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Magnetic Resonance Imaging

Week 3; Lecture 7; Section 1: Introduction to MRI

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Section 1

Introduction to MRI

‘Guilt-free’ imaging

Whole-body imager, Star Trek style

Nuclear diagnostics and X-ray imaging:

- Image constructed using ionising radiation
- Necessarily delivers dose to patient
- Dose implies risk of initiating disease

Magnetic resonance imaging (MRI):

- Image generated by exploiting magnetic moment of H nuclei
- Patient immersed in magnetic field
- No permanent harmful effects reported

Nuclear magnetic moment

Proton (and neutron) magnetic moment:

- Nucleons each have spin of $\frac{1}{2}$
- Magnetic moment generated by nuclear charge

  Contributions to nuclear spin arise from quarks and gluons. Quantitative explanation of nuclear magnetic moment is an active area of research
- For NMR and MRI critical point is that the magnetic moment, $\boldsymbol{\mu}$, is related to the nuclear spin, $\mathbf{s}$ by:

$$\boldsymbol{\mu} = \gamma \mathbf{s}$$

  where γ is the "gyromagnetic" ratio

Nuclear magnetic resonance

Effect of uniform magnetic field **B**:

- **B** provides "quantisation axis":
  $\Rightarrow$ nuclear dipoles align with magnetic field
- For proton spin is $\frac{1}{2}$, so only two states:
  Spin "up" and spin "down"
- Energy splitting; 2 energy levels:
  - Lower energy level has magnetic moment parallel to magnetic field
  - Higher energy level has magnetic moment anti-parallel to magnetic field
- Resonance:
  - Call energy splitting ΔE
  - Transitions between the two energy levels cause absorption or emission of electromagnetic (em) radiation for which $\Delta E = h\nu$
  - Resonance occurs when em radiation of frequency ν is injected

Magnetic resonance imaging

Magnetic resonance imaging (MRI) exploits this resonance

Steps:

- Apply uniform magnetic field, align proton (^{1}H) spins
- Apply radiation, at exactly ν, to cause transitions between "spin up" & "spin down" states
- Turn off the radiation ... and ...
- "Listen" for radiation at exactly ν as the spins realign

Brilliant! Simple principle and elegant technique. Now exploited in exquisitely sophisticated imaging systems.

The physical principles

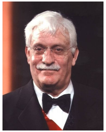
1938: I. Rabi: Discovered nuclear magnetic resonance
Nobel Prize 1944

1946: F. Bloch & E. Purcell: Developed methods that allow precision methods using NMR
Nobel Prize 1952

1955/56: E. Odeblad & G. Lindström: Applied NMR to living cells from animal tissue

1968: J.A. Jackson and W.H. Langham: First NMR measurements from living animals

Cancerous and normal cells differ



Relaxation times that characterise recovery of ground-state magnetisation shown to differ between normal and tumour cells

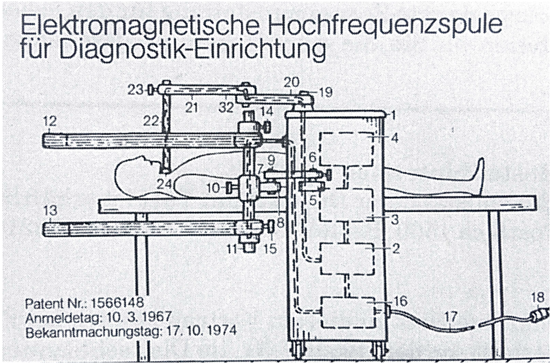
Raymond Damadian

Tumor Detection by Nuclear Magnetic Resonance
Author(s): Raymond Damadian
Source: *Science*, New Series, Vol. 171, No. 3976 (Mar. 19, 1971), pp. 1151-1153
Published by: American Association for the Advancement of Science
Stable URL: https://www.jstor.org/stable/1730608
Accessed: 01-03-2020 09:22 UTC

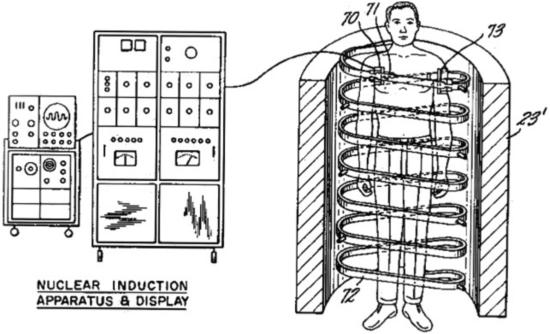
REFERENCES
Linked references are available on JSTOR for this article:
https://www.jstor.org/stable/1730608?seq=1&cid=pdf-reference#references_tab_contents
You may need to log in to JSTOR to access the linked references.

Early proposals for MRI scanners

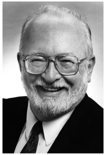
Alexander Ganssen; patent 1967



Raymond Damadian; patent 1972



Spatial localisation using magnetic-field gradients



Paul Lauterbur

Superimpose field gradient on main uniform magnetic field. Incident em radiation at frequency ν only resident in a particular location in subject

Nature Vol. 242 16 March 1973

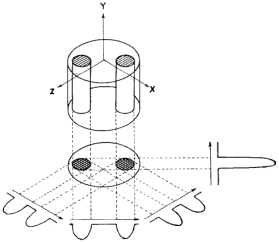


Fig. 1 Relationship between a three-dimensional object, its two-dimensional projection along the Y-axis, and four one-dimensional projections at 45° intervals in the XZ-plane. The arrows indicate the gradient directions.

Fig. 2 Proton nuclear magnetic resonance zeugmatogram of the object described in the text, using four relative orientations of object and gradients as diagrammed in Fig. 1.

Rapid, "snap-shot" MRI

Use of "echo planar imaging" to allow fast "snap-shot" imaging required active screening of fields created by currents induced in cryostat walls

Peter Mansfield

P. Mansfield, Nobel Lecture 2003

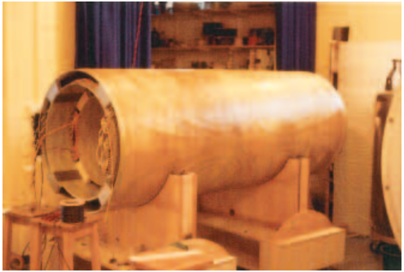


Figure 2. Photograph of a doubly screened active magnetic shielded gradient coil set for insertion in the super-conductive magnet of Figure 1.

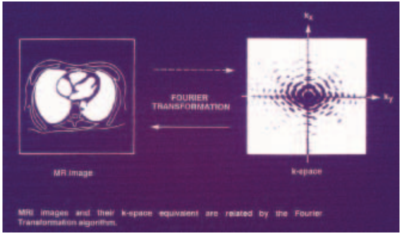


Figure 3. Diagram of a slice through the mediastinum showing the two lung fields and heart mass, also shown is the Fourier transform of this real-space image to the k-space map. (Reproduced with permission from M K Stehling, R Turner and P Mansfield, SCIENCE 253, 43–50 (1991).)

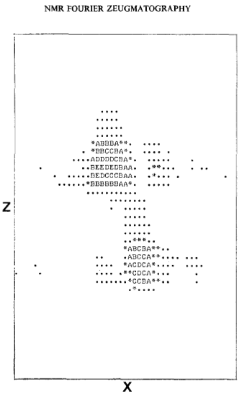
NMR zeugmatography

1975: A. Kumar, D. Welti, R. Ernst

Application of Fourier techniques to the reconstruction of images

Journal of Magnetic Resonance, Vol 18, P 69–83(1975)

zeug·ma·tog·ra·phy (zūg'mă-tog'ră-fē),
Term coined by Lauterbur in 1972 for the joining of a magnetic field and spatially defined radiofrequency field gradients to generate a two-dimensional display of proton density and relaxation times in tissues, the first nuclear magnetic resonance image.



State of the art

Summary of section 1

Magnetic moment of proton exploited to provide energy splitting, ΔE between spin-up and spin-down states in applied magnetic field

Injection of radio-frequency wave with a frequency that resonates with the splitting then used to manipulate population of protons in the spin-up and spin down states

Images produced by manipulating applied magnetic field and frequency of RF field gradients