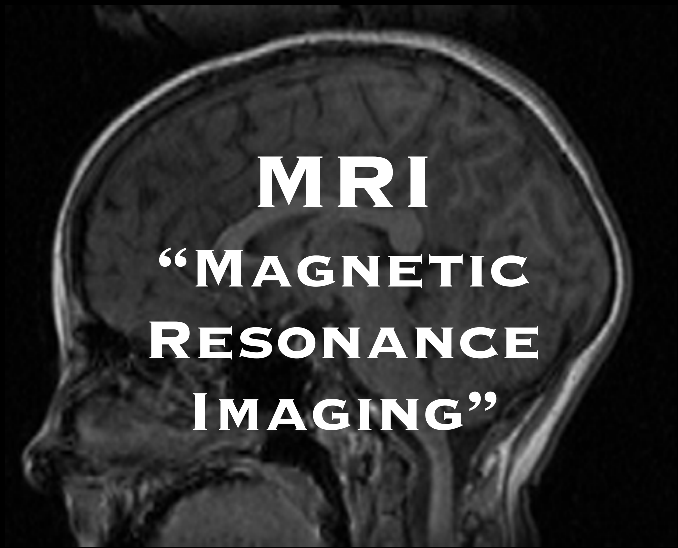


MRI

“Magnetic Resonance Imaging”

Times, October 9, 2003

This Year’s Nobel Prize in Medicine

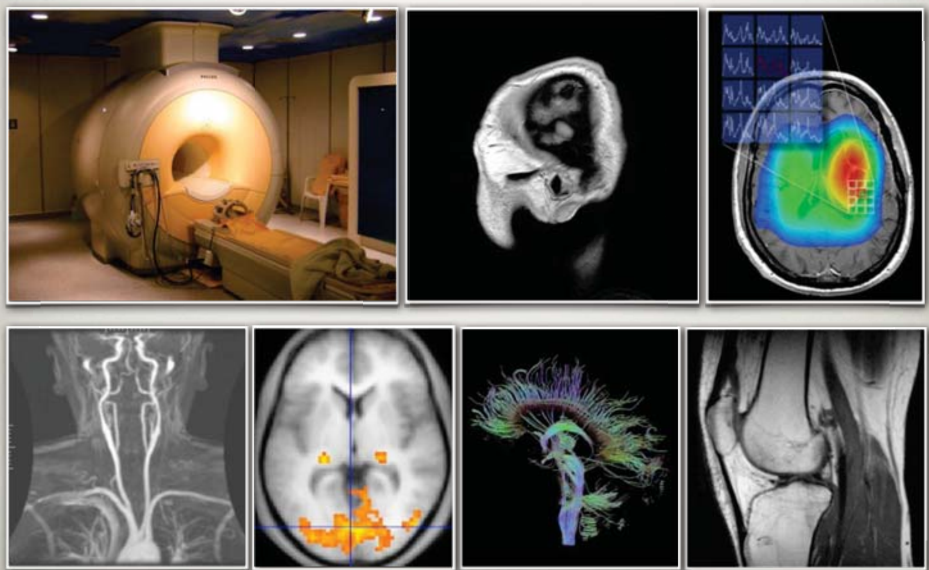
The Shameful Wrong That Must Be Righted

This year the committee that awards The Nobel Prize for Physiology or Medicine did the one thing it has no right to do: it ignored the truth. Eminent scientists, leading medical textbooks and the historical facts are in disagreement with the decision of the committee. So is the U. S. Patent Office. Even Alfred Nobel’s will is in disagreement. The committee is attempting to rewrite history.

The Nobel Prize Committee to Physiology or Medicine chose to award the prize, not to the medical doctor/research scientist who made the breakthrough discovery on which all MRI technology is based, but to two scientists who later made technological improvements based on his discovery.

WHAT EMINENT SCIENTISTS AND AUTHORS SAY

MRI is a revolutionary device



MRI

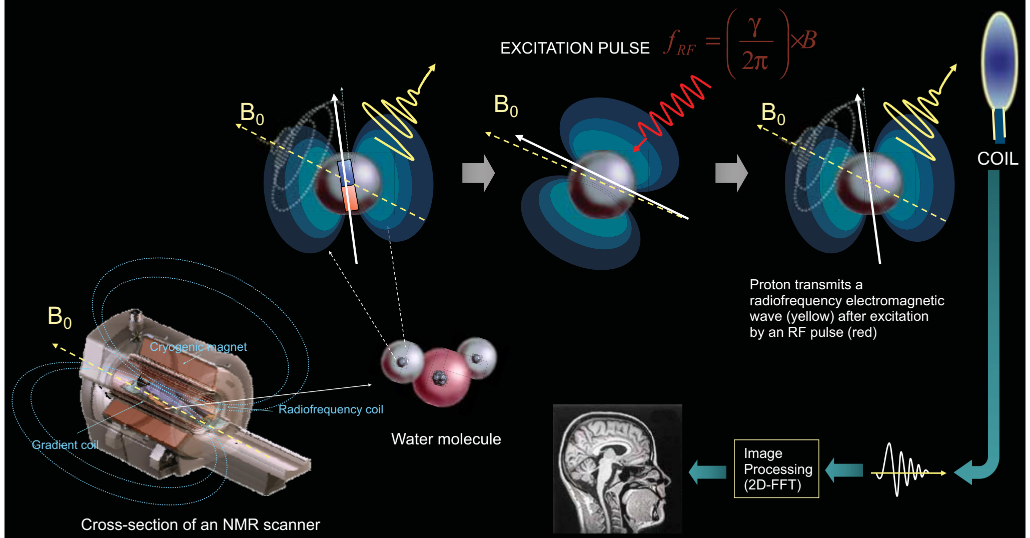
- History
- Fundamental processes
  (nuclear spin, precession, resonance, excitation-relaxation)
- Imaging I: spatial encoding
- Imaging II: contrast
- Contrast agents
- Artifacts
- Dangers, contraindications
- Applications, future trends

MRI is a non-invasive tomographic method

MRI History

- 1970 - Raymond Damadian: T1 and T2 relaxations of neoplastic and normal tissues are different.
- 1972 - Raymond Damadian: US patent
- 1973 - Paul Lauterbur: 2D MR imaging method
- 1974 - Peter Mansfield: 3D MR imaging method
- 1977 - Raymond Damadian: first MR scanner (“focused field” method)
- 2003 - Nobel-prize: Lauterbur, Mansfield
- NMR: method which has received the most Nobel-prizes (6)
  Otto Stern (1942), Isidor Rabi (1944), Felix Bloch, Edward Purcell (1952), Richard Ernst (1991), Kurt Wüthrich (2002)

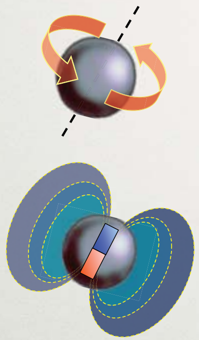
Nuclear Magnetic Resonance Imaging: Basic principle

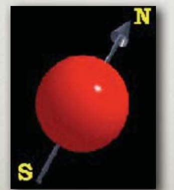


Atomic nuclei with nuclear spin: elementary magnets


Otto Stern


W. Gerlach





Atomic nuclei have mass: $m_{proton} = 1{,}67.10^{-24}$ g

Atomic nuclei carry angular momentum: $L = \sqrt{l(l+1)}\hbar$

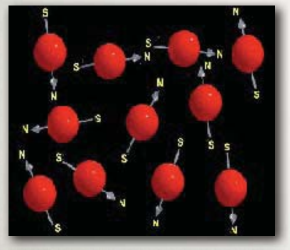
l = spin quantum number

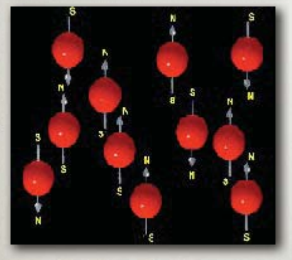
Atomic nuclei carry charge: $q_{proton} = 1{,}6.10^{-19}$ C

Atomic nuclei possess magnetic moment: $\mu_i = \gamma L$

γ = gyromagnetic ratio
L = angular momentum

Nuclear Magnetic Resonance (NMR)

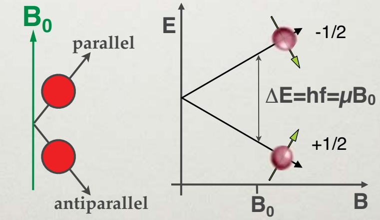




In absence of magnetic field:
random orientation of elementary magnets

In magnetic field:

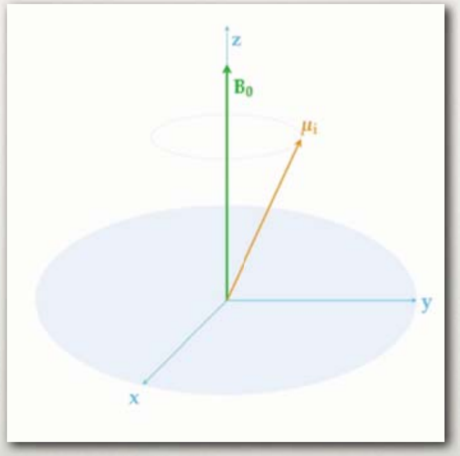
elementary magnets orient | energy levels split



Edward Purcell, 1946

Useful nuclei in MRI: ^{1}H, ^{13}C, ^{19}F, ^{23}N, ^{31}P

Nuclear Magnetic Resonance: Spin Precession



Precession or Larmor frequency:

$$\omega_0 = \gamma B_0$$

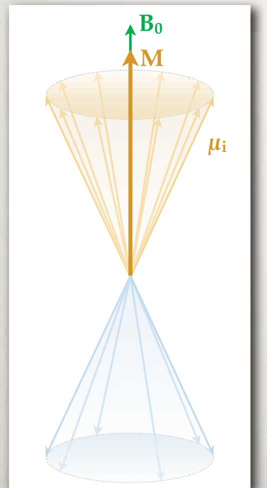
$$f_{Larmor} = \frac{\gamma}{2\pi} B_0$$

Felix Bloch, 1946

Net Magnetization

Due to spin access in different energy states

Low energy state
parallel in case of proton



High energy state
antiparallel in case of proton

B_0 = magnetic field
M = net magnetization

Ratio of magnetic spins in high- (antiparallel) and low-energy (parallel) states:

$$\frac{N_{antiparallel}}{N_{parallel}} = e^{-\frac{\Delta E}{k_B T}}$$

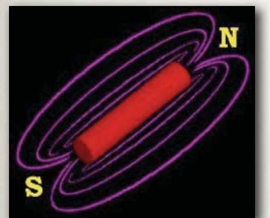
Boltzmann distribution

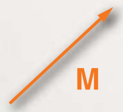
Magnetic field in MRI:
20-50 thousand times that of the Earth's magnetic field

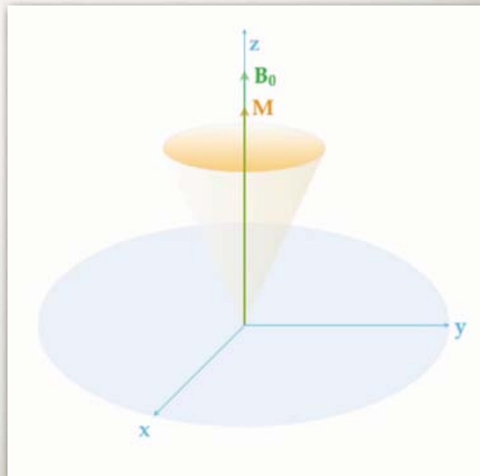
Excitation

Using radio frequency radiation

Resonance condition: Larmor frequency





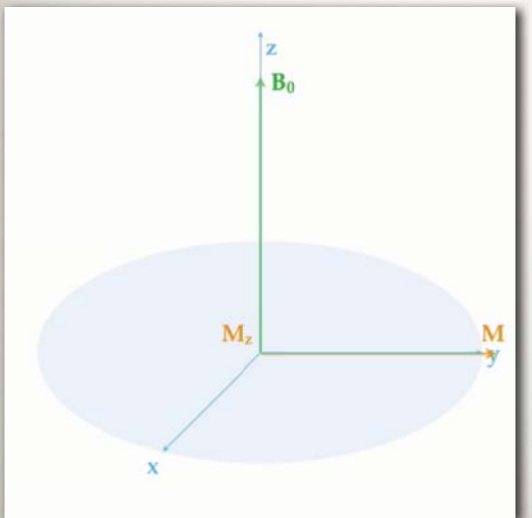


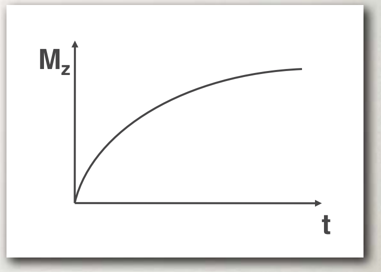
B_0 = magnetic field
M = net magnetization
B_1 = irradiated radio frequency wave

Electromagnetic radiation in MRI:
Radio waves

Spin-lattice relaxation

T1 or longitudinal relaxation

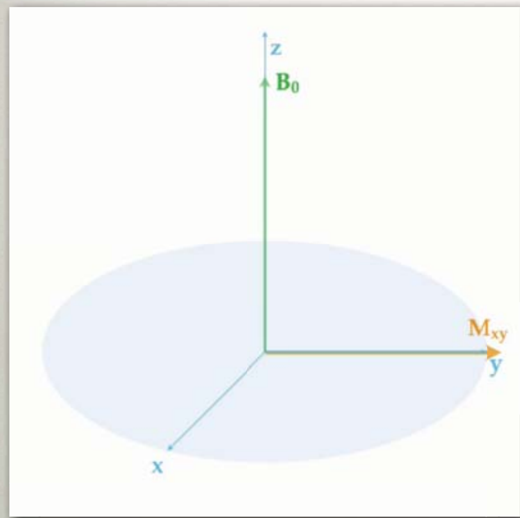


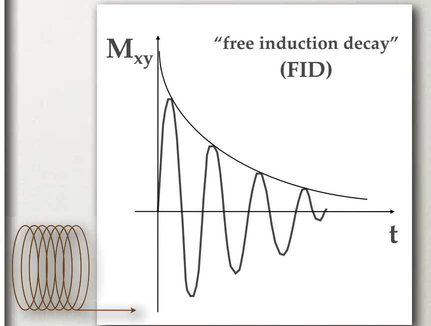


T1 relaxation time:
depends on interaction
between elementary magnet (proton)
and its environment

Spin-spin relaxation

T2 or transverse relaxation



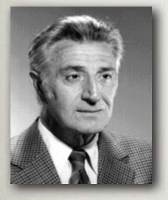


T2 relaxation time:
depends on interaction between
elementary magnets (protons)

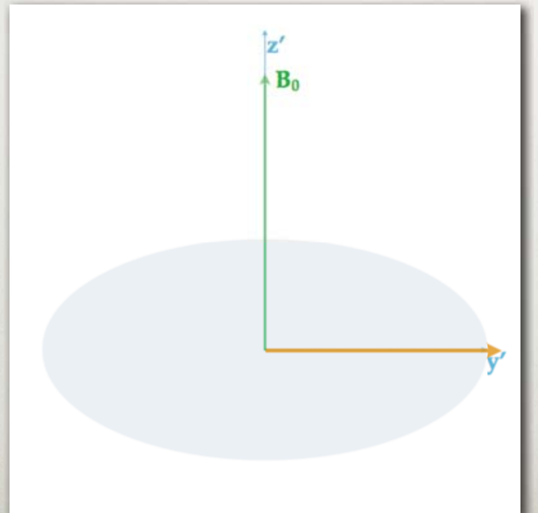
Spin-spin relaxation

T2 or transverse relaxation

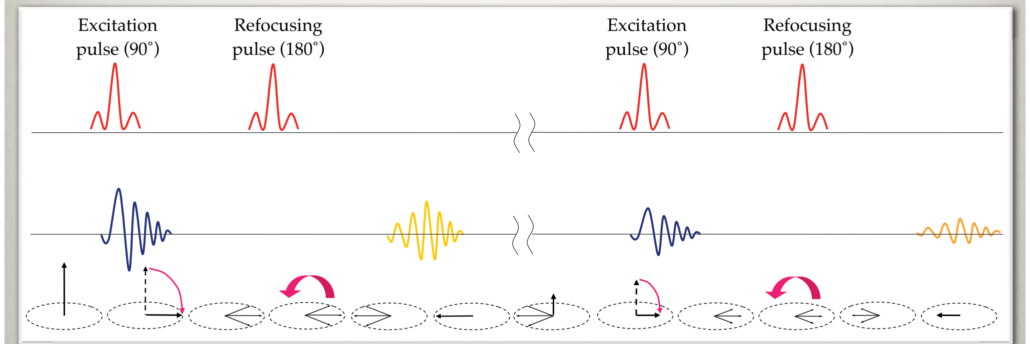
Repetitive pulses of excitation and subsequent relaxation: spin-echo sequence

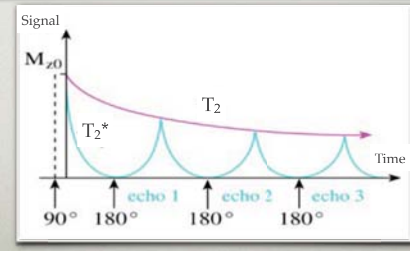


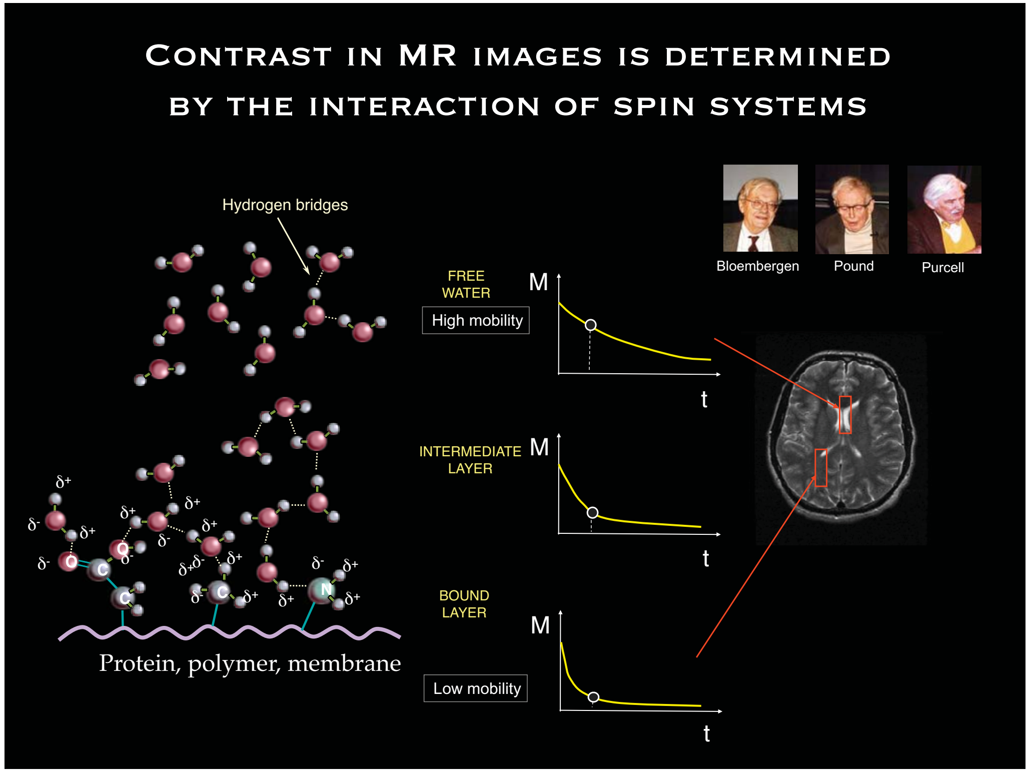
Erwin Hahn, 1949

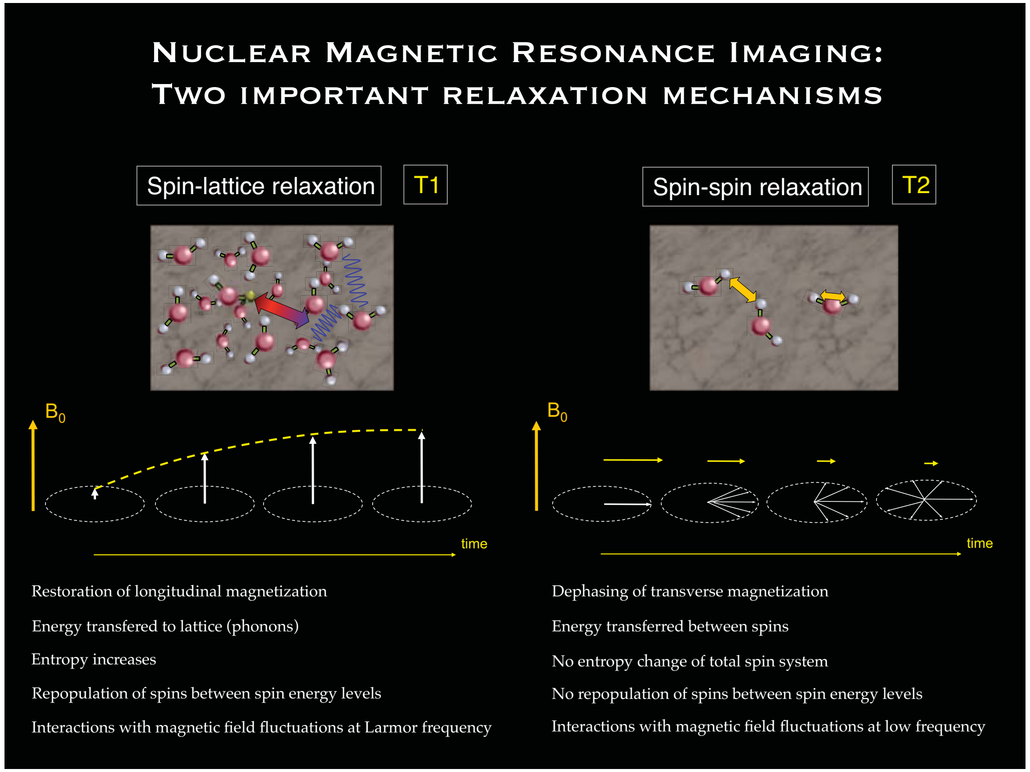


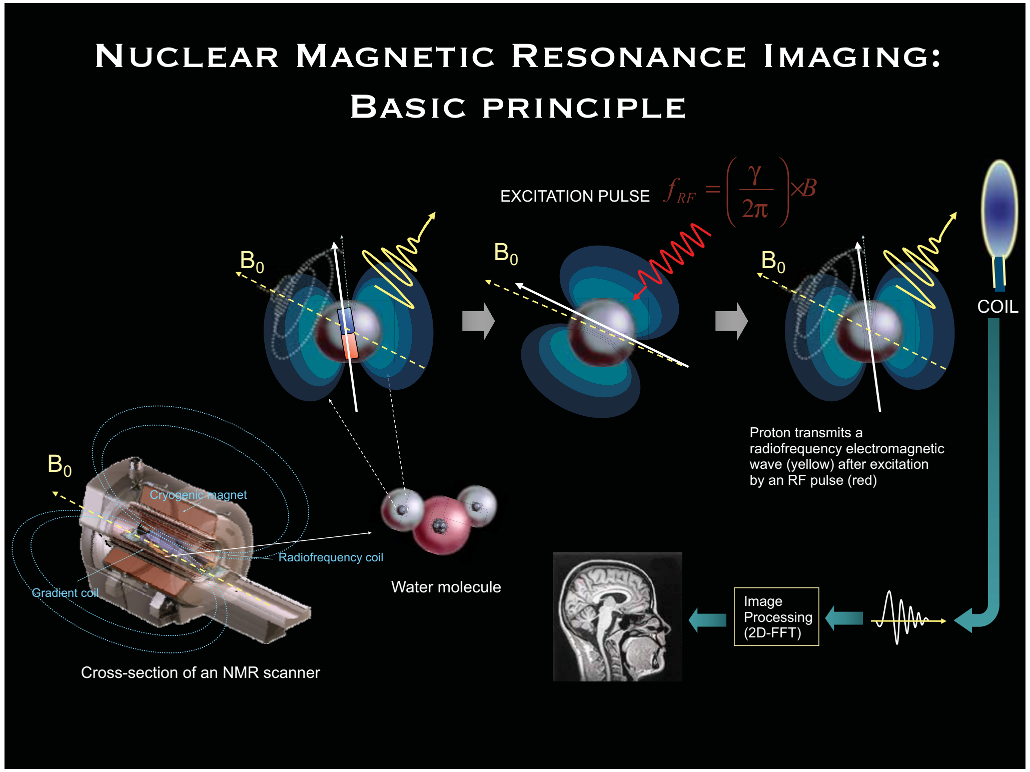
The spin-echo experiment

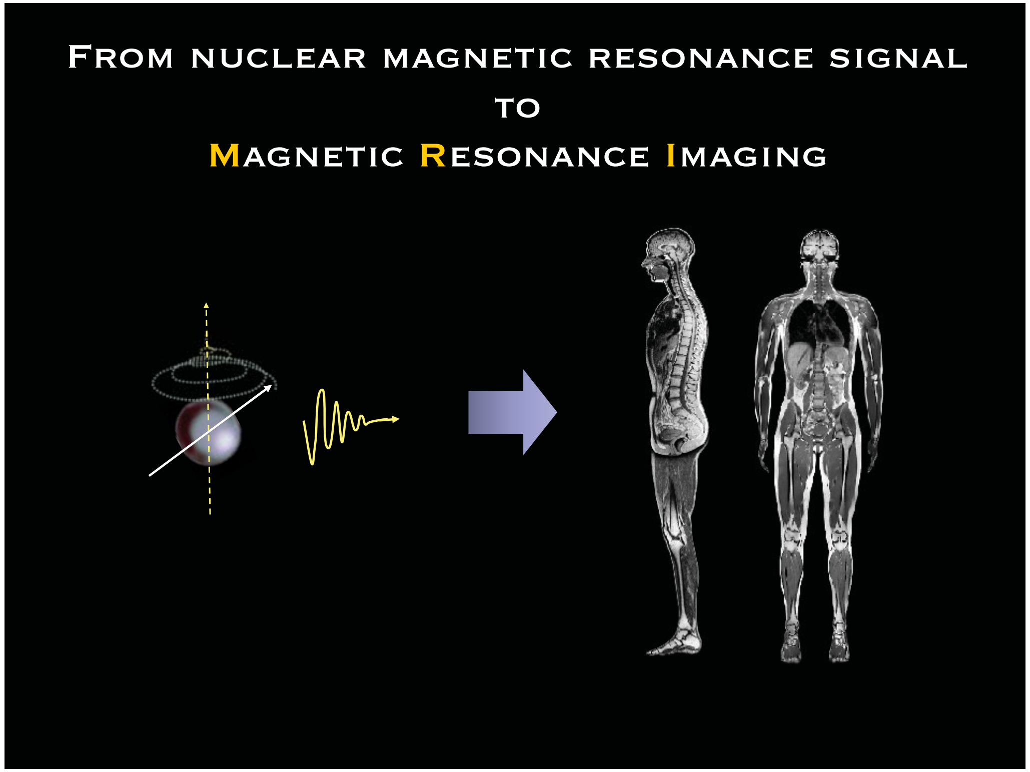





Contrast in MR images is determined by the interaction of spin systems
Hydrogen bridges
Protein, polymer, membrane
FREE WATER
High mobility
INTERMEDIATE LAYER
BOUND LAYER
Low mobility
M
t
Bloembergen
Pound
Purcell

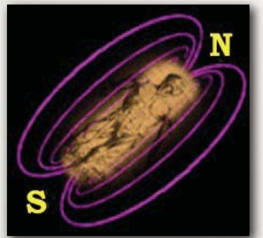

Nuclear Magnetic Resonance Imaging: Two important relaxation mechanisms
Spin-lattice relaxation
T1
Spin-spin relaxation
T2
B0
time
Restoration of longitudinal magnetization
Energy transfered to lattice (phonons)
Entropy increases
Repopulation of spins between spin energy levels
Interactions with magnetic field fluctuations at Larmor frequency
Dephasing of transverse magnetization
Energy transferred between spins
No entropy change of total spin system
No repopulation of spins between spin energy levels
Interactions with magnetic field fluctuations at low frequency

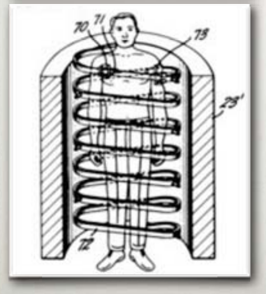

Nuclear Magnetic Resonance Imaging: Basic principle
EXCITATION PULSE $f_{RF} = \left(\frac{\gamma}{2\pi}\right) \times B$
B0
COIL
Proton transmits a radiofrequency electromagnetic wave (yellow) after excitation by an RF pulse (red)
Cryogenic magnet
Radiofrequency coil
Gradient coil
Water molecule
Cross-section of an NMR scanner
Image Processing (2D-FFT)


From nuclear magnetic resonance signal to Magnetic Resonance Imaging

MRI:

Net magnetization of the human body is generated

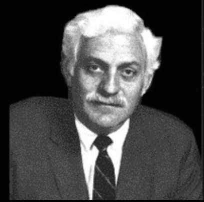




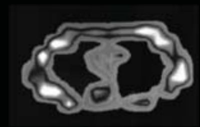
“Indomitable”

First NMR experiments in vivo

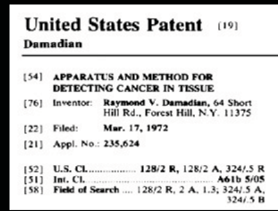
Downstate Medical Center - Brooklyn, 1972



Raymond V. Damadian



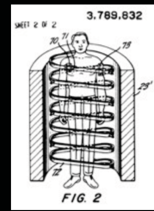
First MRI scan



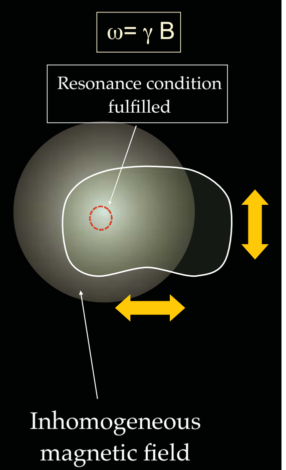
United States Patent [19]
Damadian

[54] APPARATUS AND METHOD FOR DETECTING CANCER IN TISSUE
[76] Inventor: Raymond V. Damadian, 64 Short Hill Rd., Forest Hill, N.Y. 11375
[22] Filed: Mar. 17, 1972
[21] Appl. No.: 235,624

[52] U.S. Cl. .... 128/2 R, 128/2 A, 324/.5 R
[51] Int. Cl. A61b 5/05
[58] Field of Search .... 128/2 R, 2 A, 1.3; 324/.5 A, 324/.5 B



1970: detection of lengthened relaxation times in cancerous tissues
1972: theoretical development of human in vivo 3D NMR
1977: first human MRI image



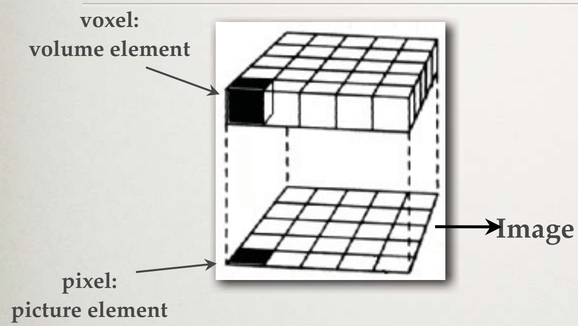
Paul C. Lauterbur

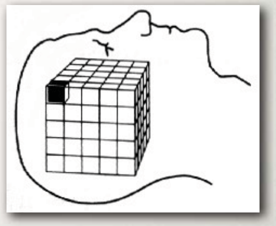
(1929-)

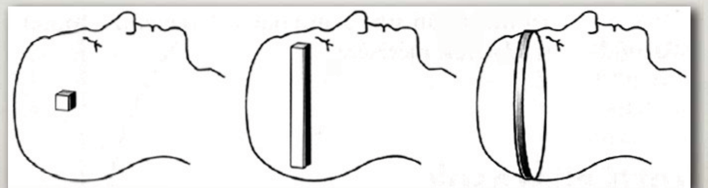
Development of spatially resolved NMR

MRI Imaging I:

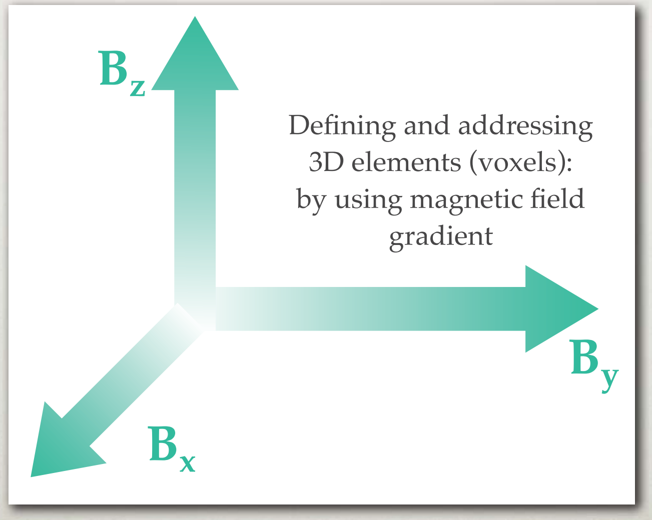
Spatial encoding



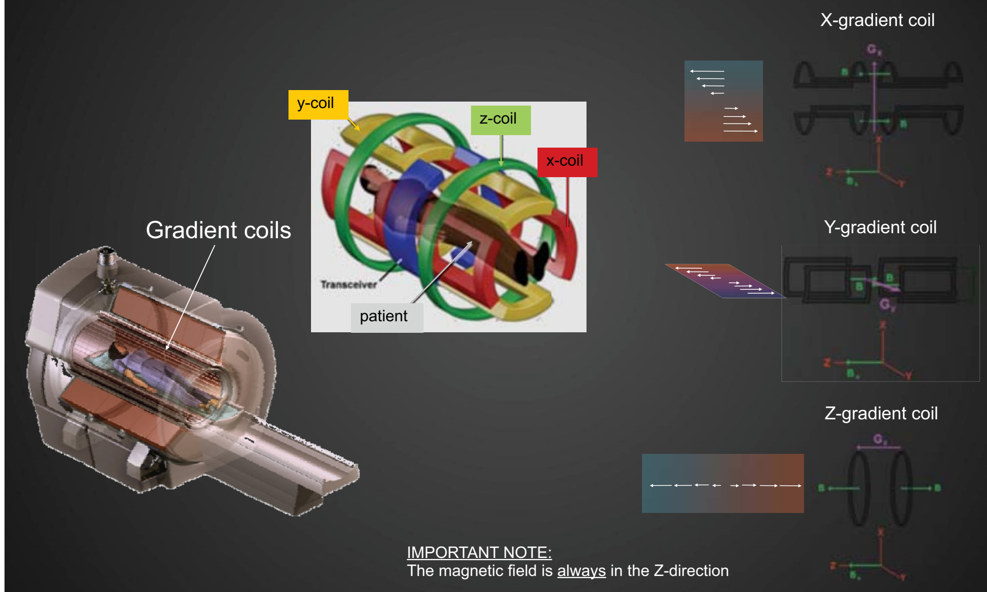




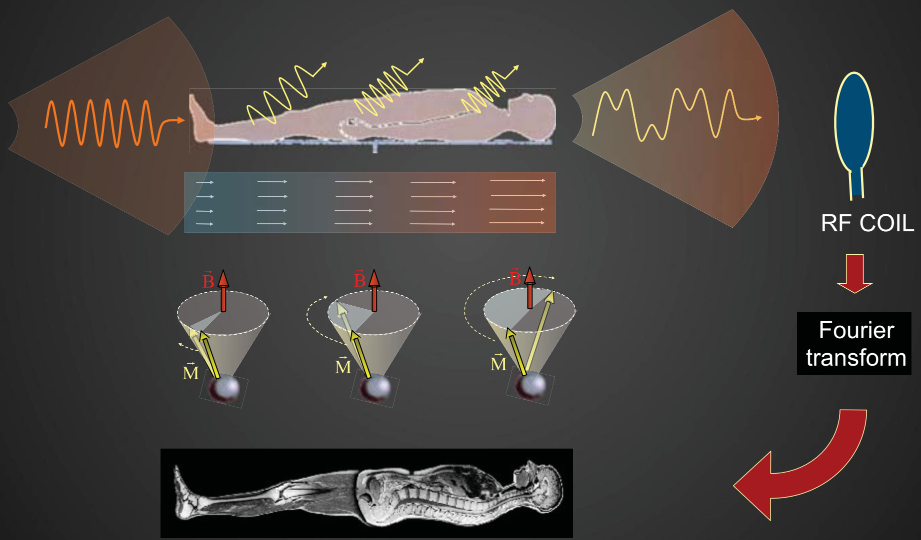
MRI Imaging I:
Spatial encoding



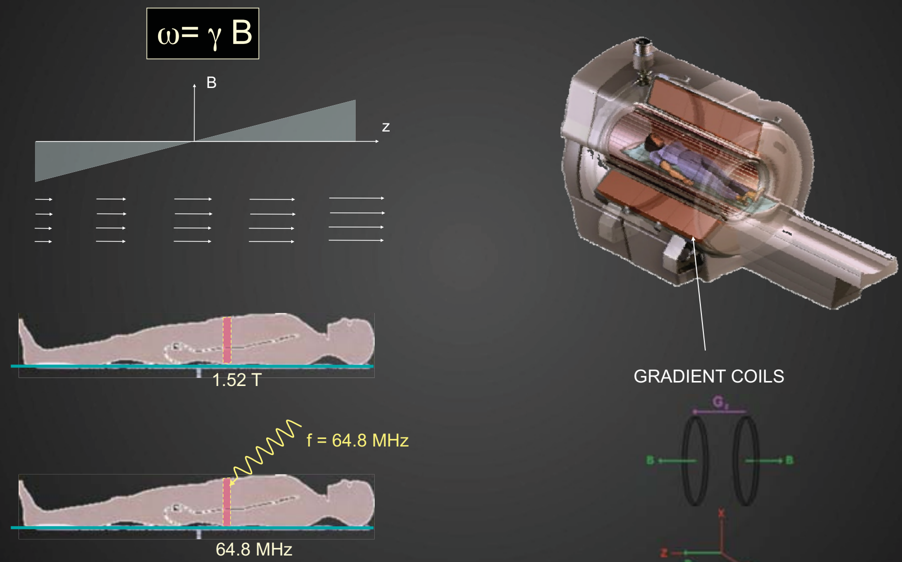
Spatial encoding of the NMR signal: Imaging gradients



Spatial encoding of the NMR signal is based on frequency changes in the precession



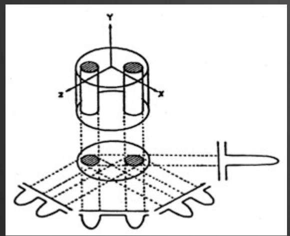
Spatial encoding: Slice selection

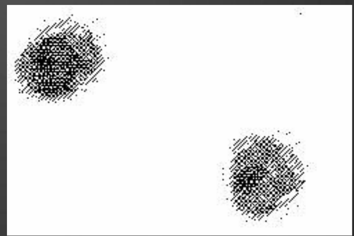


NMR scanner with backprojection

Paul Lauterbur, 1973
Illinois

Peter Mansfield, 1973
Nottingham





Nature 242, (1973), 190-191

Nobel prize for physiology and medicine (Lauterbur & Mansfield) in 2003

NMR scanner with 2D Fourier transformation

Richard Ernst, 1974
Zürich

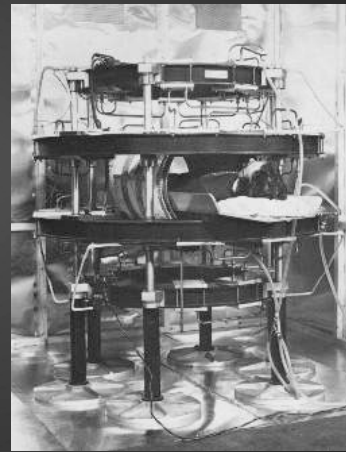
NMR Fourier Zeugmatography

Anil Kumar, Dieter Welti, and Richard R. Ernst

Laboratorium für Physikalische Chemie, Eidgenössische Technische Hochschule, 8006 Zürich, Switzerland

Received August 2, 1974

A new technique of forming two- or three-dimensional images of a macroscopic sample by means of NMR is described. It is based on the application of a sequence of pulsed magnetic field gradients during a series of free induction decays. The image formation can be achieved by a straightforward two- or three-dimensional Fourier transformation. The method has the advantage of high sensitivity combined with experimental and computational simplicity.



Nobel price for chemistry in 1991

The first MRI scanners ...

Interventional MRI unit

Open MRI unit

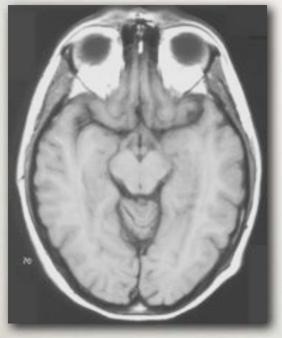
Mobile MRI unit

... and recent ones

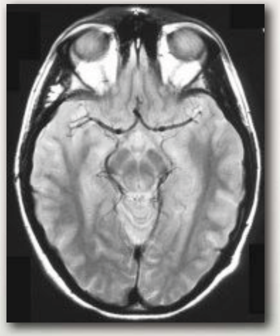
MRI Imaging:

Color resolution (contrast)

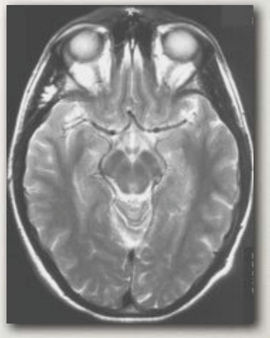
based on spin density and relaxation times



T1-weighing

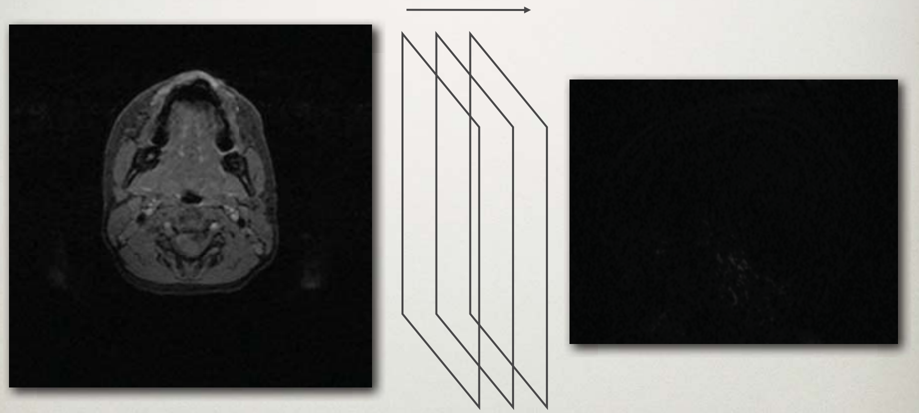


Proton density-weighing



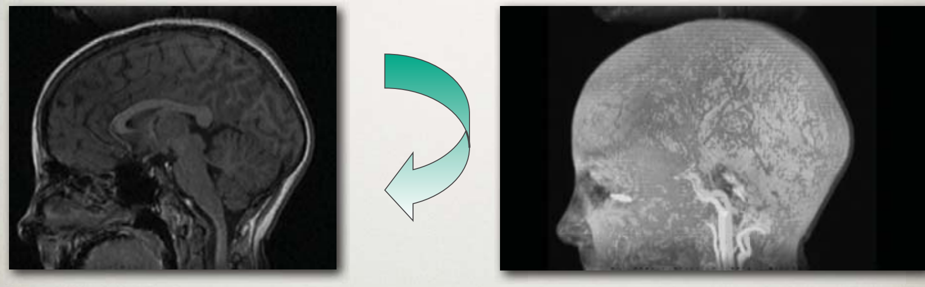
T2-weighing

MRI:
Image manipulation I



Reslicing in perpendicular plane

MRI:
Image manipulation II

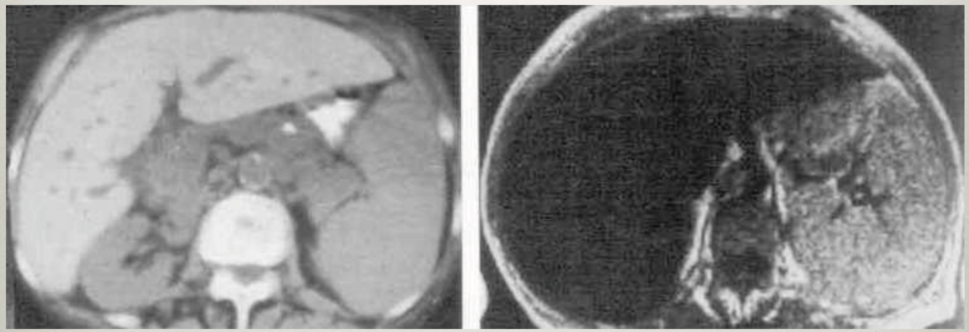


Spatial projection
(„volume rendering”)

Contrast agents

Positive: paramagnetic elements (T1 contrast): Gd, Mn

Negative: superparamagnetic, ferromagnetic (T2 contrast): FeIII, MnII

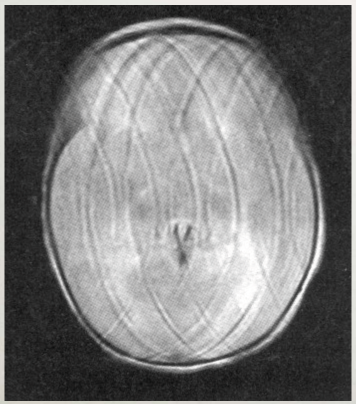


CT MR T2

Haemochromatosis hepatis

Artifacts

- Motion
- Metals (implants, injury)



Motion artifact

Metal in the orbit of the eye

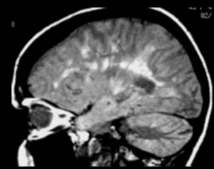
Dangers, contraindications

- Static magnetic field - metal objects
  Contraindications: implanted devices (pacemaker, defibrillator, hearing aids, drug delivery devices), neurostimulators, brain aneurysm clamps, early cardiac valve implants
- Gradient field - induced current
- Radio frequency field - thermal effects (lens, testis)

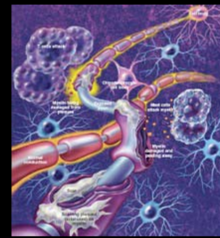


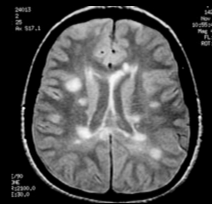


Anatomical imaging: Multiple sclerosis

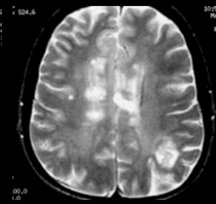


Proton density (sagital)

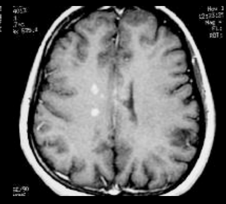




Proton density (transverse)



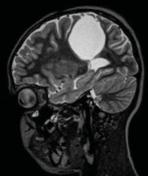
T2 weighted (transverse)



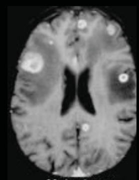
T1 weighted With contrast agent

Anatomical imaging: Oncology

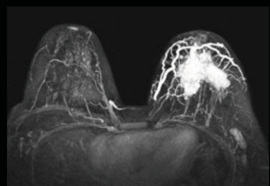
T2 weighted (chondrosarcoma)



T2 weighted (cyst)

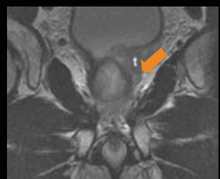


Protondensity (Brain metastasis)



T1 weighted with contrastagent (Breast carcinoma)

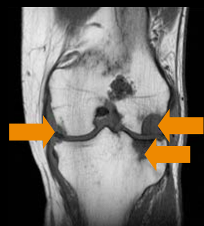
T2 weighted (cervix carcinoma)



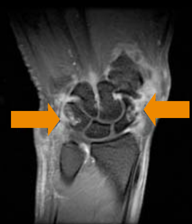
T2 weighted (prostate tumor)

Anatomical imaging Bone and soft tissue

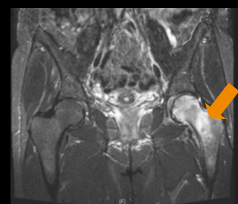
T2 weighted (torn ligaments)



Rheumatoid arthritis knee



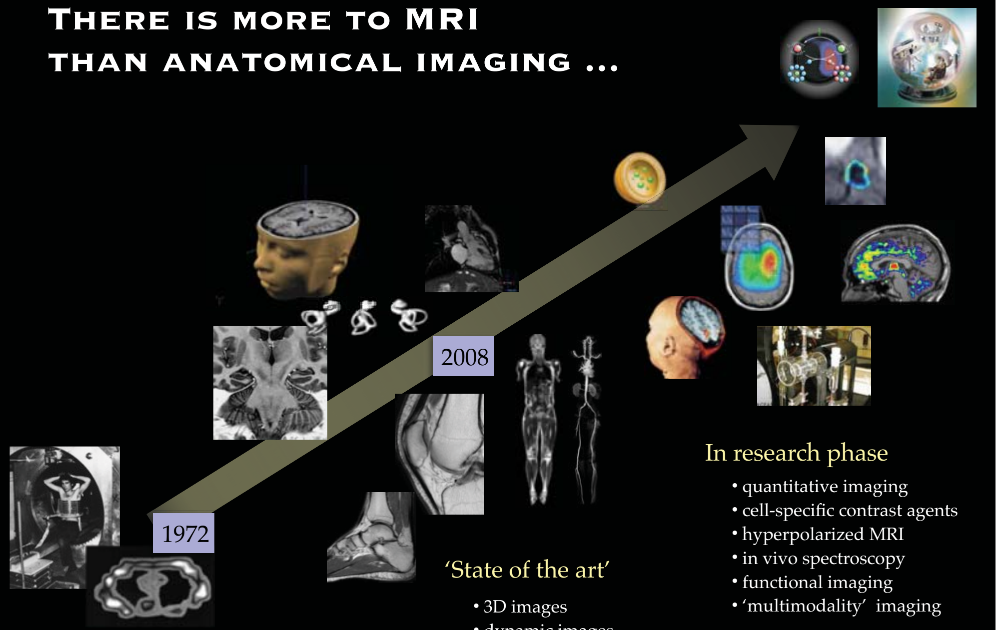
Rheumatoid arthritis whrist



Osteoporosis (femur)

T2 weighted (hernia)

There is more to MRI than anatomical imaging ...



First NMR images

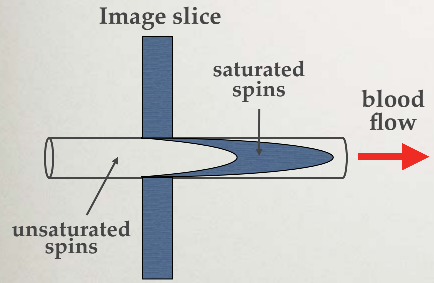
'State of the art'

- 3D images
- dynamic images
- sharp image resolution

In research phase

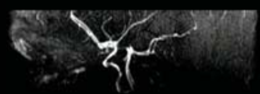
- quantitative imaging
- cell-specific contrast agents
- hyperpolarized MRI
- in vivo spectroscopy
- functional imaging
- 'multimodality' imaging

MRI:
Non-invasive angiography



MRI:
Non-invasive angiography

arteria carotis



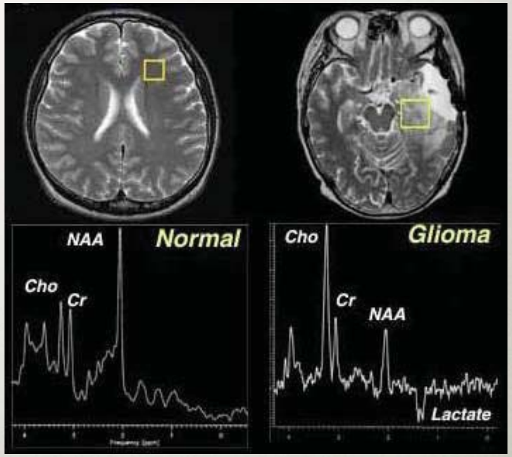
Circulus arteriosus Willisii

MRI movie
Based on high time resolution images

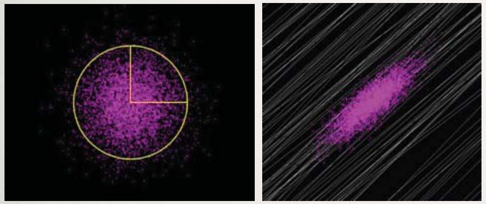
Opening and closing of aorta valve

MR Spektroscopy

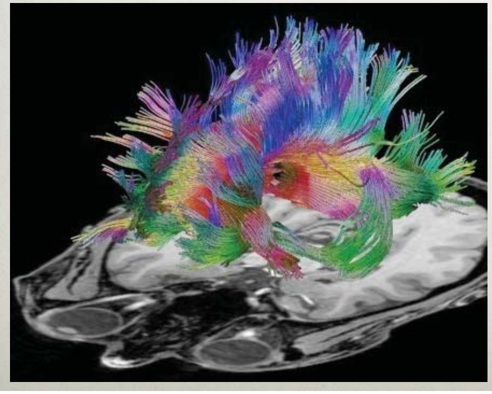
- Chemical shift
- Identification of metabolited
- Tumor diagnostics



Diffusion imaging



Anisotropic water diffusion: contrast

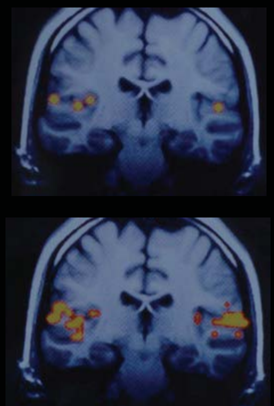


Imaging neural tracts: tractography

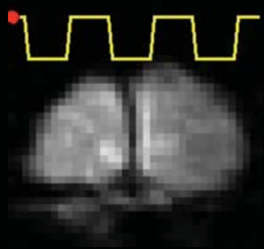
Corpus callosum

Functional MRI (fMRI)

High time resolution images recorded synchronously with physiological processes



Activation in the acoustic cortex



Effect of light pulses on visual cortex

Superposition of MRI on other information (PET)

Superimposed MRI and PET sequence

PET activity: during eye movement
Volume rendering