PD233: Design of Biomedical Devices and Systems

(Lecture-10 Medical Imaging) Thermography and MRI

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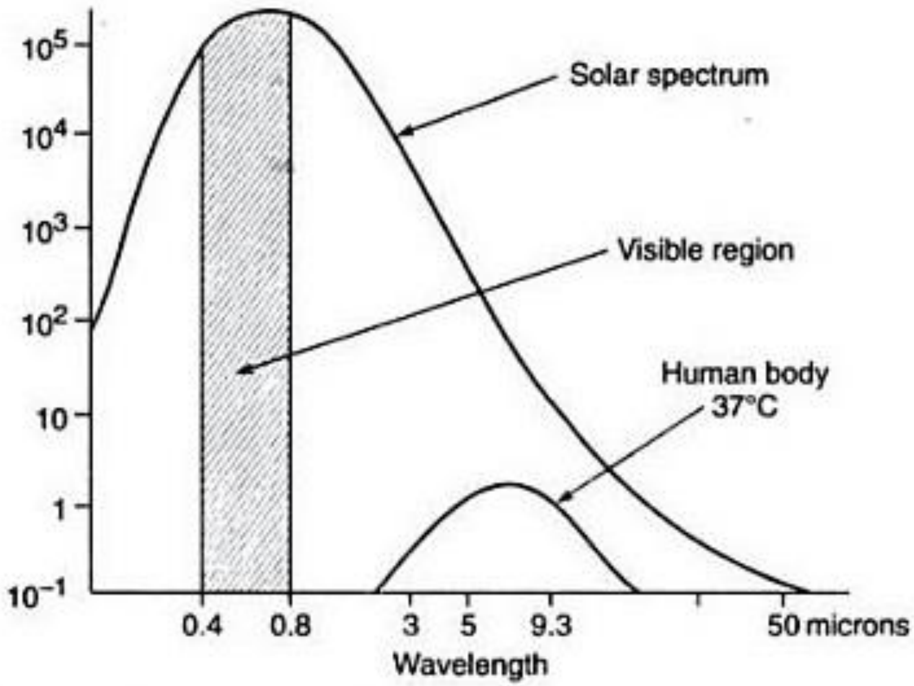
Course Website:
http://cpdm.iisc.ac.in/utsaah/courses/

What is Thermography?

- Imaging of temperature (differences) over the surface of skin
- Provides indication of metabolic processes
- Unlike radiography dose not provide anatomical information, just information about metabolic changes and circulation changes
- Human body absorbs all the infrared radiation and emits back depending on its own temperature

Physics of Thermography



Spectral distribution of infrared emission from human skin. The emission peaks at around 9 microns regardless of pigmentation

All object with Temperature > 0K emit radiation ➔ Black-Body radiation

$$W = \sigma \epsilon T^4$$

W= radiant flux density W/cm^2
ϵ = Emissivity factor
σ = Stefan–Boltzman constant
= 5.67×10^{-12} W/cm^2-K^4
T =absolute temperature

$$\lambda_{max} = \frac{2897\ (\mu m)}{T\ (K)}$$

Image source: Khandpur, pp671

Physics of Thermal Imaging

- Emissivity

The ratio of energy radiated per unit area by an object to energy emitted per unit area by a black body at the same temperature

$$\epsilon = \frac{W_o}{W_b}$$

Spectral radiant emissivity

$$\epsilon_\lambda = \frac{W_{o\lambda}}{W_{b\lambda}}$$

- Reflection

Ratio of reflected power to incident power

$$\rho_\lambda + \alpha_\lambda = 1$$

Since $\alpha_\lambda = \epsilon_\lambda$, $\epsilon_\lambda = 1 - \rho_\lambda$

- *Transmittance and Absorption* of infrared to be considered when semi transparent body is present between radiating object and detector

Thermal imaging systems

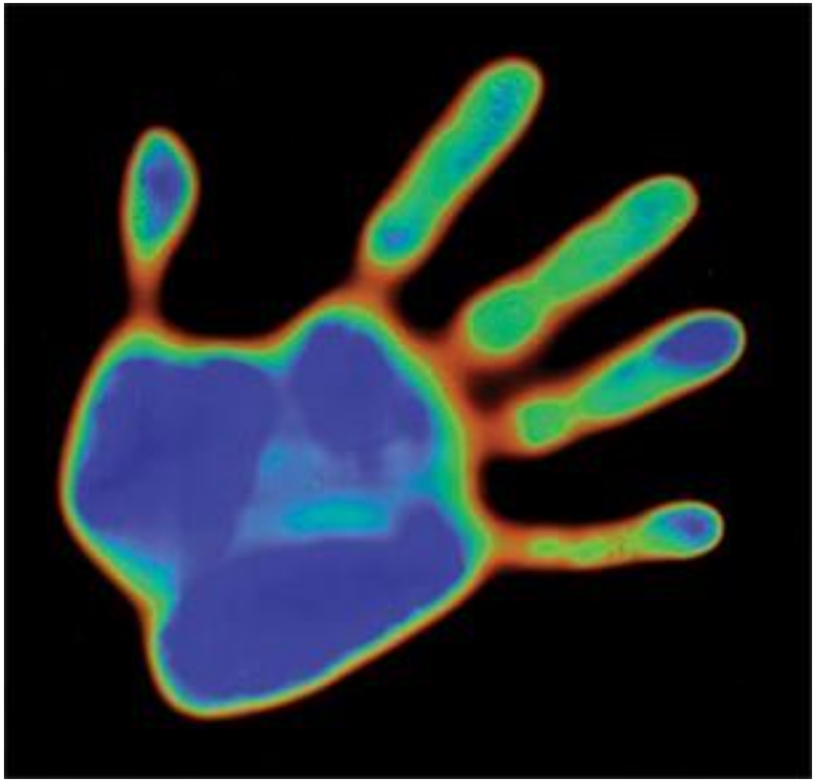
- Thermal Detector
  - depend on temperature change in detectors (e.g thermocouple and bolometer
  - Broad spectral response
  - Slow response
- Photodetector – like solar cells for Infrared

InSb (indium antimonide) sensitive in 2-6μm which has only 2.4% of energy emitted by human body

Clinically we are looking for temperature resolution of 0.5°C?

Liquid Crystal Thermography

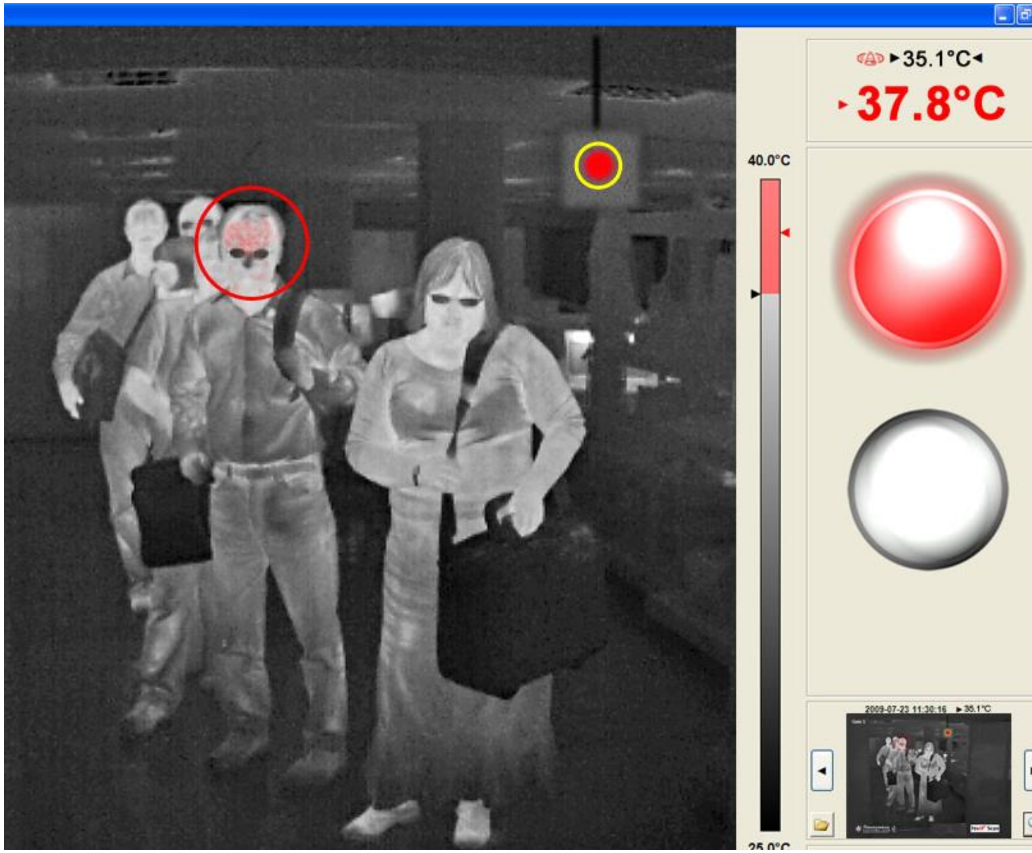
Liquid Crystals show changes in color due to change in temperature. This technology has wide ranging applications but also has been applied to medical diagnostics.



LC are applied to skin surface in conforming manner and imaged using regular camera or eye to reveal temperature changes. Compared to thermal imaging camera is more sensitive.

Digital IR cameras

- Ebola/H1N1 Screening at airports - uses IR cameras
- Though CMOS sensors are not optimum for 10um infrared they are highly sensitive to pick up temperature rise in range 0.5C
- Used together with calibrated blackbody source



Consumer Grade Thermal Imaging

~42,000 INR

~23,000 INR

Diagnostic Radiology

Thermography, Mammography, and Clinical Examination in Breast Cancer Screening LEGACY

Review of 16,000 Studies[1]

Stephen A. Feig, M.D., ,

Department of Radiology Thomas Jefferson University Hospital

11th & Walnut Streets Philadelphia, Pa. 19107

Gary S. Shaber, M.D., , Gordon F. Schwartz, M.D., , Arthur Patchefsky, M.D., , Herman I. Libshitz, M.D.[2], , Jack Edeiken, M.D., , Rudolph Nerlinger, B.S., , Robert F. Curley, B.S., , and John D. Wallace, A.B.[3],

DOI: http://dx.doi.org/10.1148/122.1.123

Abstract Cited by PDF

Breast cancer screening detected 139 biopsy-proved malignancies in 16,000 self-selected women (8.7/1,000). In these, xeroradiography detected 78% (109), clinical examination 55% (76), and thermography 39% (54). In all 16,000 women, the thermogram was interpreted as positive in 17.9% (2,864). The greatest effectiveness of mammography *vs.* clinical examination was seen in detection of early breast cancers (small lesions with negative axillary lymph nodes). In this group, thermography was less effective than it was in patients with larger lesions and lymph node metastases.

Keywords: Index terms (Breast, special procedures 0[0].120) ; Breast neoplasms, diagnosis ; Mammography ; Thermography ; Xeroradiography

Assignment 3

Q1: Calculate TP,FP, TN,FN.

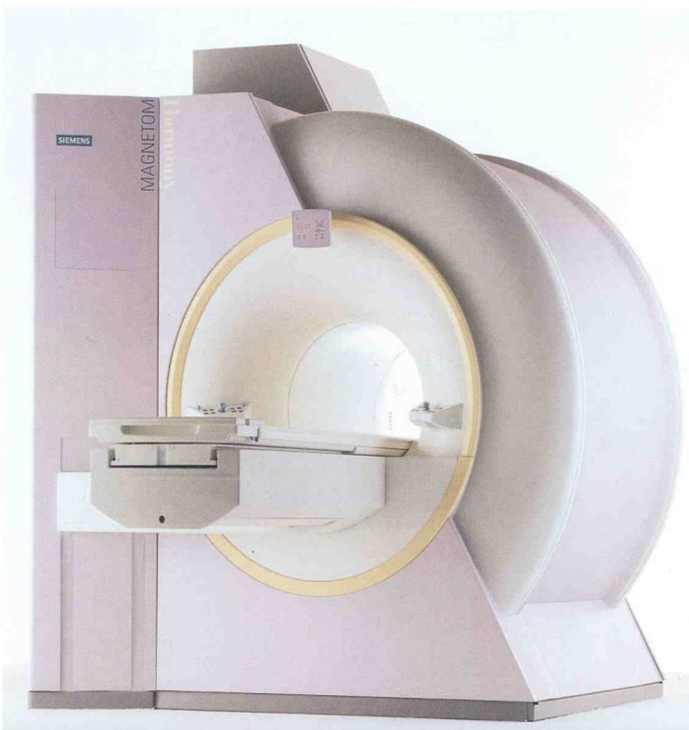
What is sensitivity and specificity of thermography for breast cancer screening?

Q2: Critically compare the results of Q1 recent claim of Indian med-tech startup Niramai which claims 98% Sensitivity and 68% Specificity.

https://waset.org/publications/10008935/thermalytix-an-advanced-artificial-intelligence-based-solution-for-non-contact-breast-screening

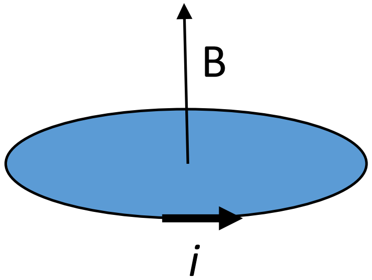
What design/technological innovation could be responsible for possible improvement?

Magnetic Resonance Imaging

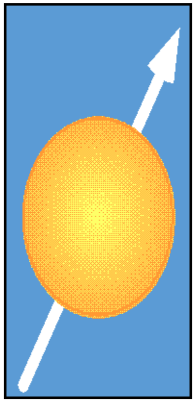


Magnetic Resonance Imaging

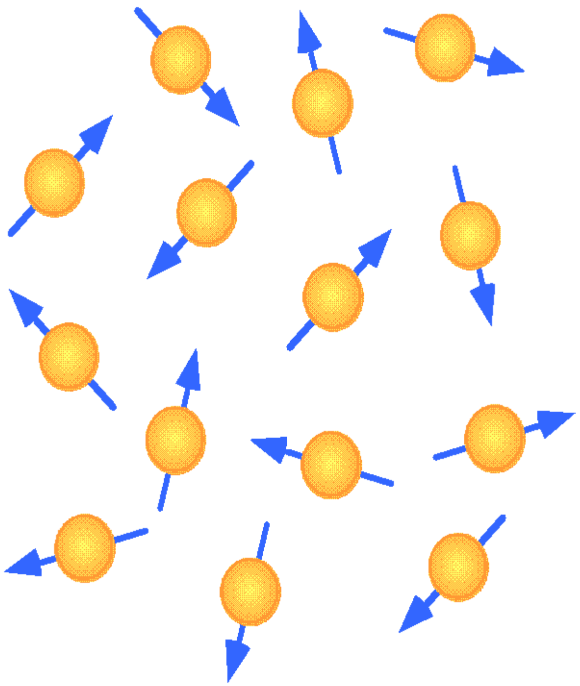
Current in a coil leads to magnetic field <u>dipole</u>



What about spinning proton?



No Magnetic Field



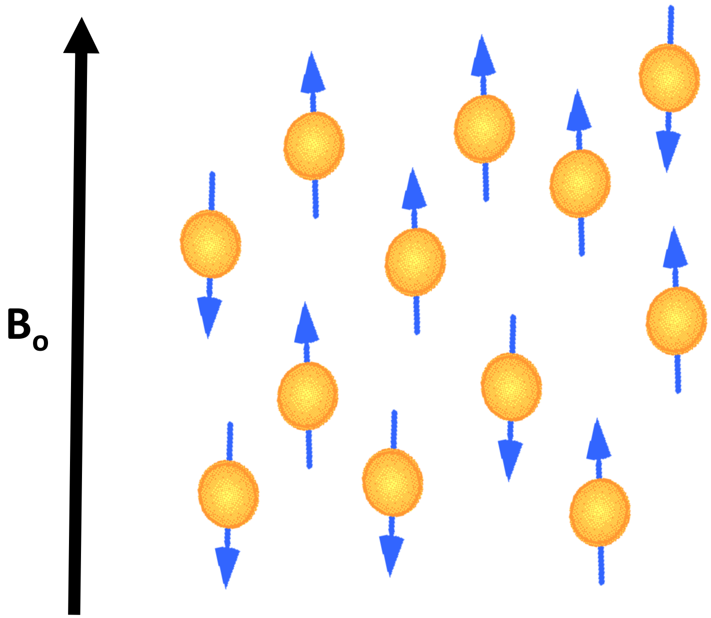
= No Net Magnetization

Random Orientation

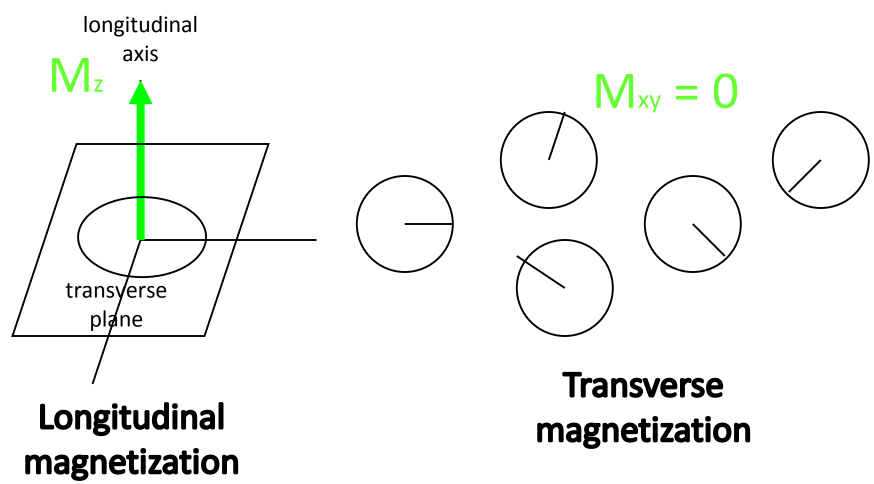
What if you apply a strong external magnetic field?

Strong Magnetic Field

- net magnetization (M) along B_0
- spins precess with random phase
- no net magnetization in transverse plane
- only 0.0003% of protons/T align with field



spins tend to align parallel or anti-parallel to B_0



B_1 Radiofrequency Field

Polarization itself be used for imaging.

A transverse Magnetic field (B_1)is applied at the resonance frequency (Larmor Frequency).

After the excitation

Relaxation time scale is measured

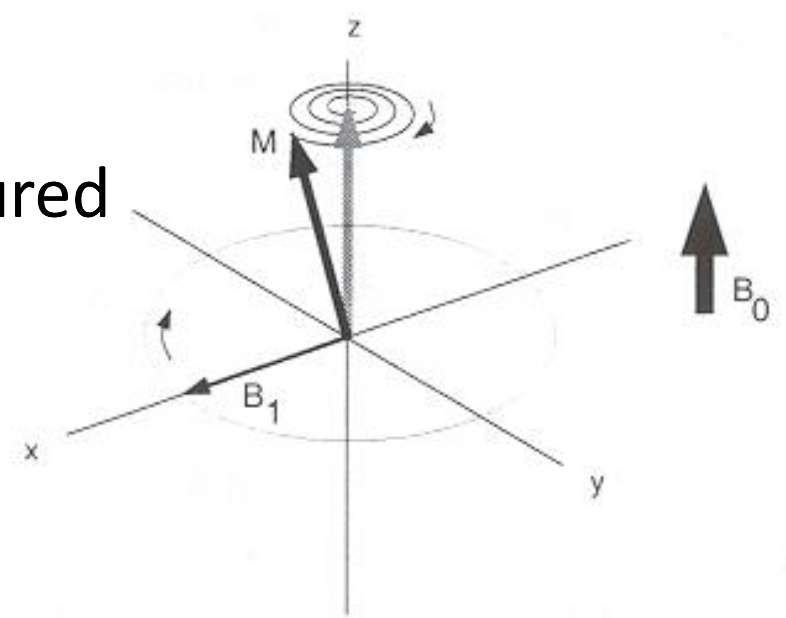
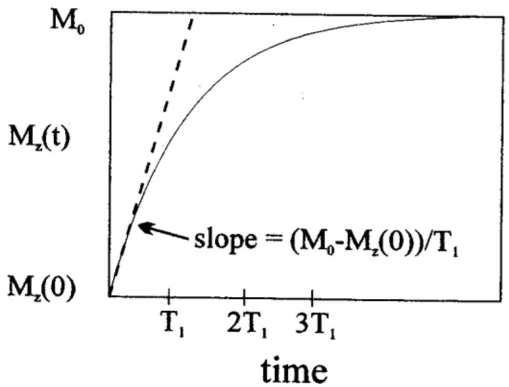
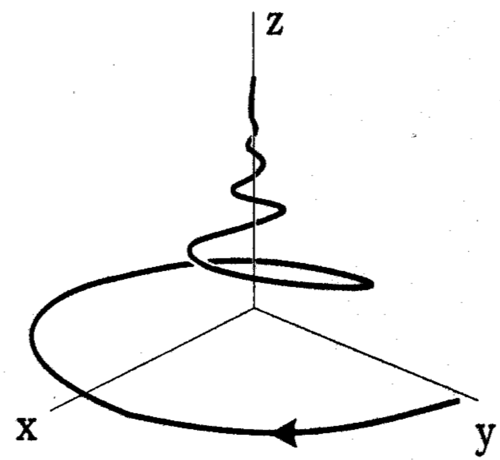


Diagram: Nishimura, Principles of MRI

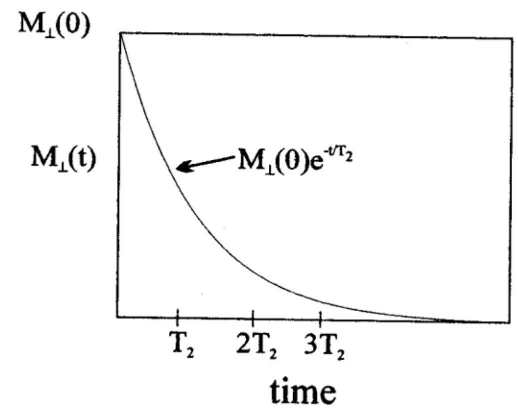
Relaxation time scales T1 and T2



Regrowth of longitudinal component $M_z(t)$ from initial value $M_z(0)$ to M_0



Evolution of Magnetization vector after perturbation
Initial perturbation is along y axis and and main field is along z axis

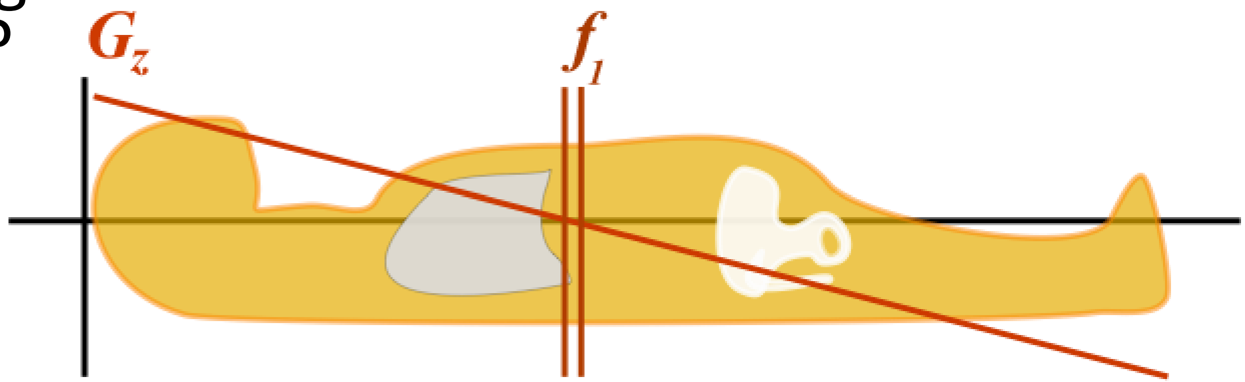


Decay of transverse magnetization value from its initial value

Tissue	T_1 (ms)	T_2 (ms)
gray matter (GM)	950	100
white matter (WM)	600	80
muscle	900	50
cerebrospinal fluid (CSF)	4500	2200
fat	250	60
blood	1200	100-200[3]

Spatial encoding?

How to get information from various location in parallel?



Slice selection is done by applying gradient magnetic field.

Recall that resonance frequency depends on magnetic field intensity.

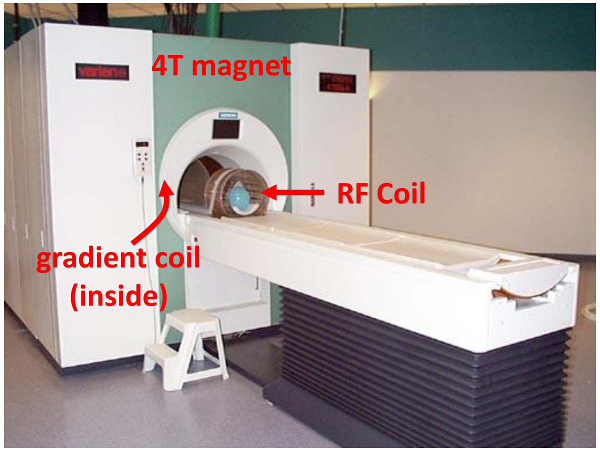
What about x and y direction:

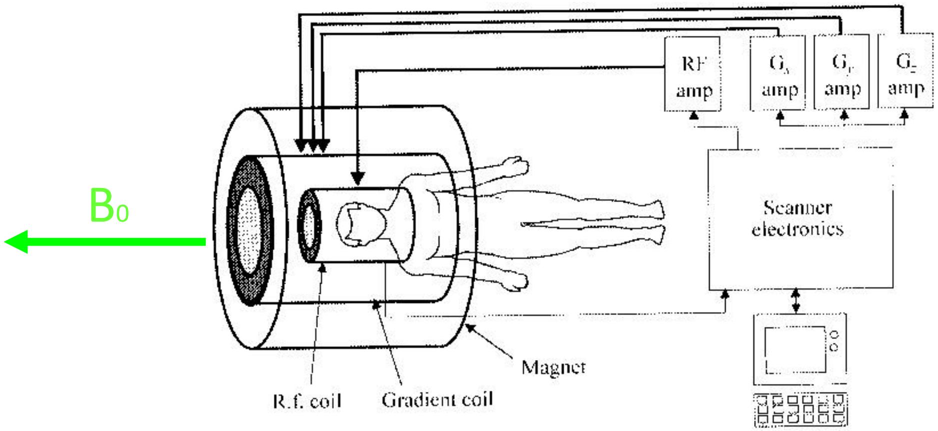
Frequency encoding resolve information in x axis

Phase encoding resolve information in y axis

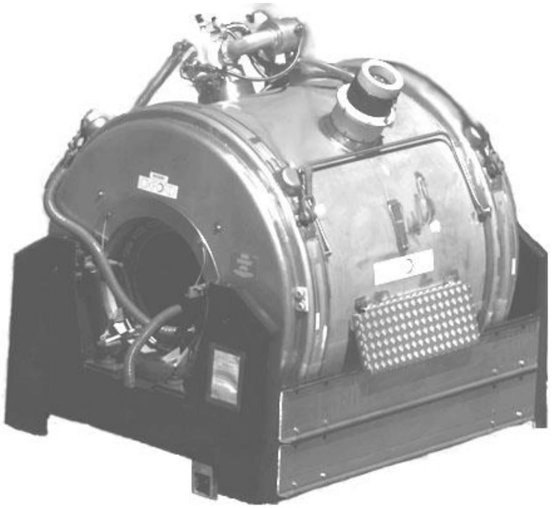
Image source: http://xrayphysics.com/slice_grad.png

Equipment



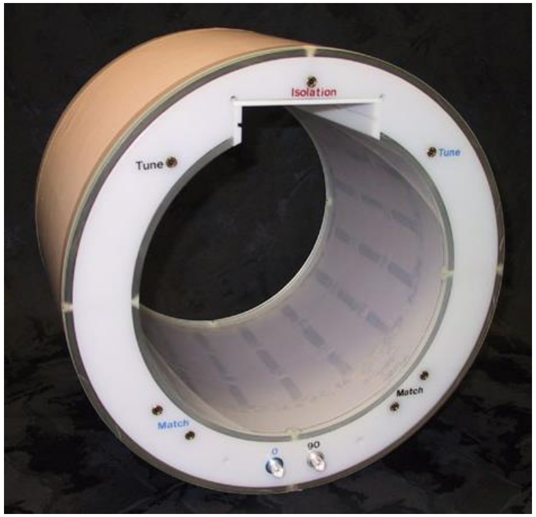


Magnet



Gradient Coil

RF Coil



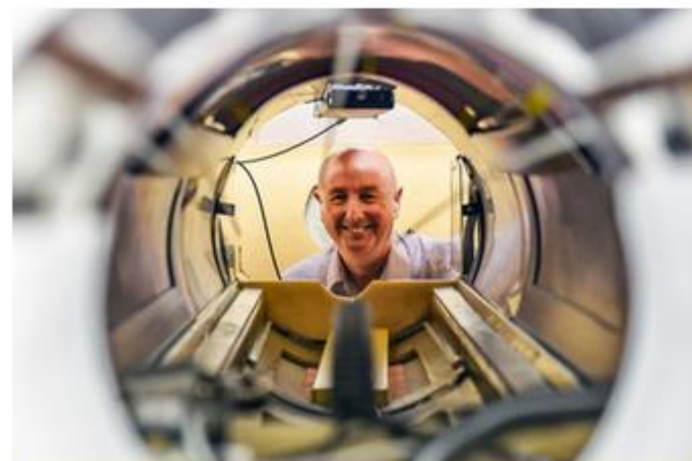
Credit: James D. Christensen

1495 UNIVERSITY OF ABERDEEN

First-ever patients scanned by new generation MRI scanner

21 November 2017

A team at the University of Aberdeen has scanned the first group of patients using a ground-breaking 'Fast Field Cycling' MRI scanner. The patients had all suffered strokes and agreed to be the first in the world to be scanned by the new machine.

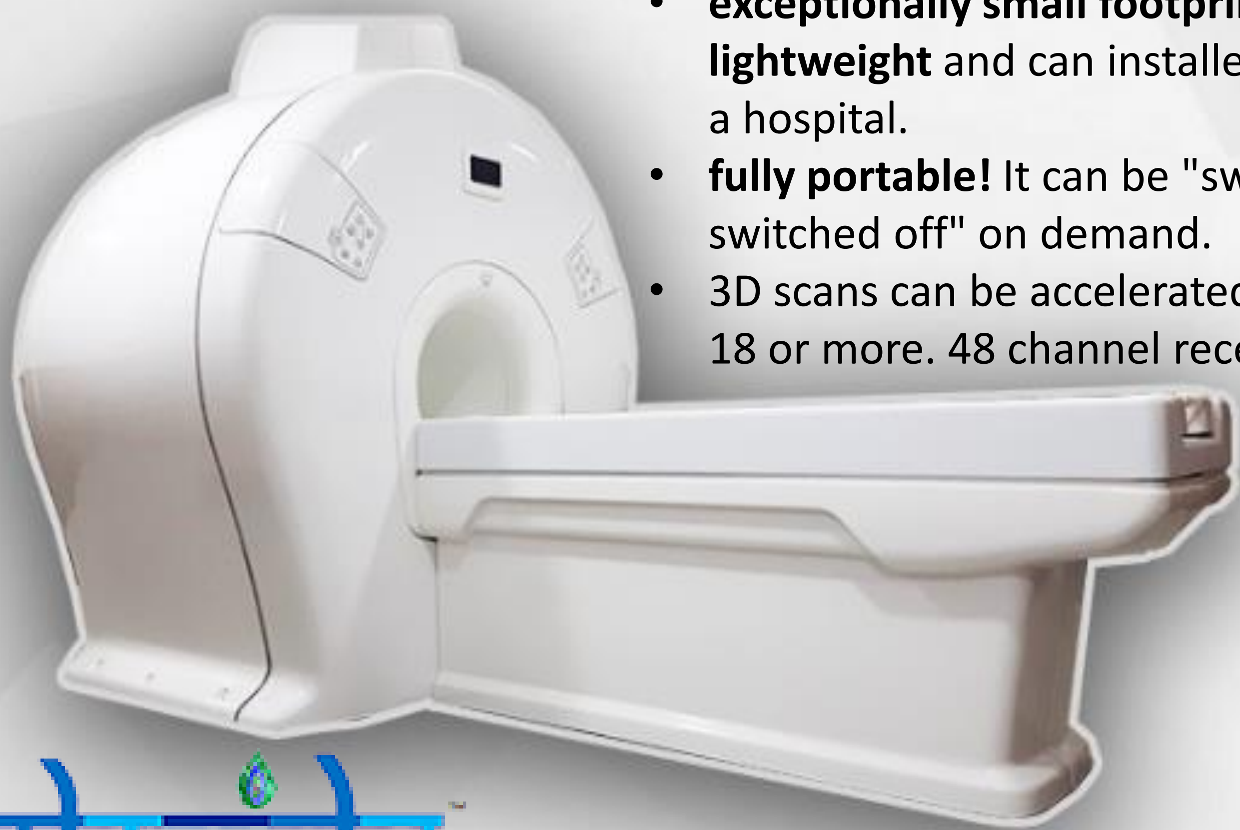


Professor David Lurie

Today's announcement marks another milestone in the University's long association with MRI machines. In the 1970's, a team at the University built the first full-body MRI scanner and used it to obtain the first clinically useful image of a patient. MRI scans are

Lightweight, Ultra-Fast, Next-Generation Magnetic Resonance Imaging (MRI) Scanners

Voxelgrids is an Magnetic Resonance Imaging technology startup that is based out of Bengaluru, Karnataka, India.



- **exceptionally small footprint**. It is also **Ultra lightweight** and can installed on any floor of a hospital.
- **fully portable!** It can be "switched on or switched off" on demand.
- 3D scans can be accelerated by factors of 18 or more. 48 channel receiver

voxelgrids™

What about function?

Profusion imaging – measure blood flow (BF), blood volume (BV) , mean transit time (MTT)

$$MTT = BV/BF$$

Using contrast agent (e.g. gadolinium)

Dynamic Susceptibility Contrast (DSC) Perfusion MRI

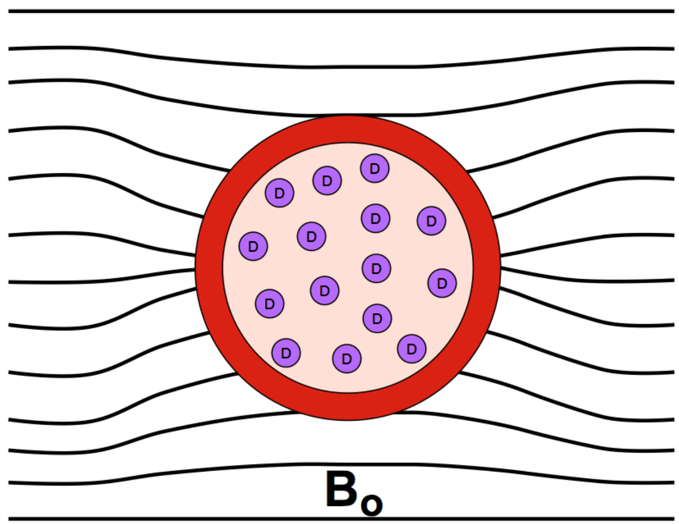
Dynamic Contrast Enhanced (DCE) Perfusion MRI

Without contrast

Arterial Spin Labelling (ASL)

BOLD (Blood Oxygen Level Dependent) MR Imaging

Oxyhemoglobin has no unpaired electrons and is weakly ***diamagnetic***. When oxygen is released to form ***deoxyhemoglobin***, 4 unpaired electrons are exposed at each iron center, causing the molecule to become strongly ***paramagnetic***.



Ability to image oxygen concentration allows investigation brain function as well.

Requires 3T or higher MRI system

Other Functional Imaging modalities

- Positron emission tomography (PET)
  - Fludeoxyglucose for Glucose metabolism
  - O-15 as a flow tracer
- Single-photon emission computed tomography (SPECT)
  - Requires delivery of gamma emitting nucleotide into the patient

  - System combining more than one modality
    - PET-CT
    - Intra-operative US/CT fusion