradient echo: T1 weighted MRI



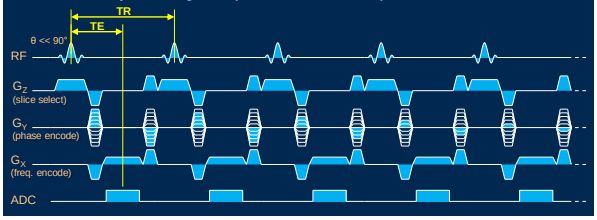
Fast Spin Echo Pulse Sequence

- A.k.a. "Turbo" spin echo. But, relatively slow…
- Refocus magnetization for every k-space line
- Achieve T2 (or T1) weighting by adjusting TR and TE



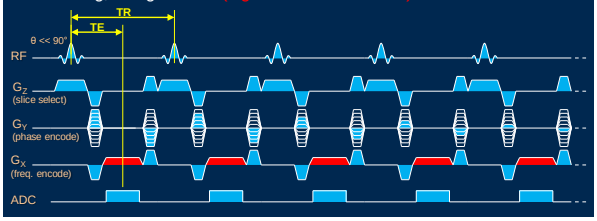
Spoiled Gradient Echo Pulse Sequence

- A.k.a. “FLASH”. Very fast, use shortest possible TR.
- Perfrom new RF excitation before every k-space line.
- Inherently T1 weighted (because TR << T1)



Fast Imaging

- Spoiled gradient-echo pulse sequence (a.k.a. FLASH)
- T1 weighted
- Strong, fast gradients (high readout bandwidth)



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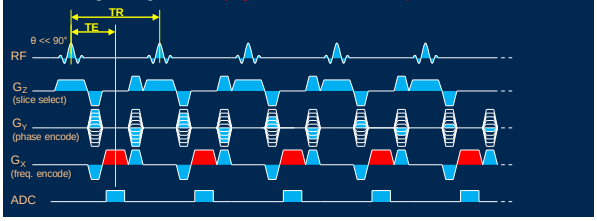

Fast Imaging

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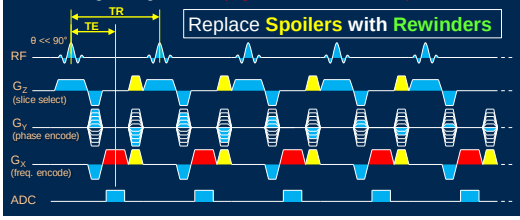
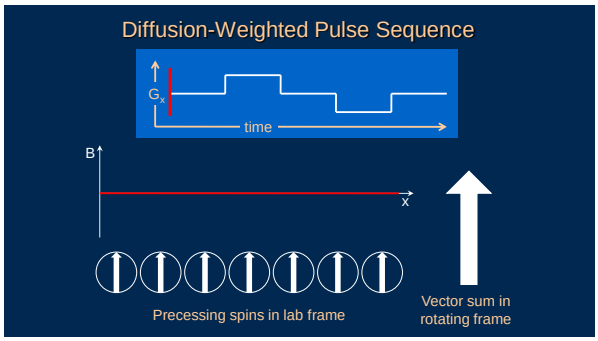


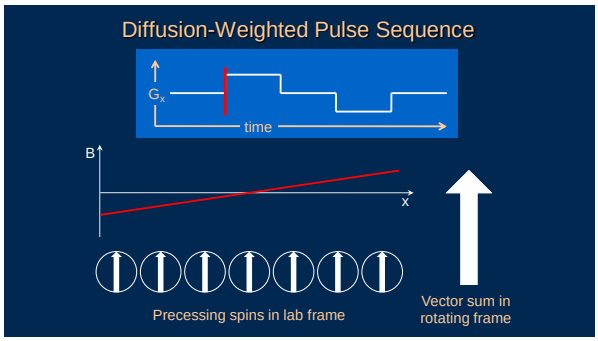
Fast Imaging

- **Steady-state free precession** (SSFP, a.k.a. TrueFISP, FIESTA)
- T2/T1 weighted; highest possible SNR for short TR
- Tradeoff: "banding" artifacts in regions of field nonuniformity

Diffusion Weighted MRI

- Use magnetic field gradients to encode displacement (changes in position over some time interval)
  - Measures random Brownian motion of individual water molecules.
- "Apparent" diffusion coefficient (ADC)
- Sensitive to tissue organization on microscopic scale.
  - Higher cellularity → lower ADC
  - Necrosis → higher ADC


Diffusion-Weighted Pulse Sequence
G_x
time
B
x
Precessing spins in lab frame
Vector sum in rotating frame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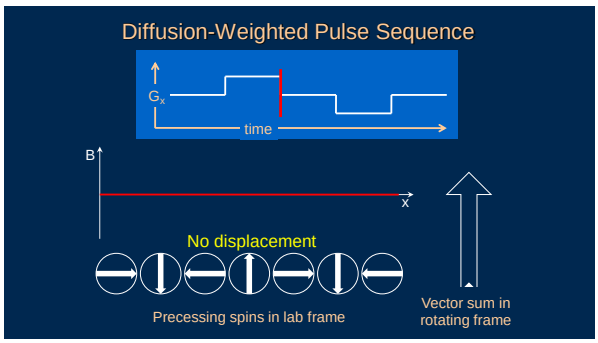
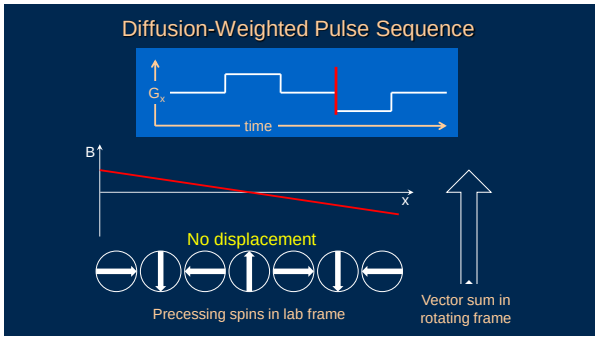

Diffusion-Weighted Pulse Sequence
G_x
time
B
x
No displacement
Precessing spins in lab frame
Vector sum in rotating frame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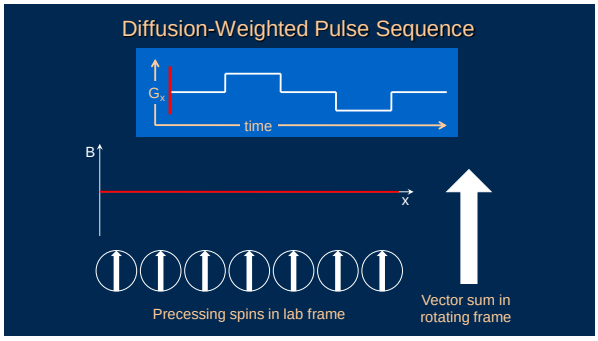
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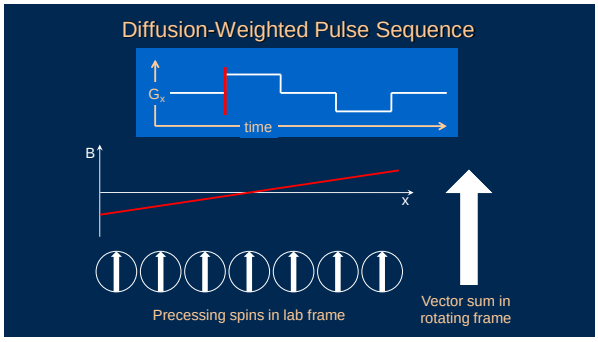
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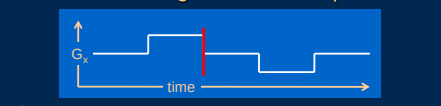
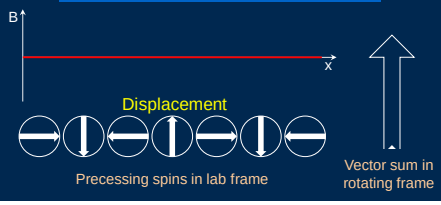
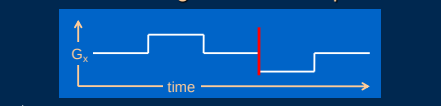
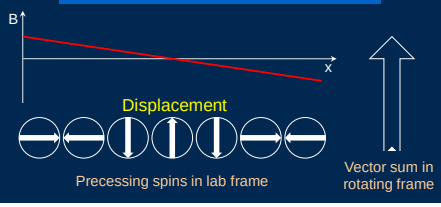
Diffusion-Weighted Pulse Sequence





Diffusion-Weighted Pulse Sequence

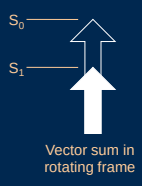




Diffusion-Weighted Pulse Sequence

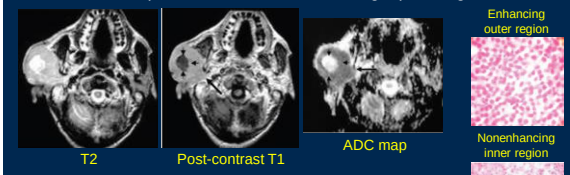
$$S_1 = S_0 e^{-b \cdot ADC}$$

- Use this equation to extract ADC (Apparent Diffusion Coefficient)
- So-called "*b* value" can be calculated from gradient waveform



Diffusion Weighted MRI

Mucoepidermoid carcinoma of the right parotid gland



- Nonenhancing part of lesion is bright on T2 and ADC
- Histopathology confirms low cellularity and necrosis

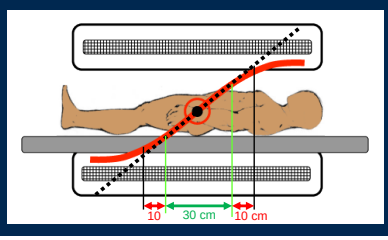
Abdel Razek et al, Acta Radiologica 2008

Geometric Distortion

- Because the spatial position is encoded into the resonance frequency, MRI suffers geometric distortion in the presence of magnetic field nonuniformities.
- Scanner-related distortion
  - Warps image at edges of large FOV
  - Correctable using built-in tools on scanner
- Subject-related distortion
  - Primarily due to magnetic field disturbances at air-tissue interfaces
  - Minimization strategies: use high readout bandwidth, refocusing RF pulses (e.g. fast spin echo)
  - Worst in echo planar imaging (EPI)

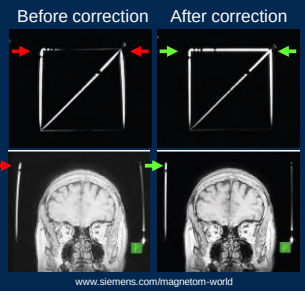
Scanner-Related Distortion

Arises from gradient nonlinearity
near the edges of the maximum field-of-view



Scanner-Related Distortion

- Gradient nonlinearity is constant and well characterized by the manufacturer
- Can be corrected for using integrated scanner software



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Thank You for staying until the bitter end !