Bildgebende Systeme in der Medizin
Magnetresonanztomographie V:
Gefahren und Schutzmaßnahmen
Dr. Friedrich Wetterling

Siemens Magnetom Symphony
• $B_0 = 1.5$ Tesla
• Quantum-gradient:
  30 mT/m
• slew rate: 125 T/m/s
• removable patient couch
• short magnet: 1.6 m
• relatively open bore
• 8 receiving channels
MRI Components: Physical Parameters

- technical component
- physical parameter

- static field $B_0$ → $M_0$
- radiofreq. RF → signal
- gradients $G_{xyz}$ → image

Operation Mode

normal operation mode
- field exposition where a physiological stress of the patient can be excluded
- routinely control of the patient is adequate

controlled operation mode 1. level
- field exposition where a physiological stress of the patient is possible
- medical patient control is required (i.e. monitoring of physiological parameters)
- MRI system has to notify higher operation mode which has to be confirmed by the operator

controlled operation mode 2. level
- field exposition with a significant risk for the patient
- application possible for clinical testing
- approval by the local ethic commission
- MRI system should not allow an unintended switch
Warnings

- strong magnetic field
- radiofrequency

interdictions:
- cardiac pacemaker
- open fire
- metallic implants
- watch, camera
- magnetic fire extinguisher
- metal: scissor, key
- magnetic disc

Static Magnetic Field: $B_0$ I

control area: 0.5 mT - line

source: Reiser and Semmler, "Magnetresonanztomographie" 2002
Static Magnetic Field: $B_0 = 3$ Tesla

control area: 0.5 mT - line
$B_0$ - Danger

$B_0$
- missile effect
  - strong forces to ferromagnetic materials
- forces and torques to implants
  - stent
  - gunshot wound, rest of projectile
- failure of electromagnetic devices
  - cardiac pacemaker
  - computer
  - controlling system
- physiologic effects
  - vertigo when entering the magnet (> 3 Tesla)

$B_0$ – Example I
B₀ – Example II

courtesy: Gross, Siemens Erlangen

B₀: Serious Accident of a Fireman

problem
  • no emergency plan of institution
  • insufficient training of fire department
  • neglecting of warnings

simulated image of accident, courtesy Olbracht, fire department Langenselbold
B₀: MR – Compatible Fire Extinguisher

when?
- only in case of emergency
- if people have to be saved
- and if saving is not possible due to magnetic field forces

how?
- inducing magnet quench
  - press “magnet stop” switch
- all persons should be saved and leave the magnet room quickly
- acute danger of suffocation
- protect magnet room

B₀: Emergency Switch-Off Magnet
$B_0$: Danger from Cold Gases and Fluids

- magnet as pressure tank
  - quench
    - evaporation of fluid helium
    - high pressure
    - quench pipeline to outdoor
    - cold gases can come into the examination room
  - "burning" at cold surfaces
  - displacement of oxygen
  - danger of suffocation

$B_0$: Magnet Stop and Emergency Stop

- magnet stop
  - interrupts super-conduction, magnet coil gets normal conducting
  - current in magnet coil comes to rest
  - coil wires get hot and helium evaporates (quench)
  - magnetic field is switched off

- emergency stop
  - all electric systems of the MR system are switched off
  - magnetic field is still on
  - cooling system is off
  - magnet stop is still possible since battery-operated
B₁: Gradient Field G(t)

G(t)
- temporal variation of magnetic field (dB/dt)
  - induction of eddy currents in the object / body
  - eddy currents run through nerves
  - peripheral nerve stimulation
  - stimulation of myocardium?
  - interaction with implants
- extreme noise
  - ear protection

B₁: Critical Values

PNS - threshold
- threshold of beginning of nerve stimulation using switching gradients (beginning of stomach pricking)
- is determined in volunteer experiments for each gradient system
- complex function of
  - gradient amplitude
  - slew rate
  - pulse shape
  - pulse duration
  - number of pulses
- compliance of threshold is done by software („SAFE model“)

<table>
<thead>
<tr>
<th></th>
<th>normal</th>
<th>1. level</th>
<th>2. level</th>
</tr>
</thead>
<tbody>
<tr>
<td>area of PNS</td>
<td>Cardiac stimulation</td>
<td>PNS 1.0</td>
<td>PNS 1.0</td>
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</table>

Normal 1. level 2. level
80% PNS 100% PNS >100% PNS
RF: Radiofrequency

radiofrequency field

- is directly absorbed
- critical value:
  - specific absorption rate (SAR)
- can be resonant induced in conductive structures
- creates offset currents in tissue
- massive heating
- flashover
- destroys not connected coils

Wagle and Smith. AJR 2000

RF: SAR Critical Values

<table>
<thead>
<tr>
<th>body part</th>
<th>normal [W/kg]</th>
<th>1. level [W/kg]</th>
<th>2. level [W/kg]</th>
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<tbody>
<tr>
<td>whole body</td>
<td>2</td>
<td>4</td>
<td>&gt; 4</td>
</tr>
<tr>
<td>part body</td>
<td>2-10*</td>
<td>4-10*</td>
<td>&gt; 10</td>
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<tr>
<td>head</td>
<td>3.2</td>
<td>3.2</td>
<td>&gt; 3.2</td>
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<tr>
<td>local (head, body)</td>
<td>10</td>
<td>10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>local (extremities)</td>
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<td>20</td>
<td>&gt; 20</td>
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<td>temperature increase</td>
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<td>1°C</td>
<td>&gt; 1°C</td>
</tr>
<tr>
<td>body stem</td>
<td></td>
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</table>

* scales with the ratio of "exposed patient mass / total patient mass"

→ patient weight and age are relevant for safety!
RF: Flashover

ECG - system “Tesla plus” EFTES03D, Mammendorfer Institute for Physics and Medicine
„MR compatible" according to producer!

Kugel et al. Eur Radiol 2003
**contra indication**
- cardiac pacemaker
- neuro stimulators
- (deep brain stimulators)
- ferromagnetic implants
- gun projectiles
- paramagnetic stents up to 2 weeks after implantation

**information**
- [http://www.mrisafety.com](http://www.mrisafety.com)

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**MR Safety Labeling**

**MR safe**
- an item which poses no known hazards in all MR environments

**MR conditional**
- an item which has been demonstrated to pose no known hazards in a specified MR environment with specified conditions of use.
  - Field conditions that define the specified MR environment include:
    - field strength,
    - spatial gradient,
    - dB/dt (time rate of change of the magnetic field),
    - radio frequency (RF) fields, and
    - specific absorption rate (SAR).
  - additional conditions, including specific configurations of the item, may be required

**MR unsafe**
- an item which is known to pose hazards in all MR environments

ASTM International. Standard practice for marking medical devices and other items for safety in the magnetic resonance environment. F 2503-05
Light Vizier

Patient localizing and referencing
- Ask patient for closing eyes before laser switch on

Danger of Crushing

Couch movement
- Watch position of arms and fingers
- Save connections, ECG-wires, and alarm ball
- Push "couch stop" – Patient couch can be moved manually
Other Safety Risks

lens effect

- phantoms should not be placed at direct sunlight

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MR Safety Aspects: Summary

static magnetic field
- missile effect
- influencing equipments
- physiological effects

gradients
- peripheral nerve stimulation
- noise

radiofrequency
- heating
- coils connected?

cold gases / fluids
- suffocation
- “burning”

emergency procedures
- magnet stop
- emergency stop
- couch stop

patient information
- patient information sheet
- alarm ball

control area
- watch and take care about
- unknown people (i.e. service and cleaning people, anesthesia doctors and staff, ...)
- unknown equipment and systems before bringing into the magnet room

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