Basic MR Physics and MR Safety

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MRI: What is in the name?

MRI: Magnetic Resonance Imaging
- Magnetic: What do protons do in a magnetic field?
  - Align and Precess
- Resonance: What does magnetic nuclei do when the right energy is applied?
  - Resonance and Relaxation
- Imaging: How to resolve spatially MR signals from different voxels in the body?
  - Spatial Encoding

How can MRI be performed safely?

Magnetic Resonance Imaging

- Non-ionizing radiation, hydrogen in the body is the source of signal
- Absorption and Emission of energy in the radiofrequency spectrum
- Image acquisition in any plane, ~1 mm resolution, good soft-tissue contrast
Magnetic
- Nuclei with odd total number of protons + neutrons possess a magnetic moment
  - H, P, Na, C

Hydrogen atoms
Spin or rotation

Magnetic field direction
N
S

A very strong magnet is needed to induce even a weak magnetization in tissue.

MR in a Nutshell
Main Magnetic Field (B0)
- Uniform magnetic field inside the cylinder
- Protons in body align along two directions
  - Parallel and antiparallel to B0
  - More protons aligned parallel to B0 (lower energy state)
- Equilibrium or net magnetization in tissue along B0
- Greater B0, greater M0
Spin Precession

Under the influence of main magnetic field (B0)
- Spinning protons begin to precess
- Frequency of precession = Larmor frequency
- Larmor frequency ∝ strength of external field (B0)

\[ f_L = \frac{γ}{2π} B_0 \]

- The phenomenon of precession makes magnetization measurable

Detecting and Measuring an MRI signal

Problem:
- At equilibrium state, \( M_z = M_0 \); \( M_{xy} = 0 \)
- Difficult to measure \( M_z \) directly
  - \( M_z \) very weak compared to \( B_0 \)

Solution
- Excite nuclei by applying an RF energy
- To generate RF:
  - Time varying electric current passed through a coil
  - Electric field converted to oscillating magnetic field (\( B_1 \ll B_0 \))
- Very short duration
  - RF pulse
**RF Pulse**

- Applied at Larmor/Precession frequency
- Protons absorb energy – Magnetic resonance
- Rotate the net magnetization away from B0 direction, towards X-Y plane

**RF Pulse OFF**

- Return to equilibrium
- Two processes occurring at the same time
  - T1 Relaxation
  - T2 Relaxation
- Tissue-specific time constants

**T1 Relaxation**

- Spin-lattice or Longitudinal Relaxation
- Regrowth of Mz towards M0
- Transfer of thermal energy between excited nuclei and surrounding atomic lattice
  - Efficient transfer – shorter T1
  - Depends on molecular motion and size, water has long T1
- Time required for Mz to regain 63% of its equilibrium value
**T2 Relaxation**

- Spin-spin or transverse relaxation
- Transverse magnetization decays back to zero
- Interaction between magnetic field and individual protons
- Time required for 63% of the initial magnetization to dissipate
- Effective transverse relaxation time (T2*) — static inhomogeneities in local magnetic field

\[ M_z(t) = M_0 e^{-t/T_2^*} \]

**Signal Detection**

- Emission of RF energy can be measured before equilibrium is obtained
- Change of \( M_x \) detected by a coil
- Free induction decay
- For cardiac imaging, a separate RF receiver coil is used to maximize signal detection

**Spatial Encoding**

- [Image of spatial encoding diagram]
Gradient Magnetic Field

- 3 pairs of coils with equal and opposite polarity

Spatial Encoding and k-space Formation

- Gradient Magnetic Field
  - Selective Excitation - Define slice for imaging and excite the protons in that slice
  - Spatial Encoding - Identify location of protons for reconstruction of MRI image
- MRI directly measures data in the frequency domain
- Inverse 2D Fourier Transform
  - Decode spatial position

Decoding the MRI Image

- Full dataset, Central k-space, Outer k-space

K-space

IFFT

Image Space
1 in 10 people undergo MR imaging in the USA annually
- More than 10,000 systems across the country
- Millions of MRI scans have been performed safely

Failure to comply with recommended safety procedures can result in
- Serious injury to patients and personnel
- Serious damage to MR equipment

MR Safety

MR systems have a very powerful magnet
- 30,000 times stronger than the earth’s magnetic field
- 200 times stronger than a fridge magnet
- 1.5 to 3 times stronger than a junkyard lifting magnet

The Magnet is ALWAYS ON
MR Safety

Ferromagnetic objects become projectiles
- Paper clips, Hair pins, Pens, Scissors (> 40 mph)
- Most clinical equipment are NOT MR Safe
- People must be screened and items have to be tested
  - Pre-procedure screening
  - Hand held magnet
  - Ferromagnetic detection systems
  - Verify presence of implants, shrapnel, machine-shop debris

Adverse MR Incidents

Fatal incidents from projectiles
- 2001, NY – child struck in the head by oxygen cylinder
- 2018, India – patient’s relative struck by oxygen cylinder

Other serious incidents
- 2009 - Gun flew into magnet from police officer’s holster
- 2018, MA – MRI-safe clothes hamper was switched with regular one, flew into magnet and fractured patients facial bone

MR Safety Labeling

MR Unsafe
- Items NOT allowed in scanner room
- Do NOT scan patients identified with MR Unsafe implants and devices

MR Conditional
- Follow information on label
- Maybe safe in the room but not the bore
- Risk/benefit decision to scan the patient

MR Safe
- No safety hazard in MR environment
- Non-metallic
- Patients identified with MR safe devices can be scanned

Safety posters: FDA  https://www.fda.gov/media/101205/download
**Implant Safety**

**Fatal incident, 1992 - Aneurysm clip wrongly identified as MR safe**

**Before**
- Check device label
- Document
- Consult
- Pre-scan procedure

**During**
- Follow guidelines for device
- Constant monitoring

**After**
- Assess patient
- Post-scan device check/reprogramming

[http://www.mrisafety.com](http://www.mrisafety.com)
Check with your institution's designated MR safety officer

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**Heating/Burn Safety**

- Most common MRI related injury
- RF energy can be deposited in the body as heat

Screen and Verify
- Avoid street clothing

Proper positioning
- Proper cable routing
- Normal mode, whenever possible

**MR Safe Electrodes**
- Keep your eyes and ears on the patient

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**Other MR Safety Concerns**

**Physiological and Biological effects**
- Tissue heating
- Peripheral nerve stimulation – tingling/twitching

**Acoustic Effects**
- Increased anxiety / Communication trouble
- Temporary and permanent hearing loss

**Tattoos/Permanent makeup/Piercings**
- Heating, Local edema and swelling
- Image artifacts

**Contrast Agent Safety**
- Nephrogenic systemic fibrosis
- Gadolinium retention

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A Safe MR exam

Completion of MR screening form
- Confirm safety of implanted devices
- Check if inpatients have temporary devices
- Stop scan if unreported object is discovered during scanning

Question twice!

MR Safety Training

Any personnel with reason to enter MR suite must be screened and trained

- Train staff on protocols for emergency in MRI
  - Medical
    - Remove patient from scan room, close door
  - Fire, Flood
    - Emergency Power OFF
  - Life-threatening event / Uncontrolled fire
    - Quench

MR Safety Training

Emergency POWER OFF

Resources

MR Physics
- [https://www.mriquestions.com/index.html](https://www.mriquestions.com/index.html)

MR Safety
- [http://www.mrisafety.com](http://www.mrisafety.com)
- Gilk and Kanal. 2013. JMRI 37:531-543
WITH GREAT POWER COMES GREAT RESPONSIBILITY