MRI: Medical Applications of NMR

Meike Roth
Basis Seminar AK Spieß, SS 08
Outline

1. History of MRI
2. Theory and Facts
3. Applications in medicine
   Abilities, Contrast, Comparison of imaging techniques
4. Techniques and contrast agents
   Angiography, $^3$He, dynamic MRI, f-MRI
5. Summary and Outlook
History of MRI

- 1971: distinction between tumors and healthy tissue by NMR (Damadian)
- 1973: Gradient fields by Lauterbur, Sir Mansfield
- 1975: Phase and frequency encoding, FT-NMR (Ernst)
- 1977: EPI (Echo Planar Imaging)
- 1985: FLASH by Frahm and Haase
- 1993: fMRI as new application of EPI
- 1999: 1st truly portable MRI (MagneVu)
Prototype MRI Equipment in 1970s
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Theory

Spectroscopy

\[ \omega = \gamma B \]

MRI

\[ G_x = \frac{\partial B_z}{\partial x} \]

→ Frequency encoding (during acquisition)

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MRI of humans

- protons are suitable to use for NMR and MRI
- the human body consists of a bigger part of water → many protons
- problems:
  - shrapnel
  - cardiac pacemaker
What do you need...

receiver and computer

magnet

patient

amplifier
detector

B = \mu_0 l

"Now you know why it's called an Open MRI."
The measurement
Choose of the slice during excitation

\[ \omega(z) = \omega_0 (B_0 + G_z \cdot z) \]

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Spatial encoding

Phase encoding

during the evolution time $t_{ph}$
Phase encoding
Frequency encoding during acquisition

Voxel
The k-space

\[ s(t) \xrightarrow{\text{FT}} S(\omega) \]

\[ t \xrightarrow{\gamma G} \vec{k} \xrightarrow{\text{FT}} P(\vec{r}) \]
The k-space

FT

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**Facts**

- weight 3900 kg
- helium capacity 1640 L
- RF-System 63 MHz, 15 kW
- gradient: 20-40 mT
- 2003: ~ 22000 MRI scanners worldwide with ~ 75 million scans per year
- possible risks:
  - warming (>1°C), noise
  - stimulation of peripheral nerves by gradients (highfield scanners)
  - giddiness, claustrophobia
  - no genetoxic potential of magnetic fields known
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Whole body MRI
Abilities of MRI?

- no physiological stress due to ionizing radiation
- information of functions
- good determination between different kinds of tissues
## Contrast in MRI – relaxation times

<table>
<thead>
<tr>
<th>Tissue</th>
<th>$T_1$ [ms]</th>
<th>$T_2$ [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>muscle</td>
<td>850</td>
<td>45</td>
</tr>
<tr>
<td>fat</td>
<td>250</td>
<td>80</td>
</tr>
<tr>
<td>liver</td>
<td>400</td>
<td>40</td>
</tr>
<tr>
<td>blood</td>
<td>1400</td>
<td>180/250</td>
</tr>
<tr>
<td>CSF</td>
<td>2000</td>
<td>150</td>
</tr>
<tr>
<td>solids</td>
<td>1</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Comparison of imaging techniques

x-ray
- Projection (only)
- Bones bright
- Poor tissue contrast

CT
- Slices (only transversal)
- Bones bright
- Moderate tissue contrast

MRI
- Slices (any direction)
- Bone marrow bright
- Nice tissue contrast
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Contrast in MRI

$T_1$ contrast
$T_E = 16$ ms
$T_R = 400$ ms

$\Rightarrow$ white matter

$T_2$ contrast
$T_E = 95$ ms
$T_R = 3000$ ms

$\Rightarrow$ gray matter

Gd enhanced
$T_1$ contrast
$T_E = 16$ ms
$T_R = 500$ ms

Nobuhiko Hata, Ph.D.1, Paul R. Morrison, M.S.2, Joachim Kettenbach, M.D.1, Peter McL. Black, M.D., Ph.D.2, Ron Kikinis, M.D.1, Ferenc A. Jolesz, M.D.1

Angiography

Angioplasty of the diabetic foot syndrome

Novel intravascular contrast agent: Vasovist®
Perfusion of the heart

ml/min/g ?

Pre contrast agent
Peak contrast agent right ventricle
Peak contrast agent left ventricle
Peak contrast agent myocardium

Weber S
Perfusion of the lung

Neeb D, Kreitner KF et al, Magn Reson Med
Ventilation of the lung

Enhancement of lung images with hyperpolarized $^3$He

$^1$H

$^3$He
Ventilation of the lung

hyperpolarized $^3$He
Functional MRI of the brain

- illustration of brain activities
- change of blood circulation
  - measureable
  - activity in regions of the brain

[Image: Illustration of brain activity with color-coded regions indicating different levels of activity.]
Conclusions

• MRI powerful diagnostic tool in medicine

• todays limits:
  - spatial resolution (0.5 mm ... 100 µm)
  - time resolution: 70 ms
  - sensitivity: 1 µmol
  - physiological: stimulation of peripheral nerves
  - field intensity: whole body 11 T, experimental 17.6 T
  - costs: clinical, 1.5 T: 2 M€

• future:
  - smaller -> microimaging
  - faster -> fMRI (brain)
• D. Weishaupt, V. D. Köchli, B. Marincek. Wie funktioniert MRI. Springer

• O. Dössel. Bildgebende Verfahren in der Medizin. Springer

• Paul-Philipp Zänker. NMR spectroscopy and imaging of hypedrpolarized gases: Fundamental aspects ans applications. Dissertation 2007

• H. Friebolin. Ein- und zweidimensionale NMR-Spetroskopie. Wiley
THE END

nonsmoker

smoker

Guenther et al. NBM 2000