MRI Safety Considerations

in the Staglin Center for Cognitive Neuroscience

This slide show is available as a video at http://www.cognitiveneuro.org/SafetyLinks.php
An Incident

Michael Colombini, *six years old*, was undergoing an MRI at Westchester County Medical Center when an oxygen canister was turned into a guided missile by the powerful MRI magnet. The canister was drawn into the magnet core while the boy was in the machine.
An Incident

Michael Colombini Lived to be Six Years Old.
General Facts

- The MRI is ALWAYS ON
- The Static Field has *no known* Biological Safety Risks
  
  *but…*
- There Have Been Numerous Disabilities and **Deaths**
- Most MRI Safety Hazards are Non-Intuitive
- Almost all MRI Accidents are Preventable
- Radio Frequency Energy Deposition May be High
- Cryogen Venting Can **Kill** by Suffocation
- High Voltages Exist Throughout the Facility
Overview

■ Principles of Operation
  ❑ Three Electromagnetic Fields
■ Instrument Risks
■ External Device Risks
■ Patient/Subject Risks
■ Consenting
■ Minimizing Exposure
■ Human Factors
■ Reporting
■ Resources
Safety

Stored Energy Equivalent to 2 kg of TNT
Push only the **Correct** Button

Emergency Electrical Stop

Scanner Stop
WARNING

DANGER!

THIS MAGNET IS ALWAYS ON!
Projectiles

www.SimplyPhysics.com
Projectiles

www.SimplyPhysics.com
Projectiles

NEVER TRY TO REMOVE OBJECTS ON YOUR OWN. CALL SERVICE or SENIOR CCN PERSONNEL.

www.SimplyPhysics.com
Push the Correct Button

Magnet Quench Button
ASTM MRI Labeling

MR SAFE. Poses no known hazards in the MRI environment.

- Non-Conducting
- Non-Magnetic
- Non-Metallic
ASTM MRI Labeling

**MR SAFE.** Poses no known hazards in the MRI environment.
ASTM MRI Labeling

**MR CONDITIONAL.** Poses no known hazards under specific conditions of use, such as field strength, position, etc...
ASTM MRI Labeling

MR UNSAFE. Not to be brought into the MRI environment.
Short Term Bioeffects

No scientifically confirmed harmful short-term bioeffects related to exposures to strong static magnetic fields

At 3 Tesla, reported effects include:

- Vertigo
- Headaches
- Metallic Taste
- Nausea
What are the Hazards?

Projectiles account for 10% of reported safety incidents.

10% are from Implanted Devices

71% are burns!
Current

- Electrical Kinetic Energy is called Current
- Current is the motion of charge
- Current Flows “through” conductors
- Current is Usually Denoted as, $i$
- The Unit of Current is “Amperes” or amps.
Current and Magnetism

- Current Flow
- Magnetic Field
- Electro Motive Force (Voltage)

Current Flow
Resistance

- Current flowing through a path experiences *Resistance*.
- Less current flow through higher resistance:
  - Larger resistance -> less current
- Energy is dissipated (lost) to that resistance
- Power

\[ P = iV = i^2 R = \frac{V^2}{R} \]
Induced Currents in the Body

Electrical Current

Magnetic Field
Specific Absorption Rate

Magnetic Field

Electrical Current
Specific Absorption Rate

- Electrical Current
- Magnetic Field
- Heat
Non-Magnetic Materials and Safety

- EKG Leads
- Pulse Oximeter
- Bolts from Fixation Device
- Tatoos

http://www.simplyphysics.com/
RF Safety

- Prevent skin-skin contact
- Keep sufficient distance between RF coil cables and skin
- Keep RF coil cables straight and avoid loops
- Keep RF coil cables parallel to the magnet bore
- Keep RF coil cables and ECG/VCG cables separated
- Never use damaged coils
Specific Absorption Rate

- SAR is **Quadratic** in Field Strength
- SAR Limits FSE, Spectro and MT protocols
- SAR can be Reduced by Faster Gradients
Rules

FDA Says:

- <8T for Adults and <4T for children is non-significant risk
- S.A.R. Limited by Temperature OR Power
  - < 0.1°C Core Temperature Increase
  - < 0.5°C Local Temperature Increase
  - < 2W kg
- Acoustic Noise < 140 dB (ouch!)
- Gradient Switching
  - 20 T/sec for Normal mode or Direct Determination on Humans
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Specific Absorption Rate (SAR)
Factors that Increase SAR

- Fast Spin Echo/RARE Sequences
- Short Echo Spacing, Long Echo Train Length
- Short tr or Many-Slice Spin Echo Scans
- Inversion Pulses: E.g., MP-RAGE
- Long Sequences
- Magnetization Transfer
- Saturation Pulses
Controlling SAR in Fast Spin Echo

- Increase the Echo Spacing
  - Allows more time for tissue cooling
  - \textit{Increases minimum te and blurring}

- Decrease the Echo Train Length
  - \textit{Increases imaging time}

- Increase the TR
  - \textit{Increases Imaging Time}

- Reduce the number of slices
  - \textit{Reduces volume coverage}
Controlling SAR

- In MP-RAGE Small Increases in TE can help
- In Spin Echo Imaging, increase tr or decrease number of slices
- Use SAT pulses only when needed
- BOLD EPI Scans are Intrinsically low S.A.R. studies
- Allow Cool Down after High SAR studies
- Do not use excess blankets, clothing or covering
- Advise subjects that significant heating is NOT normal
Thermoregulation Problems

- Diabetes
- Obese Patients
- Cardiovascular Disease
- Fever
- Hypertension
- Old Age

- Diuretics
- Beta Blockers
- Sedatives
- Muscle Relaxers
Unsafe Populations

- Mechanical
  - Aneurysm Clips
  - Shrapnel in Eyes or Brain
  - Recent Implants in Soft Tissue
  - Piercings (?)

- Thermal
  - Implanted Leads or Wires
  - Certain Makeup
  - Hair Weaves
  - Almost ANY Electrical Conductor
Device Hazards

- Movement or Displacement
- Heating
- Altered Device Performance
- Artifacts

Common Problems include
- Aneurysm Clips
- Stents
- Pacemakers
- Surgical Wires
- Dental Appliances
- Shunts/Drains
- Heart Valve Prosthetics
- NeuroStimulators
- Permanent Contraceptives
Electromagnetic Waves

Antenna Resonance

- Occurs when antenna length bears half integer relation to RF wavelength
- Effective Antenna Length depends on Material Properties and Shape
- Wavelengths:
  - 3T: 2.3 meters
  - 1.5T: 4.6 meters
- Hazards may *Increase* or *Decrease* with field strength
- Do NOT Assume that A Device is Safe Because it has been Used Before
Deep Brain Stimulation (DBS) Electrodes

T2-weighted MRI scan of the brain showing edema around the left DBS electrode.
Safety Results

Removing resonance reduces heating
Acoustic Noise

- Ear Protection is Always Required
- Ear Plugs and/or Noise Reducing Headset
- Always Ask Subject about Noise Level
Magnetostimulation & Gradient Shape

He Feels Stimulation
She Feels Nothing

Sensory stimulation by time-varying magnetic fields.
Cohen MS, Weisskoff RM, Rzedzian RR, Kantor HL

Physiological effects of fast oscillating magnetic field gradients.
Budinger TF, Fischer H, Hentschel D, Reinfelder HE, Schmitt F.
Screen Everyone

Medical Personnel

Friends and Family

Research Colleagues

Emergency Workers
Patient Interview

- Metallic Foreign Body?
- Permanent Cosmetic or Tattoo?
- Prior Surgery?
- Wig or Hair Weave?
Pregnancy

- No Known Pregnancy Effects

- ISMRM and ACR:
  - MRI Is Acceptable in Pregnancy to Address Clinically-Important Questions
  - Acceptable Regardless of Trimester
  - Informed Consent Should be Obtained
Subject Consent

- Consent is Required for ALL Human Subjects at the Staglin Center.
- IRB Documents must be Current and on File Prior to Scanning.
- Subject Consent Should be Obtained in Private
  - Personal Medical Information is Confidential
  - Some Questions may be Personal
- Subjects Should not be Exposed to Extra Risk for Research Scans.
- Any Potential Safety Risk Must be Evaluated by Senior Personnel.
Subject Preparation

Ask subjects to wear loose comfortable clothing:

- Sweat Pants
- Track Suits
- T-Shirts
- Scrubs
Subject Comfort

“Twenty-five percent of the participants experienced moderate to severe anxiety during the MRI scan.

Prescan scores on the Claustrophobia Questionnaire (CLQ: Rachman and Taylor, 1993) significantly predicted participants' distress during the scan; pain and anxiety sensitivity did not.”

Claustrophobia and the Magnetic Resonance Imaging Procedure

Heather K. McIsaac,1,3 Dana S. Thordarson,1 Roz Shafran,1 S. Rachman,1 and Gary Poole2

Journal of Behavioral Medicine, Vol. 21, No. 3, 1998
Subject Comfort

- Don’t Drink (coffee) and Scan
- Ask Subjects to Void Before Scanning
- Tell Your Subjects What to Wear and How to Dress
- Avoid Asking for, “Just one More” Scan
- Stay in Contact
- Avoid Restraints
- Offer Music or Videos
Subject Preparation

Remove all:
- Metallic Personal Belongings
- Hearing Aids
- Watches
- Jewelry
- Clothing with Metal Fasteners
- Makeup
- Void before scanning.
Subjects Must Remove the Following:

- Cell phones
- Beepers
- Watches
- Jewelry
- Prostheses
- Wigs
- Hairpins
- Barrettes
- Metallic Rx patches
Emergency Procedures

- Press the switch appropriate to the emergency
- Evacuate the subject immediately
- Inform rescue workers of the magnetic field dangers
- Only use MR-compatible equipment
- Document the emergency or accident
In the Event of a Quench

- Subject and MR personnel vacate room **Immediately**
- Inform rescue workers **Immediately**
- Inform service engineers **Immediately**.
Recommendations

- Ensure regular equipment maintenance
- Create emergency plans
- Conduct emergency exercises
- Provide precise emergency documentation
- Provide non-magnetic tools for cleaning and emergency service
The Biggest Risk

- The Biggest Risk is Inattentiveness
- Never Defer Responsibility for Safety to Someone Else in the Room

Aug. 1, 2001 Michael Colombini was undergoing an MRI, or magnetic resonance imaging, at Westchester County Medical Center last Friday when an oxygen canister was turned into a guided missile by the powerful MRI magnet. The canister was drawn into the magnet core while the boy was in the machine. The result was a fatal blow to the child's head.

The nurse who carried the oxygen canister into the room where Colombini was being scanned mistakenly believed the canister was made of a nonmagnetic material, like aluminum.
Our Goal

- ZERO SAFETY INCIDENTS.
Safety Resources

http://www.semel.ucla.edu/staglin

http://users.fmrib.ox.ac.uk/~peterj/safety_docs/index.html
Resources

Questions: Mark Cohen, mscohen@ucla.edu, or other senior members of the Staglin Center

These slides are available online at:

http://www.semel.ucla.edu/staglin and
http://www.cognitiveneuro.org/SafetyLinks.php