MRI Physics III

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- **Review: Spatial Encoding**
- **MRI Contrast: Basic sequences**
  - T_2
  - T_1
  - T_2*
  - Diffusion

Spatial encoding of the MR signal

- The principle: Larmor equation ($\omega = \gamma B_{tot}$)

$$\omega_{(r)} = \gamma \left(B_0 + G.r\right)$$

G : magnetic field gradient
r : distance from magnet's center

- Corollaries:

1) While the gradient is on (constant) ⇒ changes in frequency = changes in position

($\Delta\omega = \gamma G \Delta r$) if we measure signal coming from different frequencies, we measure signal coming from different positions

2) If G is on for short time Δt, then G is off ⇒ changes in phase = changes in position

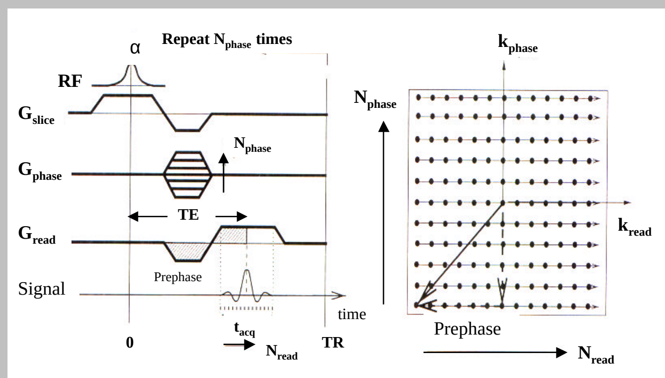
($\Delta\theta = \gamma G \Delta t \Delta r$) G Δt : spatial phase periodicity
if we measure signal after G Δt
only structures with (G Δt) contribute

J. Jovicich *Review: spatial encoding*

Conventional pulse sequences

Gradient echo sequence
(sensitive to T_2*)

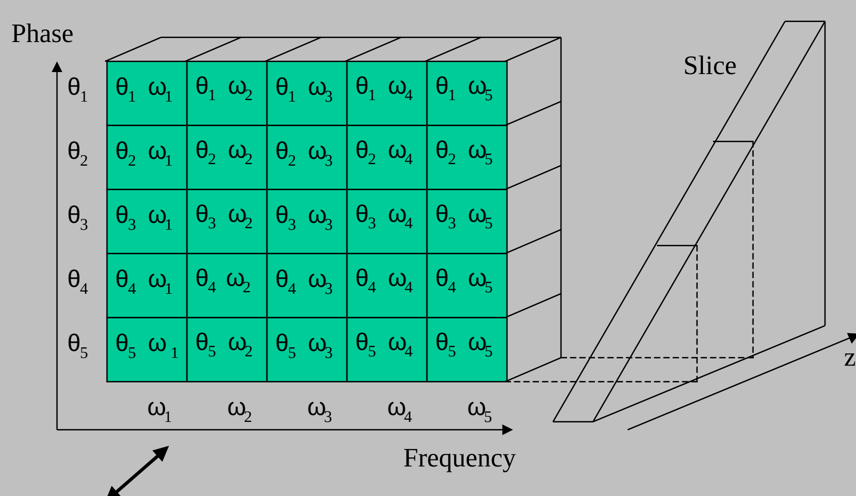
***k*-space trajectory**
(spatial frequency space)



TE: echo time
TR: repetition time

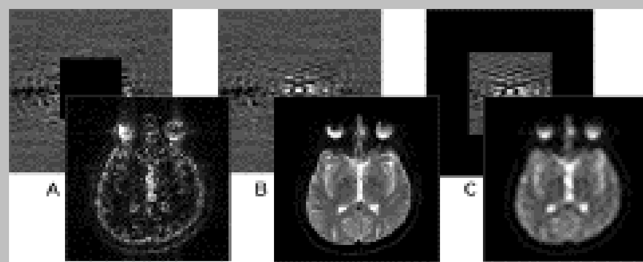
K-coordinate: area under a gradient

Spatial encoding: summary



2D Fourier transform ⟷ **IMAGE**

Understanding *k* - space



K-Space: spatial frequency information of the image
- Center: low frequencies global features, image intensity (C)
- Periphery: high frequencies sharp features, edges (A)

Images from: http://thelonius.loni.ucla.edu/AMR/EPITheory.html

Pulse Sequences and Image Contrast

Overview:

- **Definition of Contrast**
- **Contrast parameters**
- **Concept of MRI contrast weighting**
- **Properties of pulse sequences & sequence parameters**
  - **- Spin- Echo (ρ , T_1, T_2 contrasts)**
  - **- Good T_1-contrast: Inversion Recovery Sequence**
  - **- Gradient-Echo (T_2* contrast)**
  - **- Diffusion weighting**

Image Contrast Definition

- Goal: maximise the contrast (USEFUL IMAGES!)
- Contrast: difference in MR signals between different tissues

	Tissue 1	Tissue 2
Water protons:	T_1, T_2, T_2^*, ρ, Diffusion,Flow	T_1, T_2, T_2^*, ρ, Diffusion,Flow
Pulse sequence & sequence parameters:	S_1	S_2

Intrinsic Contrast:

$$C = \frac{S_1 - S_2}{S_1 + S_2}$$

Image Contrast: What can we manipulate?

Tissue Properties: fixed

Tissue	T_1 (ms)	T_2 (ms)	ρ*
Fat	260	84	0.90
White Matter	780	90	0.72
Gray Matter	920	100	0.84
CSF	3000	300	1.00

ρ*: % H_2O relative to CSF

Experimental Variables

- Pulse sequence
- Pulse sequence parameters
  - Repetition time: TR
  - Echo time: TE
  - Inversion time: TI
  - RF flip angle: α
- Contrast agent

Image Contrast: Concept of Weighting the MR Signal

- **General MRI pulse sequence: combination of contrasts**

  Signal Intensity:

  $$S(x,y) = k \times \rho \times T_1 \times T_2 \times \ldots$$

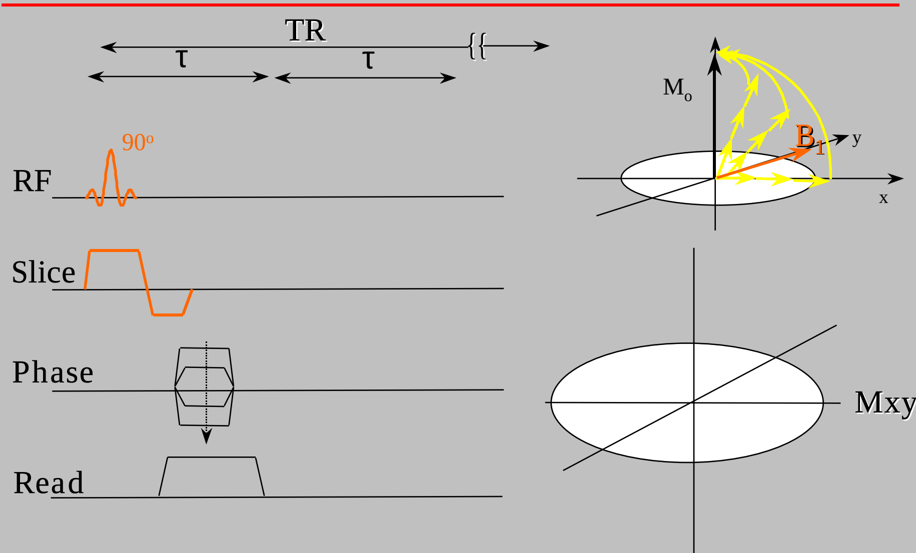
- **Contrast Weighting: maximise one term, minimise the others**

  Example: T_1-weighting

  $$S(x,y) = k \times \rho \times T_1 \times T_2 \times \ldots$$

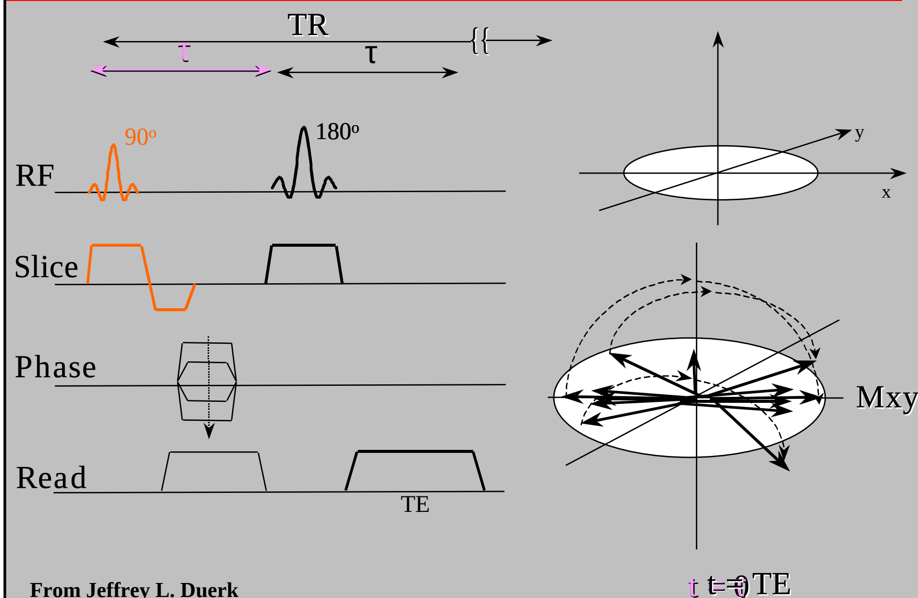
J. Jovicich *MRI Contrast*

Pulse Sequences: Spin Echo



From Jeffrey L. Duerk

Pulse Sequences: Spin Echo



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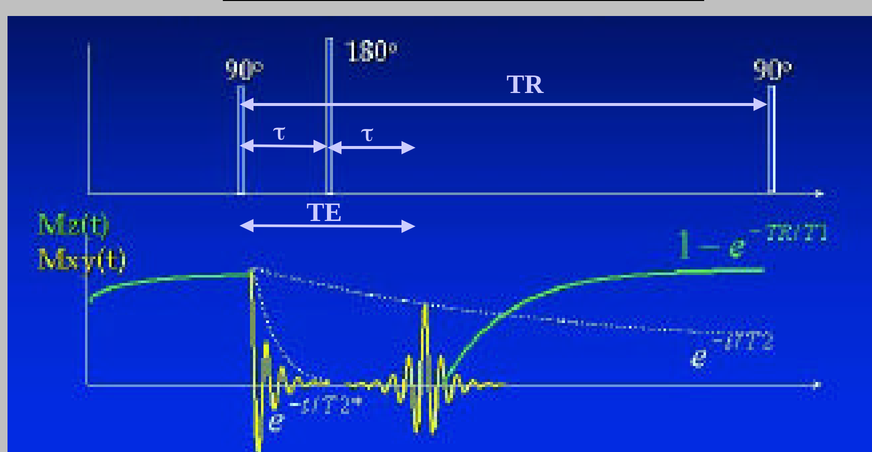
Spin-Echo Sequence: The MR Signal



$$S_{SE} = M_0 \left[1 - \exp\left(-\frac{TR}{T_1} \right) \right] \exp\left(-\frac{TE}{T_2} \right)$$

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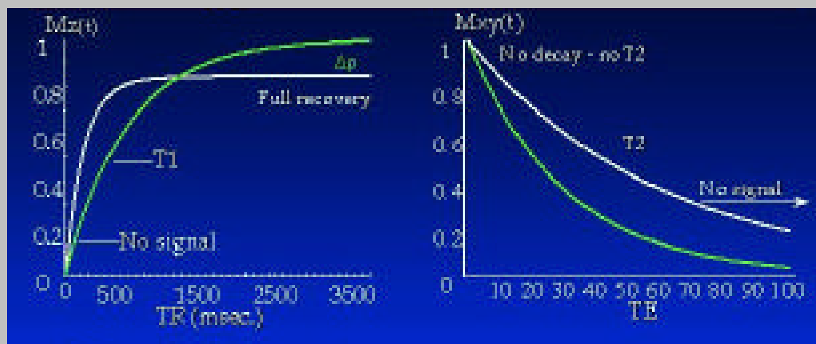
Spin-Echo Contrast



Pixel intensity: $$S_{SE} = M_0 \left[1-\exp\left(-\frac{TR}{T_1}\right)\right]\exp\left(-\frac{TE}{T_2}\right)$$

ρ term **T_1 term** **T_2 term**

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Spin-Echo Sequence: Proton Density Weighting

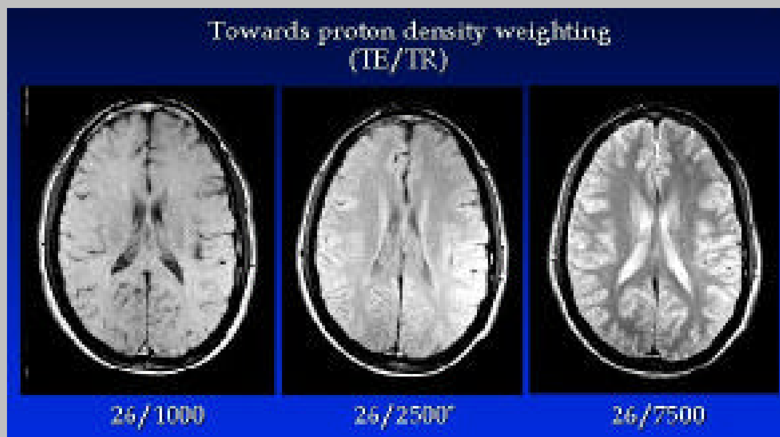
Pixel intensity: $$S_{SE} = M_0 \left[1-\exp\left(-\frac{TR}{T_1}\right)\right]\exp\left(-\frac{TE}{T_2}\right)$$

ρ term **T_1 term** **T_2 term**

If ρ-weighting desired ⇒ need to make (T_1 & T_2 terms) ≈ 1

⇒ short TE & long TR

Spin-Echo Sequence: Proton Density Contrast



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Spin-Echo Sequence T_2-weighting

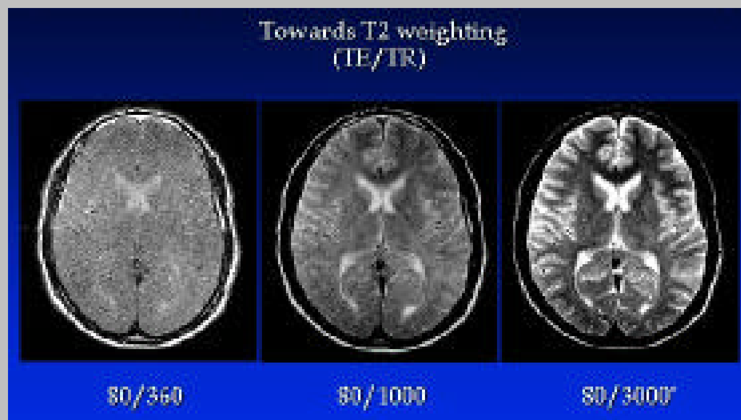
Pixel intensity:

$$S_{SE} = \underbrace{M_0}_{\rho \text{ term}} \underbrace{\left[1 - \exp\left(-\frac{TR}{T_1}\right)\right]}_{T_1 \text{ term}} \underbrace{\exp\left(-\frac{TE}{T_2}\right)}_{T_2 \text{ term}}$$

If T_1-weighting desired ⇒ need to make (T_2 term) ≈ 1

⇒ short TE

Spin-Echo Sequence
T_2-weighting



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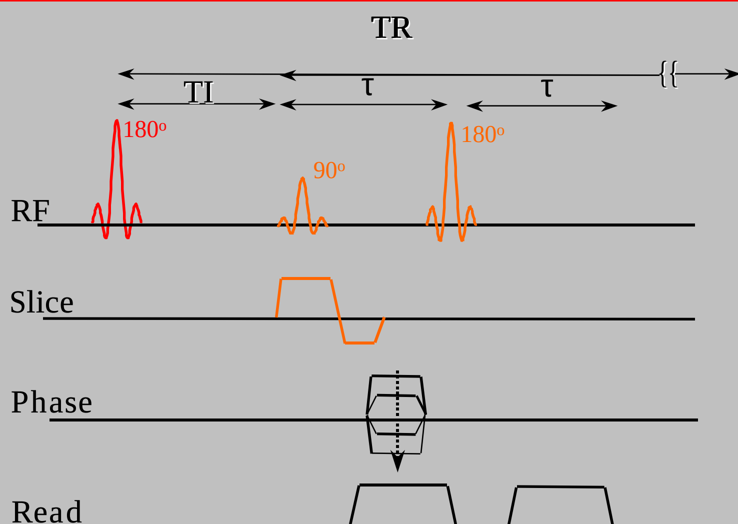
Pulse Sequences: Inversion Recovery



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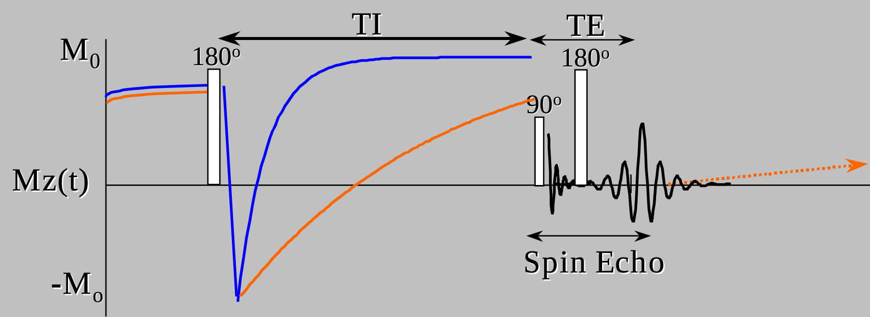
Pulse Sequences: Inversion Recovery



180° Inversion: prepare magnetization prior to Spin Echo detection

Pixel $\rho(1-2e^{-TI/T1}+e^{-TR/T1})\,e^{-TE/T2}$

Twice dynamic range as SE

Signal null at TI = ln(2)* T1

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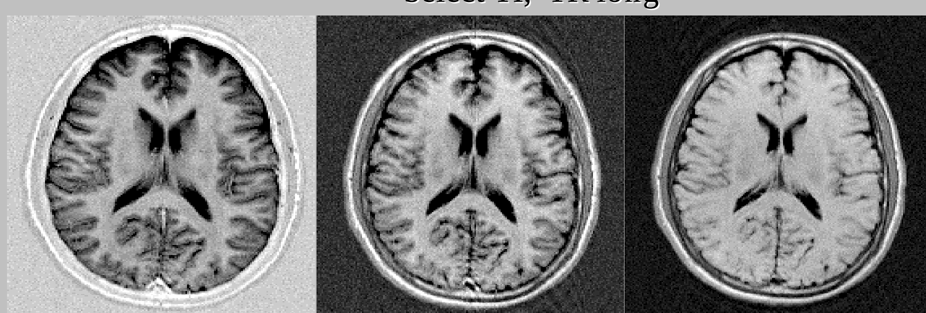
Inversion Recovery: T1 Contrast

Pixel $\rho(1-2e^{-TI/T1}+e^{-TR/T1})\,e^{-TE/T2}$

T1 contrast: Little or no T2 Effect
T1 effect > ρ effects
Select TI, TR long



48 / 200 / 3500 | 48 / 500 / 3500 | 48 / 800 / 3500

TE / TI / TR

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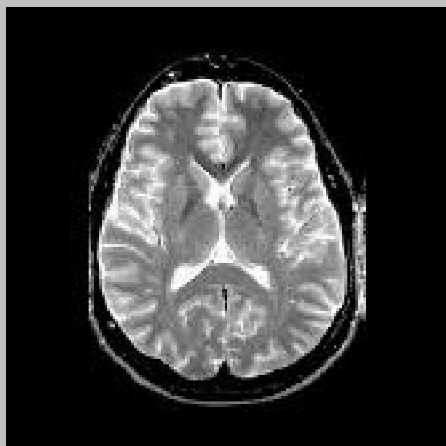
Inversion Recovery: Fluid Suppression

Fluid Attenuating Inversion Recovery: FLAIR
T1 csf ~ 3500 msec at 1.5T TI ~ 2500 msec (long)



SE 80 / 3500

IR 80 / 2500 / 7500

From Jeffrey L. Duerk

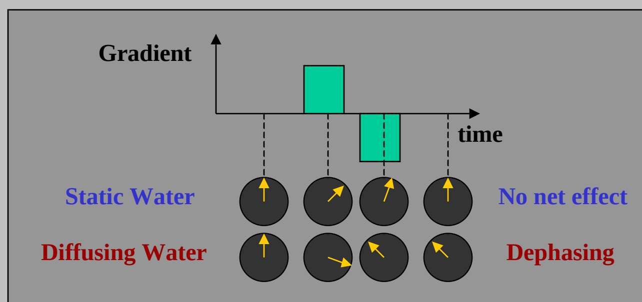
Diffusion MRI:
Observation of Tissue Structure

- **Water in vascular system ⇒ follows flow**
- **Water in extra-vascular system ⇒ random motion**
- **Water diffusion: incoherent motion of extravascular H_2O**

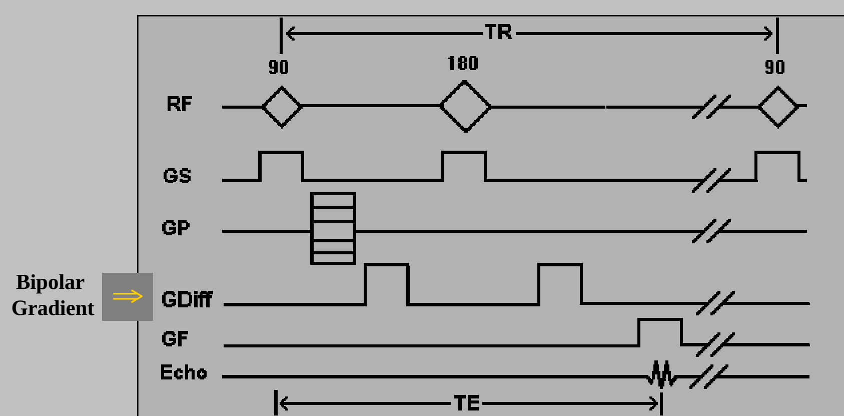
- **Free Water ⇒ isotropic diffusion**
- **Water in Tissue ⇒ anisotropic diffusion (prefered directions)**

Diffusion weighted MRI: The Principle

- Bipolar magnetic gradients added to sequence
- Static Water ⇒ no net dephasing ⇒ MR signal recovered
- Diffusing Water ⇒ dephasing ⇒ MR signal loss
- Signal loss related to diffusion along applied gradient (also strength and duration of gradient)



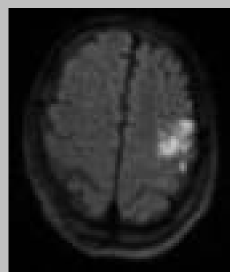
Diffusion weighted Spin-Echo Sequence

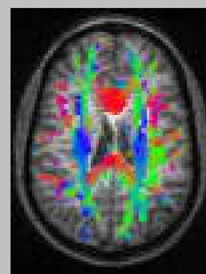


Diffusion weighted MRI: Applications

Clinical (stroke) **Brain Structure Research**


Spin-Echo


DW Spin-Echo


Diffusion Tensor Map

Acknowledgments

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  http://www.uhrad.com/research/1997cat/index.htm