Magnetic Resonance in Medicine
Course Introduction & Principle Review
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Guests from Eulji University, Korea
- Department of Radiological Science

Congratulations!
- You are HERE!

From Basics to Bedside
- Magnetic Resonance Imaging
  http://www.ym.edu.tw/~cflu/CFLu_course_BIRSmri.html
  Principles of MRI
  Equipment, pulse sequence, tissue contrast, image reconstruction, MRI artifacts, safety issues
- Magnetic Resonance in Medicine
  http://www.ym.edu.tw/~cflu/CFLu_course_BIRSmrm.html
  Clinical Applications of MRI
  MR contrast agent, functional MRI, diffusion weighted imaging, angiography, MR spectroscopy
  Visiting NYMU 3T MRI Facility
Syllabus

1 Review of MRI basic principles
2 Review of Pulse sequences
3 Diffusion weighted imaging (DWI)
4 Diffusion tensor imaging (DTI)
5 MR angiography
6 MR contrast agent
7 MR perfusion: DCE & DSC
8 (4/8) No class this week due to cross-university activities
9 MR perfusion: arterial spin labeling (ASL)
10 (4/12) 16:00-18:00 Yang-Ming 3T MRI room visiting and scanning
11 Susceptibility weighted imaging (SWI)
12 Functional MRI (fMRI)
13 (5/13) No class this week due to ISMRM annual meeting
14 MR Spectroscopy (MRS)
15 Cardiac MR imaging
16 MR muscle skeleton imaging
17 (6/17) Final Competition

Textbooks

- MRI The Basics (3rd edition)
  - Ray H. Hashemi, William G. Bradley, Christopher J. Lisanti
  - Lippincott Williams & Wilkins, 2010
- MRI in Practice, (4th edition)
  - Catherine Westbrook, Carolyn Kaut Roth, John Talbot
  - Wiley Blackwell, 2011
Online Teaching Materials

- [http://www.ym.edu.tw/~cflu](http://www.ym.edu.tw/~cflu) Teaching Materials → MRM(UG)

Evaluation

- Attendance (10%)
  - Attendance of at least one-third lectures is required.
- Participation of class discussion (30%)
- Final exam (60%)
  - Group competition.

Review of MRI Principles

1. Alignment (magnetization) $B_0$
2. Precession $\omega_0 = \gamma B_0$
3. Resonance (given $B_1$ by RF with $\omega_2$) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
   - The most effective resonance is produced when $\omega_0 = \omega_2$
4. MR signal (EMF, relaxation time )
5. Imaging (Pulse sequencing: SE, GRE, EPI)
   - Tissue Contrast: Image weighting
   - Spatial localization: Slice selection & Spatial Encoding
   - Data space/K space
6. Tissue Suppression Techniques
7. Artifacts and Safety Issues
Principles of MR imaging

Setup
- Outer → inner
  - Active shielding
  - Main magnet
  - Shim coil
  - Gradient coil
  - Body coil
  - Receive coil

RF Coil Shapes

T1 & T2 Relaxation Time

\[ T1: \text{The longitudinal relaxation time} \]
\[ T2: \text{The transverse relaxation time} \]

\[ M_0(t) = M_0(1 - e^{-t/T1}) \]
\[ M_{xy}(t) = M_0e^{-t/T2} \]

RF coils need to be plug in on table!!
Received Signal: Free Induction Decay

- The oscillating, decaying signal is called an FID.
- $M_{xy}(t) = M_0 e^{-t/T_2^*} (\cos \omega_0 t)$

The frequency of the received signal is also $\omega_0$.

TR (Repetition Time)

- To spatially encode the signal and to increase the signal-to-noise ratio, we have to apply the RF pulse multiple times while varying the gradients.
- The time interval between RF pulses is called TR.

TE (Time to Echo or Echo Delay Time)

- We wait a short period of time (TE) after RF pulse and then make the measurement.
- The $T_2^*$ decay curve (FID) starts out at the value of $M_0 (1 - e^{-TR/T_1})$ on the $T_1$ recovery curve and then decays very quickly.

Image Contrast

- Long TR, short TE $\Rightarrow$ proton density
- Long TR, long TE $\Rightarrow$ $T_2^*$-weighted
- Short TR, short TE $\Rightarrow$ $T_1$-weighted
- Short TR, long TE $\Rightarrow$ no signal

Example:

<table>
<thead>
<tr>
<th></th>
<th>$TR$</th>
<th>$TE$</th>
<th>Flip angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
<td>short</td>
<td>short</td>
<td>large</td>
</tr>
<tr>
<td>$T_2$</td>
<td>long</td>
<td>long</td>
<td>small</td>
</tr>
<tr>
<td>Proton density</td>
<td>long</td>
<td>short</td>
<td>small</td>
</tr>
</tbody>
</table>

Table 2. Parameters used in gradient echo.
Adjust T1 and T2 weighting

Time → Intensity

| T1: CSF > GM > WM |
| T2: CSF > GM > WM |
| N(H): CSF > GM > WM |

T1: H2O > Solid tissue > Fat
T2: H2O > Fat > Solid tissue
N(H): H2O > Fat > Solid tissue

t1/t2/pd weighted images

Image Construction

1. Slice selection
   (only excite spins on a specific slice location)

2. In-plane spatial encoding
   (differentiate spin signals at different locations)

Image of K-Space

- The center of k-space contributes to the primary information of image.
- The periphery of k-space provides information regarding fitness of the image and clarity at sharp interfaces.
Spin-echo pulse sequence diagram

- Radio-frequency Pulse
- Slice-select gradient
- Phase encoding gradient
- Frequency encoding gradient
- Echo
- Signal/FID

An echo is acquired per TR.

Fast spin echo

- In FSE, before each 180° pulse, we place a different value of the phase-encoding gradient.
- For the 180° pulse before the echo we choose as the $T_{eff}$ (in this case, 102 msec), we use a phase-encoding gradient with the lowest strength.

Center slab: zero phase

$T_{eff} = 102$ msec

GRE Pulse Sequence Diagram

- Three operator-controlled parameters that affect the tissue contrast.

Single-shot EPI

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

An odd-even coverage of k-space
Contrast in EPI

- 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)

Suppression techniques

- To suppress the signal coming from a certain tissue.
  - Two common targets (tissues): fat and water

- Suppression techniques
  - Inversion recovery (IR) techniques
  - Chemical/spectral saturation
  - Dixon method
  - Spatial presaturation
  - Magnetization transfer (MT)

Glioblastoma MRI

T2 Weighted image  T2 FLAIR (Water suppression)

edema vs. water


Breast cancer MRI

T1 Weighted image  Fat saturation + Gd enhancement

T1: H2O > Solid tissue > Fat
Gd contrast agent can shorten tissue T1

British Journal of Cancer (2003) 88(1), 4-10
Inversion recovery, IR

- After the 180° RF pulse, the magnetization starts to recover from -M₀ instead of zero.
- TI(null) = (ln2)T₁ ≒ 0.693 T₁.

Tissue Suppression: STIR & FLAIR

- STIR: Short tau inversion recovery, fat suppression
  - At 1.5T, TI = 0.693 x 200 = 138.6 msec
- FLAIR: Fluid attenuated inversion recovery, water suppression
  - At 1.5T, TI = 0.693 x 3600 = 2494.8 msec

Water & fat chemical shift

- Peak location
  - Water 4.7 ppm
  - Fat (lipids) 1.3 ppm
- ppm: parts per million
  - ω = 42.6 x 1.5T = 63.9 MHz
  - 1.5T: (4.7-1.3) x 63.9 = 217.36 Hz
  - 3.0T: (4.7-1.3) x 127.8 = 434.52 Hz

Chemical/spectral presaturation

- A frequency-selective presaturation pulse is applied before the RF excitation pulse.
- CHESS: Chemical shift selective
  - We select appropriate frequency (based on the Larmor equation) to suppress fat or water.
  - At 1.5T, water protons precess 210-220 Hz faster than fat protons;
  - At 3.0T, water protons precess 420-440 Hz faster than fat protons.
Mumbai MRI death: Nair hospital radiologist arrested in connection to Rajesh Maru’s death, released on bail

Feb 02, 2018

Mumbai: A radiologist of the Nair hospital was arrested in connection with the death of a man in a freak Magnetic Resonance Imaging (MRI) machine accident at the facility on 27 January, police said on Friday.

Agripada police said Dr Siddhant Shah was arrested on Thursday after the family of the 32-year-old victim, Rajesh Maru, told them that the radiologist was also present when the accident occurred.

Shah was charged with negligent discharge, released on bail. Shah’s wife and three-year-old daughter, Latvia, were also arrested on charges of criminal negligence causing death.

Maru had accompanied a relative to the hospital for an MRI examination. An oxygen cylinder burst on impact, pulling the patient with it. The MRI machine was damaged.

Metal objects are not allowed inside rooms having MRI machines.

THE END

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