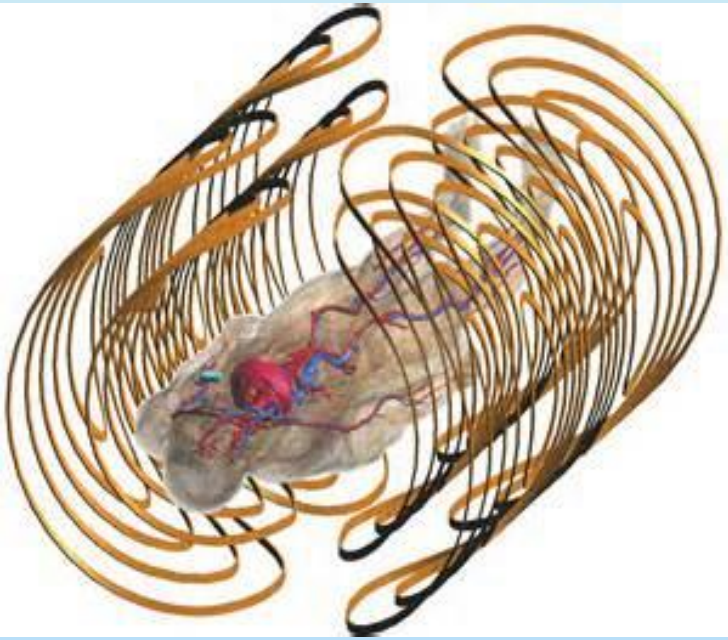
MR SAFETY BASICS



Vera Kimbrell BSRT (R)(MR)FSMRT

Brigham and Women's Hospital
Presenter Disclosure Slide

Vera Kimbrell, BSRT

Nothing to disclose

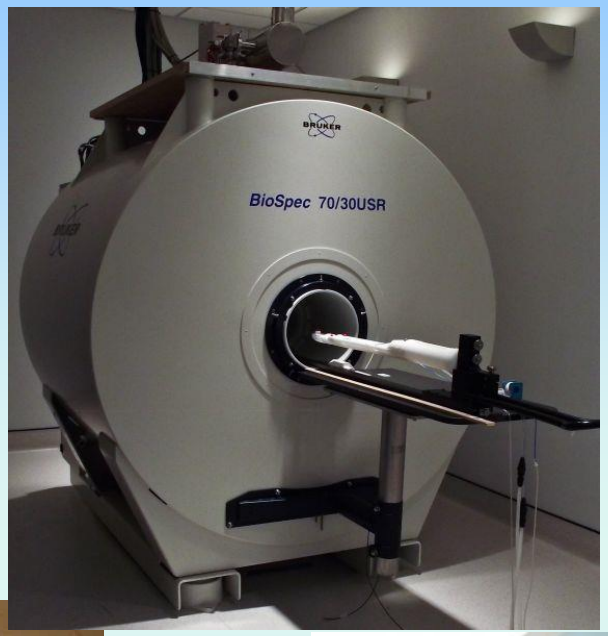
Safety Issues in MR

- **Static Field**
  - Measured in Tesla/Gauss
  - Projectiles
  - Quench
    - Related to Superconductive magnets
- **Spatial gradient**
  - Torque
  - Maximum Spatial Field Gradient (g/cm or T/m)
  - Lenz Forces***
- **RF**
  - Heating
  - SAR limits
  - B_1+RMS
- **Gradients (Time varying)**
  - Current producing potential
    - PNS
  - Acoustic Noise
    - Decibel levels (decibels)
    - Hearing Protection
- **Contrast**
  - **Reactions**
  - **Gadolinium issues**
- **Implant interactions**
- **Artifacts**

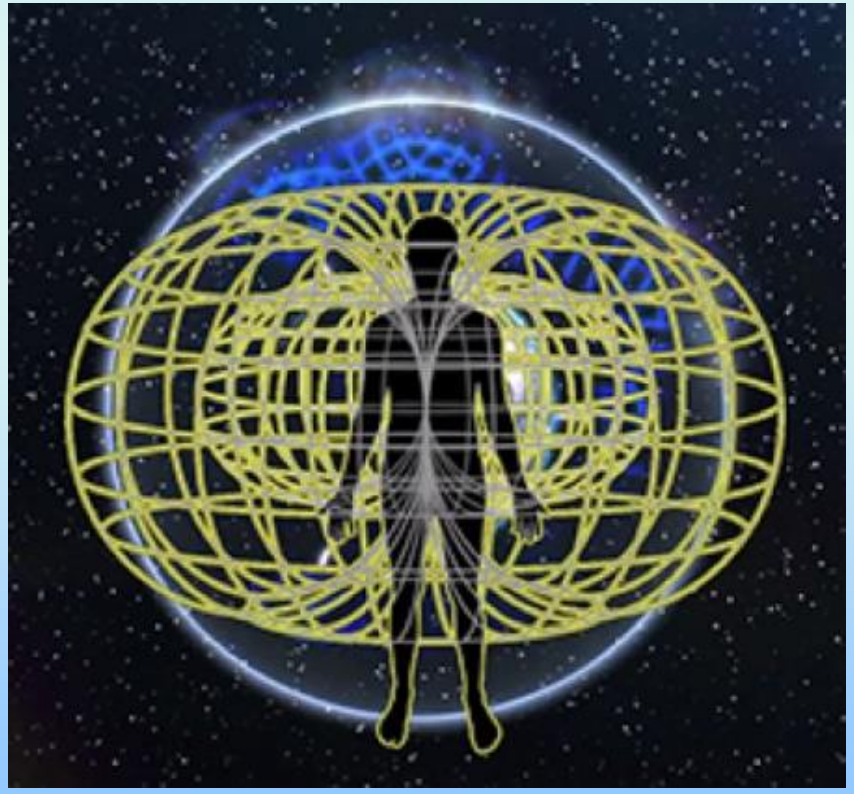
The Early Years of MRI

1973-MRI-invented-Sir-Peter-Mansfield-and-colleagues

THE MAGNET



Static Field



Equimax.no

Static Magnetic Field

- Referred to as Bo and measured in units of Tesla
- Types of Magnets
  - Permanent
  - **Superconductive**
  - Resistive
- For MR imaging the Bo field aligns hydrogen protons in preparation for the RF pulse
- No proven long term biological concerns from exposure
- Clinical magnets vary in field strength form 0.2T to 7T

Static Magnetic Field Effects

- Some people experience side effects when moving through high spatial gradients of the static magnetic field, including:
  - Vertigo
  - Nausea
  - Metallic taste in their mouth
  - Flashes of light
- Sensitivity varies amongst individuals
- More common at higher field strengths (3T and above)

http://www.cecruncher.com/latest+news/chiropractic+seminar+highlight+-+dealing+with+the+dizzy+patient/

Superconductive Magnets

- **Cryogens**
  - **Helium in modern scanners**
    - Insulated by cold water (chiller pumps)
    - Limited resource
- **Why we need them**
  - Keep the internal Magnet coils cool (really cold) maintaining superconductivity
  - Part of the process that allows for high field strength

- **Removing the Field**
  - Emergency-Quench
  - Routine upgrade-Ramp down
- **Precautions**
  - Door that opens outward or blow-up panels
  - Vent fans in the ceiling
  - Regular monitors of levels
  - Training of emergency procedures
  - PM by trained personnel along with refills of cryogens

- One liter of liquid helium produces 748 liters of helium gas when boiled off
- A whole body scanner typically contains 1,500 liters of liquid helium
- During a quench typically 1,000,000 liters of gas are liberated
- Cost for helium gas approximately $30,000

Metal and Magnetism

- Magnetism in Metal is created by an uneven distribution of electrons
- Metals have different magnetic properties depending on temperature
- To become ferromagnetic
  - Need an unpaired outer atomic shell
  - When in a magnetic field becomes polarized

Magnetic Properties of Solids

- Paramagnetic
  - Aluminum
- Diamagnetic
  - Water
- Ferromagnetic
  - Iron
- Antiferromagnetic
  - Terbium
- Ferrimagnetic
  - Ferrite

- For the purpose of MR Safety:
- Paramagnetic
  - Gadolinium
- Ferromagnetic
  - Iron, Nickel, Cobalt,
- Diamagnetic
  - Silver
  - Copper
  - Lead

PROJECTILES

- Ferrous objects are attracted toward the center of the bore at considerable force, causing a "missile effect." A hairpin or paper clip within the 5-10 gauss line range could reach velocity of **40 mph** and will be attracted to the center of the magnet.

Ferrous & Non Ferrous Metals

- Ferrous Metal:
  - Mild Steel
  - Carbon Steel
  - Stainless Steel
  - Cast Iron
  - Wrought iron

http://img.jsgtlr.com/2016/11/13/metal-objects-l-b8887098b1535570.jpg

http://www.newstalk.com/The-strangest-objects-found-in-the-human-body

- Non Ferrous Metal:
  - Aluminum
  - Copper
  - Brass
  - Silver
  - Lead
  - Gold
  - Platinum
  - Titanium

http://dreamatico.com/gold.html

Missile Effect

- Quench scenarios
  - Prevent injury or death
- Fatalities and serious injuries have occurred
  - Death from projectiles
  - Internal injury and fractures
  - Damage to equipment and the MR scanner itself

http://www.koppdevelopment.com/mri_safety.html

Translational and Rotational Forces

- As a ferrous object crosses the Gauss lines toward iso-center it experiences a force causing rotation-Torque
  - Size, shape, mass, and angle of the object
- Multi-factorial equation that means objects may not make it to the center of the bore

Protecting the environment

- Education
- Site design-(refer to ACR/IEC guidance)
- Controlled access
- Ferromagnetic metal detectors
- Constant vigilance of work flow and equipment

Restricting Access To MRI

- Access to MRI is restricted to prevent MR system related accidents and injuries
- The MRI staff, including you, are the “gate keepers”
- The MRI radiologist is ultimately responsible for MRI safety

http://www.allmri.com/product_info.php?language=en&info=p768_mrt-sicherheitsschranke-techgate.html&=

Safeguarding Zone 4

$\Delta B \times B$

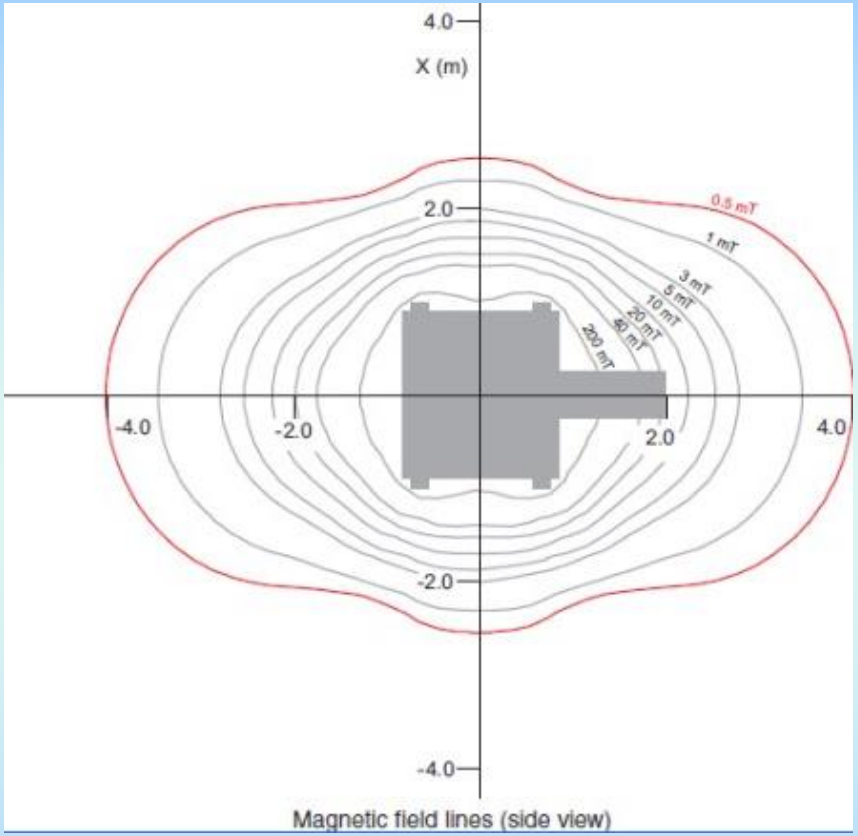
Spatial Gradient Fields

Force Product

1 T/m is equal to 100 G/cm.

Spatial Field Gradients

- The Fringe field around a magnet is measured in Gauss and its' shape an ellipse
- The field strength gradually decreasing from Iso-center outwards
- Where and how fast that field degrades varies according to both internal and external factors
  - Active shielding
  - Passive shielding

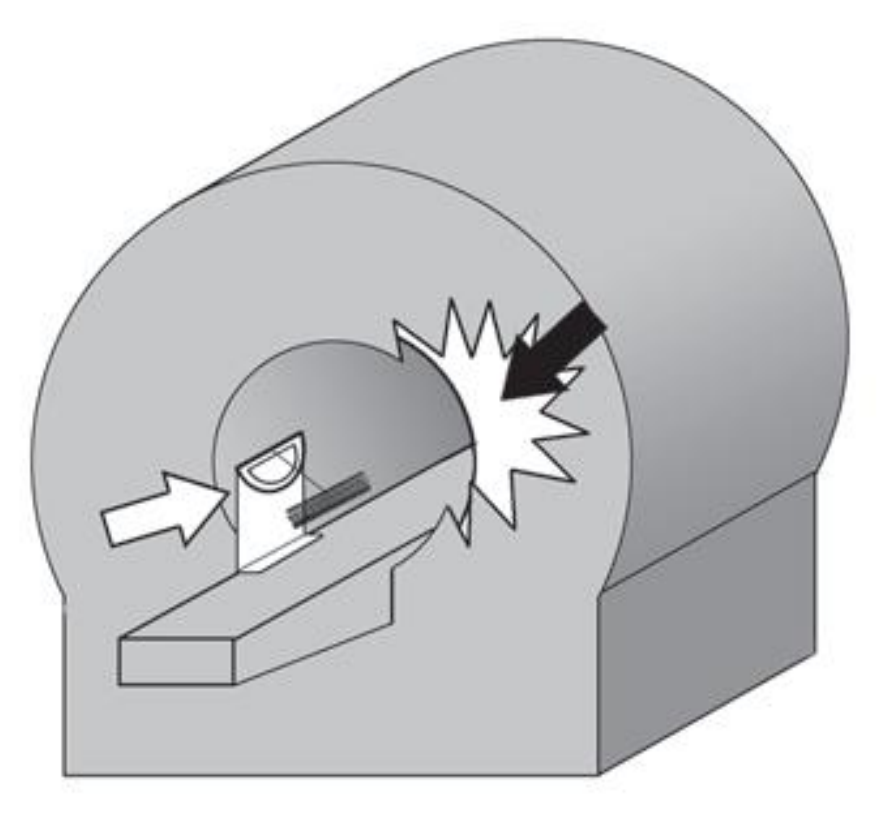


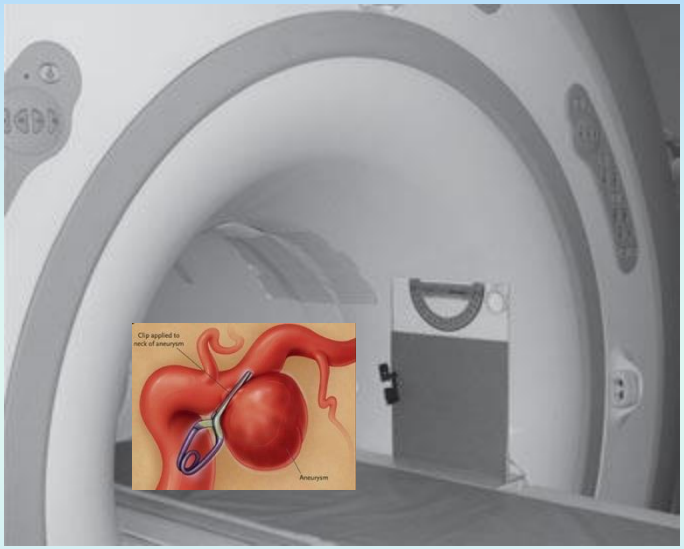
The Maximum spatial gradient is usually at the "flare of the bore" in most MR scanners

Measured in Gauss/cm or Tesla/m

Spatial Field Gradients

Where is the implant? Will it be exposed to the max SFG?





http://www.imrser.org/PDF/2010.Shellock.AJR.Mag.Field.pdf

Peripheral Nerve Stimulation

Nerve Stimulation

- Gradient magnetic fields can induce electrical fields that stimulate nerves
- Faster and stronger gradient magnetic fields are more likely to induce greater currents
  - The normal threshold for nerve stimulation is approximately 60-70T/sec
  - Some patients are more sensitive than others
- Gradient fields used in clinical MRI may cause mild twitching (usually in the limbs)
- Stop the scan if a patient reports pain or discomfort

Gradients & PNS

- Rapidly Changing Gradients can induce e-fields in human tissue
  - Not a frequent issue clinically in MR Imaging but does happen from time to time
  - Gradient strength is measured in terms of db/dt
  - Pulse sequences like EPI are more likely to be culprits
    - Most scanners have a “pop-up warning”

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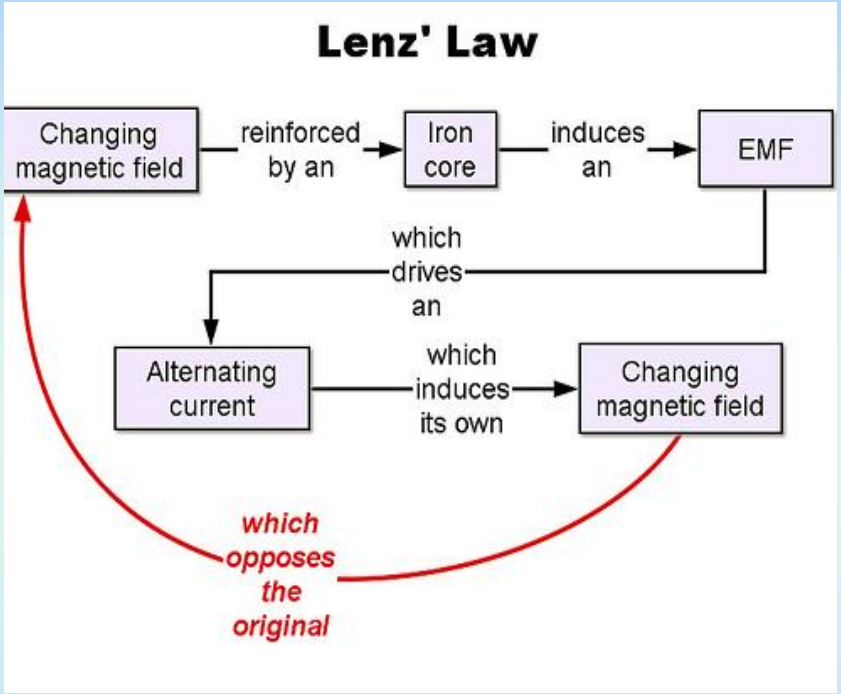
Electrical Potential from Gradient Switching

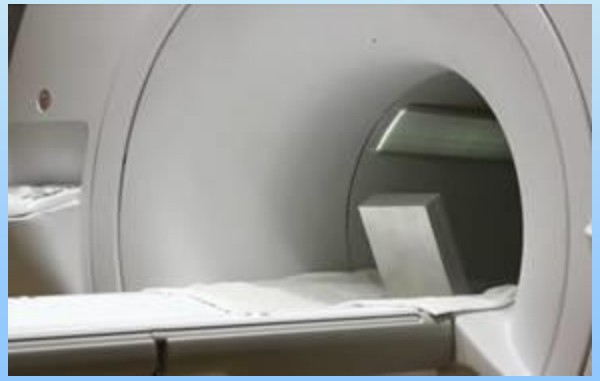
- Peripheral Nerve Stimulation
  - twitching or pain
- Magnetophosphenes
  - Light flash sensations caused by rapidly changing magnetic fields
- Induced Electrical Voltage
  - is proportional to $\Delta B/\Delta t$ (slew rate)
  - Current MRI scanners operate at about (33-40 mT/m maximum amplitude with 200 μs rise time)

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/farlaw.html#c2

Lenz's Law

- An EMF is generated by a change in magnetic Flux (Faraday)
- The polarity of the induced EMF produces a current whose Magnetic field opposes the change that produces it
- Creates unwanted time varying gradients and shifts in Bo (Eddy Currents)
  - Worse with DWI, Spect, MRA, Balanced GRE, and short TE sequences





Acoustic Noise

Gradients and Acoustic Noise

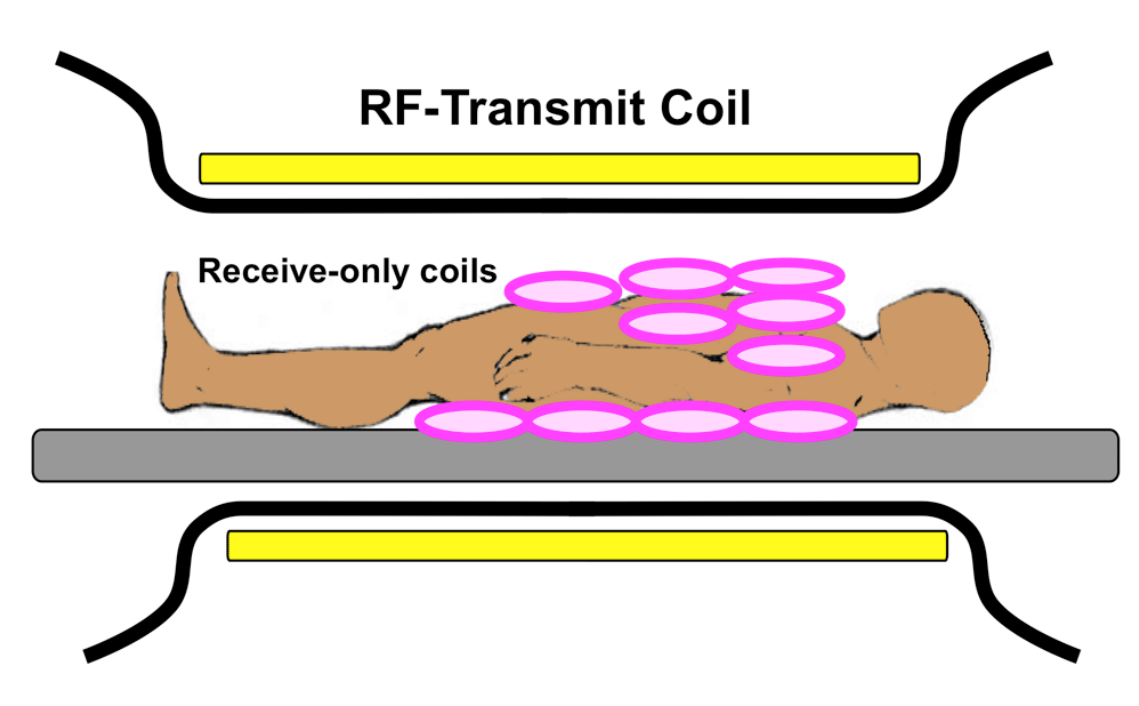
- The "knocking" in MR exams is caused when rapid motion of current in the gradients produces Lorentz forces
  - The gradient coils vibrate against their mountings
- Typically measured in dB (Decibel intensity)
- Parameters that influence db level
  - Slice thickness
  - FOV
  - TR, TE
  - Pt size and position within the bore
  - Pulse sequence

Acoustic Noise

- In a nutshell when the gradients are pushed harder the acoustic noise is increased.
- Sound intensity can reach 140 dB
  - Equivalent to a jet engine at take-off
  - Earplugs attenuate approximately 33 db.
- New technology available for scanners greatly reduces the decibel level
  - Hearing protection is still needed for most scanners and pulse sequences

Radiofrequency

Radiofrequency and Coils



http://mriquestions.com/receive-only-coils.html

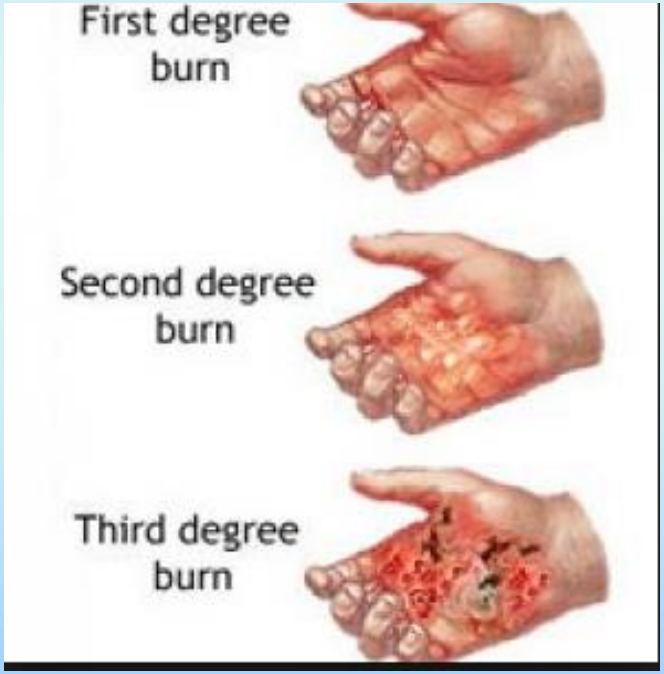
RF's Role in MR

- A necessary component of MR imaging. The RF pulse is the "excitation pulse" that causes resonance in the Hydrogen protons
- Referred to in MR imaging as the B_1 field
- During imaging energy is deposited in tissue and heating occurs through induction
  - Resistance of the tissue transformed into heat
  - The heating is caused by the electrical component of the RF pulse
- Since a current is produced that current will flow into any path available
  - Loops
  - Wires
  - Metallic Objects

Measurements of Heating

- SAR- Specific Absorption Rate
  - Normal
    - 2W/kg whole body
  - First Level
    - 4 W/kg whole body
  - 2nd level (research)
    - Limits are higher….
- B1+rms
  - B1 field plus an average of the RF amplitude
  - Becoming more frequently used in implant labeling

RF Potential for Burns



March 2010

Hidden Risk — Recent Incidents Highlight Need for Safety Vigilance in the MRI Suite

By Beth W. Orenstein
Radiology Today
Vol. 11 No. 3 P. 24

Several recent incidents involving patients receiving burns while in an MRI tube highlight the risk of presuming something can safely be brought near an MRI magnet. Maintaining a safe MR environment takes continual vigilance, noted MRI safety expert Tobias Gilk.

"There is no master list of things not to bring into the MR suite in part because it would take a team of people to develop such a list and treme keep it current," said Gilk, president and MR safety director for Mednovu products and services, including ferromagnetic detection systems for MF

http://www.nyalihealthcare.com/burns/

Antenna Effect

- RF burns can also occur in a length of conducting wire that doesn't form a loop
  - A result of electric field resonant coupling, or commonly called the "antenna effect"
- Heat energy is concentrated at the tip of the wire
- For example: These RF burns can occur using traditional pulse-oximeters in the MR environment

http://e-aps.org/search.php?where=aview&id=10.5999/aps.2016.43.6.612&code=2023APS&vmode=PUBREADER

MRI BURN PREVENTION

Tips for Keeping Patients Safe

Screen patients for implants, devices, and other metallic objects. Assume anything unknown is MR Unsafe.

Screen objects to ensure that anything entering the scan room is MR Conditional or MR Safe. Match conditions on MR Conditional devices with your scanner. All metals, even non-ferromagnetic ones, have the potential to heat up and cause burns.

Have patients change out of street clothes whenever possible.

Position patients to avoid skin-to-skin contact (e.g. no hands on hips, no crossed arms, no crossed legs, etc.).

Always use the manufacturer-provided padding to insulate the patient. Sheets and blankets may be added for patient comfort but are not a substitute for manufacturer-provided padding.

Route cables out of the scanner in a straight line. Don't coil cables or allow them to touch the patient.

Use only Normal Operating Mode and the lowest SAR, whenever possible.

Keep your eyes and ears on the patient at all times. Stay in communication with patients to identify warming. Monitor sedated patients using MR Conditional monitoring equipment.

FDA

SMRT

RF Electromagnetic Fields (B_1)

Required use of sponge pads to separate & insulate
(slides courtesy of Anne Sawyer)

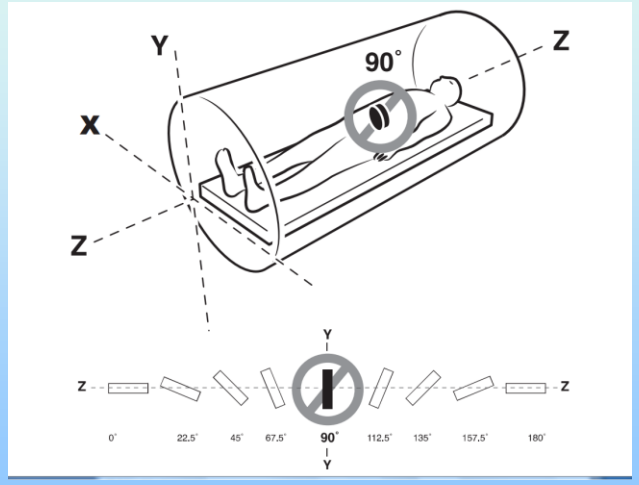
¼ inch (0.635 cm) of air GUARANTEED

Absolute requirement to scan human subjects

RF Electromagnetic Fields (B_1)

Sponge pads are required between arms & magnet bore walls and between any bare skin and anything else (skin to skin, wires to skin, coil to skin, etc)

Implant Safety



MR Dangers for Implanted Devices

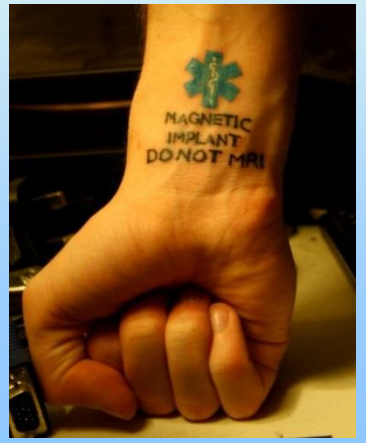
- Implant malfunction or damage
- Tissue Heating
- Induced electrical current
- Displacement of device
- Artifacts

Device interactions

- RF- Potential for
  - Interaction with Device
  - Heating
  - Induced electrical current
- Gradients can cause
  - Induced currents
- Static Fields
  - Displacement
  - Distortion and Artifacts
  - Some batteries may be affected and drained

Biomedical Effects on Implants

- Electro-mechanical devices can stop working due to exposure to the static magnetic field
  - Batteries can flatten
  - The patient must be monitored before and after MRI and the device checked +/- reprogrammed
- The function of Biomedical implants may be impaired by translational forces on the object
  - E.g. valves not working correctly



http://forum.biohack.me/discussion/101/neodymium-implant-questions/p1


MR

Artifacts

- Signal Loss due to dephasing
- Fat Suppression failure
- Displacement artifacts
- Warping between the implant and body tissue

Regulatory Guidelines

- FDA and IEC:
  - Controlled access over 5 gauss
    - 4T or greater IRB/IDE approval
    - 8T for Human subjects
  - PNS- threshold is pain
  - Normal Mode is suitable for all pts
    - 1st Level requires medical supervision
  - Heating
    - Head-38' or 3.2 average SAR
    - Torso- 39" or 10 w/kg ave SAR (over 10 grams)
    - Extremities- 40' or 10 w/g SAR (over 10 grams)

Training and Screening

- To ensure safety in a MR environment it is necessary that all individuals entering Zone 4 are properly prepared:
  - Screening-ALL
  - Training-All Staff
    - Yearly competencies
    - Frequent drills
    - Signs
    - Ferromagnetic detectors

MRI Safety Policies & Procedures

- As a Level 2 MRI Safety trained individual it is your responsibility to understand and apply MRI safety principles
- Regularly review and update MRI Safety policies and procedures
  - Follow them and ensure others do the same
- Safety information changes – be up to date

https://www.ncmic.com/prc/blog/office-staff/how-to-create-a-policy--procedures-manual.aspx

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  - Acoustic Noise
    - Decibel levels
    - Hearing Protection
- **Implant interactions**
- **Artifacts**

Credits

- WWW.MRSAFETY.COM
- HTTP://HYPERPHYSICS.PHY-ASTR.GSU.EDU
- MICHAEL STECKNER PHD TOSHIBA MEDICAL
- ANNE SAWYER BSRT R MR FSMRT-STANFORD UNIVERSITY
- MRIQUESTIONS.COM
- ACR WHITE PAPER ON MR SAFETY
- FDA GUIDELINES FOR MR SAFETY