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Medical Imaging

– Part I, the basics of Ultrasound, MR, CT and PET/SPECT

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- 1851–1890 – Establishment of Constituent Colleges
- Imperial College founded in 1907 through merger of three older institutions
  - **City & Guilds College**
  - **Royal College of Science**
  - **Royal School of Mines**
- Mergers with other London Medical Schools
  - **1988 – St Mary's Hospital Medical School**
  - **1995 – National Heart & Lung Institute**
  - **1997 – Charing Cross/ Westminster & Royal Postgraduate Medical Schools**
- 2000 – Merger with Wye College
- 2000 – Kennedy Institute of Rheumatology

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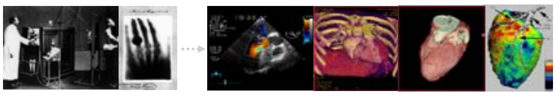
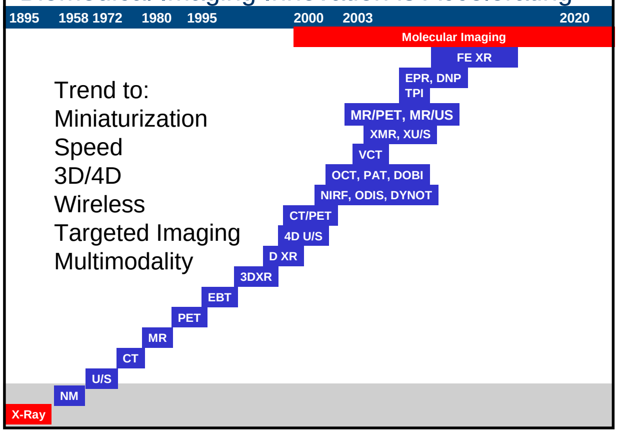


c. 400 BC Disease concept introduced by Greek physician Hippocrates.
1612 Medical Thermometer devised by Italian physician Sanctorius
c. 1660 Light microscope developed by Dutch naturalist Antohj van Leeuwenhoek
1810 Stethoscope invented by French physician Rene' Laennec.
1850 - 1900 Germ theory of disease proposed by French scientist Louis Pasteur and developed by German bacteriologist Robert Koch.
1895 X-rays discovered by German physicist Wilhelm Conrad Roentgen. He also produced the first x-ray picture of the body (his wife's hand) in 1895.
1900 Chest x-ray, widespread use of the chest x-ray made early detection of tuberculosis (which was the most common cause of death) a reality.
1906 X-ray contrast medium. First contrast filled image of the renal system (kidneys).
1910 Barium sulfate introduction of as contrast agent for gastro-intestinal diagnosis.
1910-1912 Theory of Radioactivity published by Marie Curie and investigation of x-ray radiation for patient therapy (e.g. treatment of cancer).
1906 Electrocardiograph (ECG) invented by Dutch physiologist Willem Einthoven to monitor and record the electric signature of the heart.
1924 Radiographic imaging of the gallbladder, bile duct and blood vessels for the first time.
1929 Cardiac catheterization first performed by Forssmann on himself.
c. 1932 Transmission electron microscope (TEM) constructed by German scientists Max Knoll and Ernst Ruska.
1945 Coronary artery imaging. Visualization of (blood vessels that feed the heart).
1950 Nuclear Medicine applied imaging the kidneys, heart, and skeletal system.
1955 X-ray Image Intensifier-Television units to allow dynamic x-ray imaging of moving scenes. These fluoroscopic movies provided new information of the beating heart and its bloc
c. 1955 Panoramic x-ray images of the entire jaw and teeth.
1957 Fiber endoscopy pioneered by South African-born physician Basil Hirschowitz at the University of Michigan.
1960 Ultrasound imaging is developed to look at the abdomen and kidneys, fetal baby, carotid blood vessels and heart.
1970 X-ray mammography finds widespread application in imaging the breasts.
1972 Computed Tomography (CT) scanning invented by British engineer Godfrey Hounsfield of EMI Laboratories, England, and South African born physicist Allan Corn
1975 Chronic villus sampling developed by Chinese gynecologists as an aid to the early diagnosis of genetic disorders.
1976 Coronary Angioplasty was introduced by surgeon Andreas Gruentzig at the University Hospital, Zurich, Switzerland. This technique uses x-ray fluoroscopy to guide the compres
1978 Digital radiography: the TV signal from the x-ray system is converted to a digital picture which can then be enhanced for clearer diagnosis and stored digitally for future review.
1980 Magnetic Resonance Imaging (MRI) of the brain was first done on a clinical patient. MRI was developed by Paul Lauterbur and scientists at Thorn-EMI Laboratories
1984 3-Dimensional image processing using digital computers and CT or MR data, three dimensional images of bones and organs were first made.
1985 Clinical Positron Emission Tomography (PET) scanning developed by scientists at the University of California.
c. 1985 Clinical Networks were first implemented to allow digital diagnostic images to be shared between physicians via computer network, allowing a doctor in Boston to review a CT
1989 Spiral CT allows fast volume scanning of an entire organ during a single, short patient breath hold of 20 to 30 seconds. Spiral CT had caused a renaissance in CT and lead the
1989 MR Angiography developed and clinically available to allow non-invasive imaging of the blood vessels without radiation or contrast injection.
1993 Echo Planar MR Imaging (EPI) developed and clinically available to allow MR systems to provide early detection of acute stroke. EPI also makes possible functional imaging, f
1993 Open MRI Systems developed to allow MR scanning of severely claustrophobic or obese patients who could not tolerate convention MR imaging in a close bore system.

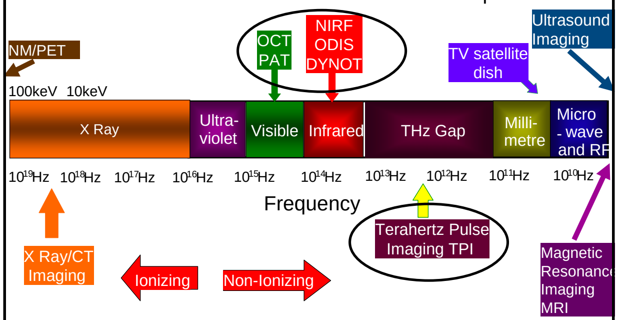
Biomedical Imaging Innovation is Accelerating



Trend to:
Miniaturization
Speed
3D/4D
Wireless
Targeted Imaging
Multimodality

Imaging Utilizes Different Wavelength Energies

Different wavelengths means different interactions with tissues
PET and MR are at different ends of the EM spectrum

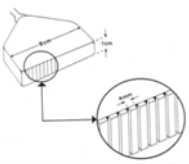


Ultrasound Imaging

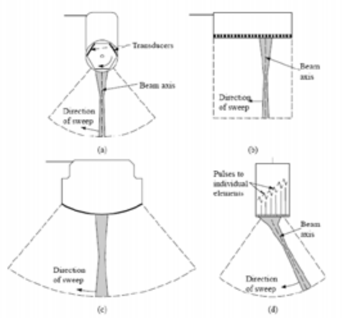
- First use of ultrasound for medical application in the 1950s
- A real-time modality that uses sound waves as the basis for tissue discrimination
- High frequency sound (between 2 and 15 MHz) are sent to the anatomical structure

Transducer

- Main part of the ultrasound system, the transducer produces the sound wave and collects the reflected signals
- Consists of multiple crystal elements



Transducer

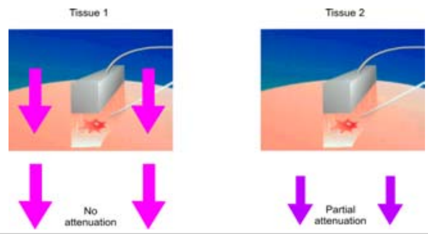


Pulse Echo Effect

- Ultrasound transducers convert electricity into sound (pulse)
- The emitted pulse interacts with the target soft tissue
- An echo is recollected, which depends on various tissue properties (Attenuation, Velocity of sound in the material, Reflection)
- The echo is interpreted and rendered by the computer

Attenuation

- The reduction in power and intensity as the sound travels through a medium

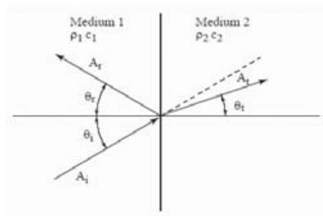


Tissue Examples

Medium	**Speed sound (m/s)**	**Attenuation (10^{-2} (cm Mhz)$^{-1}$)**
Blood	1566	2
Brain	1505	10
Fat	1446	7.5
Kidney	1567	12
Liver	1566	11
Muscle	1542-1656	15-38
Bone	2070-5350	230
Water	1480	
Air	333	

Reflection

- At a locally planer interface, the wave's frequency will not change, only its speed and angle



Ultrasound Modes

- A-mode: The echo from a single line scanned through body is plotted as a function of the depth. Aimed at specific tumour characterization
- B-mode: most popular mode. A linear array of transducers simultaneously scan an image plane
- M-mode: the M corresponds to motion. Widely used in cardiology
- Doppler mode: makes use of Doppler effect to visualize flow using colours

Main Applications

Cardiovascular:

- Ventricular morphology and function
- Main arteries and valves

Urology: (e.g., bladder function, testicular cancer)

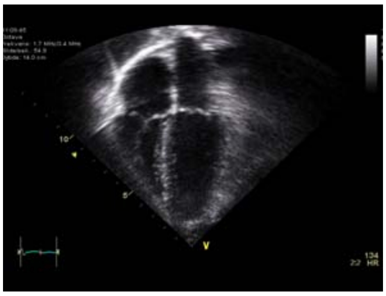
Pregnancy management:

- Foetal abnormality screening, gender identification

Gynaecologic examination:

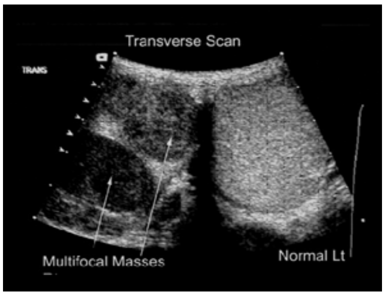
- Pelvic, ovarian and breast (lesions, cancer)

Echocardiography

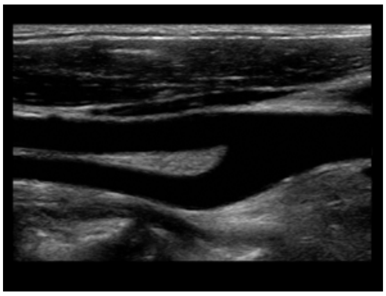


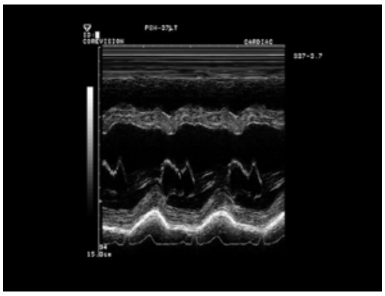
Foetal scan

Urology

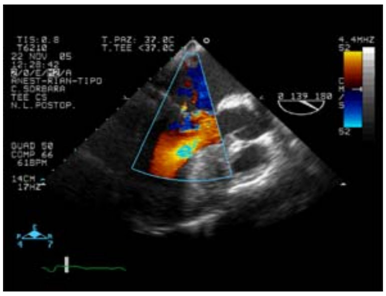


Vessels





Doppler Mode



3D Ultrasound

Echocardiography

- The most commonly used modality for cardiac assessment, since it is widely available and portable
- Can evaluate cardiac chamber size, wall thickness, wall motion, valvular anatomy, valve motion, the proximal great vessels and the pericardium
- The main challenge of echocardiography is obtaining images of the best possible quality
- Technical expertise is generally an important factor in echocardiography

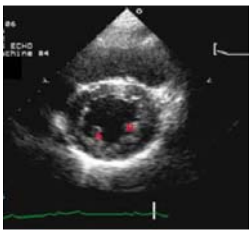
Ventricular Assessment

An example showing ventricular septal defect

Ventricular Assessment

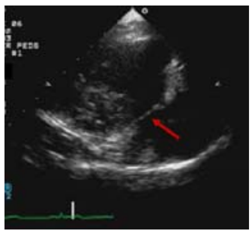
A: Posteromedial papillary muscle

B: Anterolateral papillary muscle

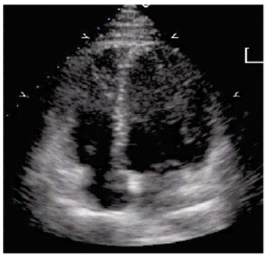


Valve Assessment

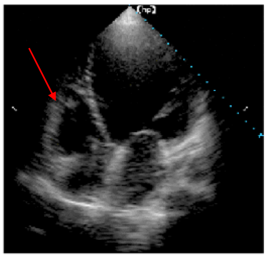
Image view showing tricuspid valve posterior leaflet



Cardiomyopathy

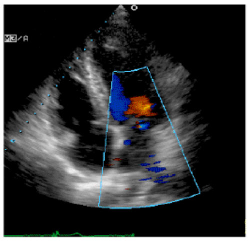


Normal

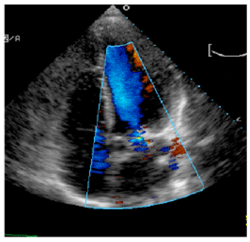


Cardiomyopathy

Mitral Regurgitation

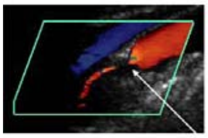


Mild



Severe case

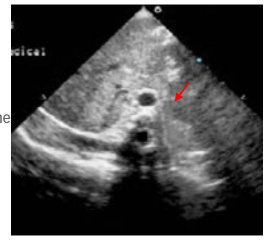
Carotid Assessment



Color Duplex image showing
stenosis, as demonstrated
by an angio on the right figre

Great Vessels

Transverse view showing the
descending aorta



Great Vessels

A: Superior vena cava

B: Right pulmonary artery

C: Right atrium

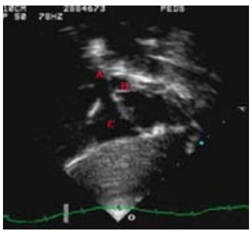
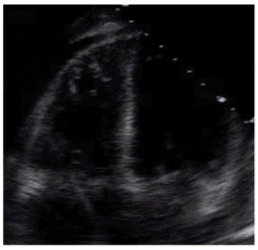


Image Guided Surgery

Illustration showing guiding of
a trans-septal puncture

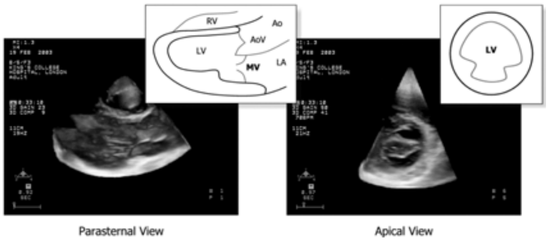
2D vs. 3D Echo



2D Echo

3D Echo

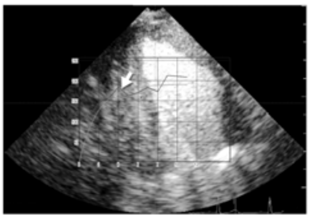
3D Echo

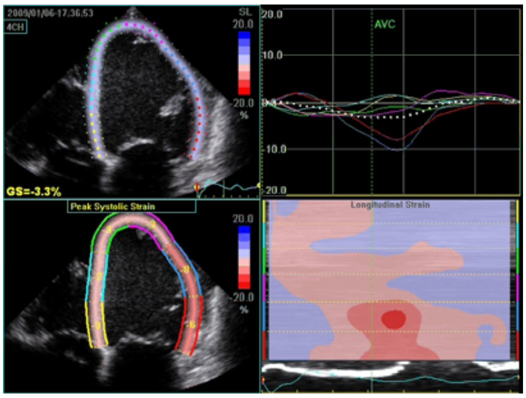


Perfusion

An example of perfusion echocardiography showing the uptake of the microbubble contrast agent into the myocardium.

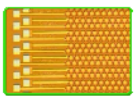
The curves superimposed show the recovery of the signal at the septum.





Solid State Ultrasound

MEMS Enabled Portable, Integrated, Imaging& Information Devices



cMUT MEMS Array

Enabling Technologies

Integration

- MEMS transducer and electronics in the same miniature circuit

Miniaturization

- Highest density, performance interconnect & packaging

Benefits

Portable applications

Flexible sheet-like "probe"

Low-cost manufacturing

Discussion

Advantages:

- Live real-time images, useful for rapid and flexible diagnosis
- Safe (no known side-effects)
- Small, easily transportable
- Inexpensive

Weaknesses:

- Limited applications (e.g. cannot penetrate bone for brain scanning, is affected by gas in intestines)
- Operator dependent, requires experienced user
- Image quality can be limited

Conclusions

- Ultrasound is a real-time, inexpensive and practical imaging modality
- It is based on the pulse-echo effect associated with high-frequency sound
- Ultrasound is the most widely used modality in clinical environment
- The technique can have limited image quality in some examinations

Computed Tomography

- First CT scanner developed by in the 1970s by G. Hounsfield in the UK (Medicine Nobel Prize 1979)

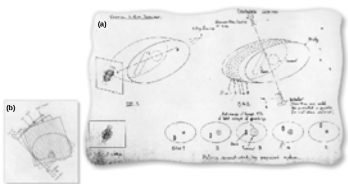
Godfrey later joined the RAF as a volunteer reservist at the outbreak of the second World War in 1939

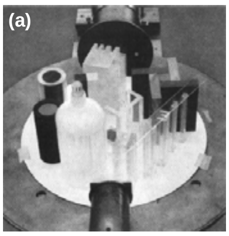
He excelled in research into Radar.

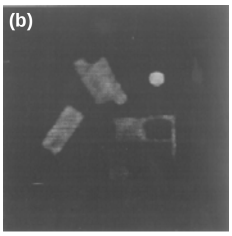
In 1951 he joined EMI to work on Radar and guided weapons.

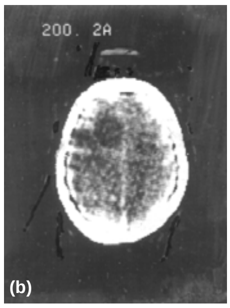
Godfrey took a fervent interest in digital computers and in 1958 he led a design team in building the first all-transistor computer in Britain (the EMIDEC 1100)

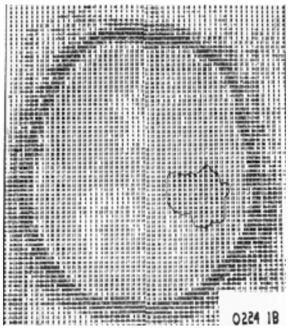
1967

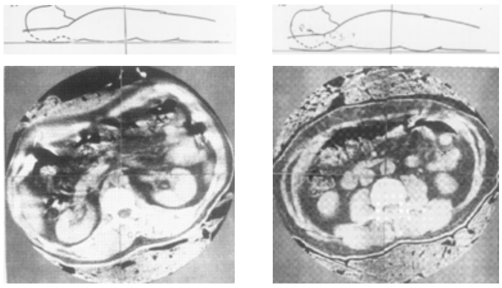






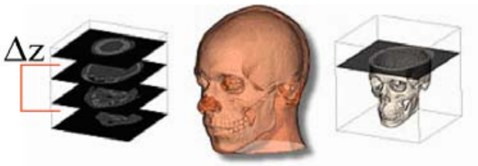






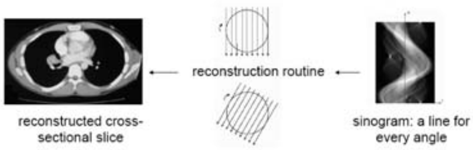
Basic Principles

- Tomography comes from Greek: Tomos (layer) Graphia (describe)
- The aim is to reconstruct several image cross-sections of the anatomical structure



Principle

- X-rays are taken at various angles
- Image is reconstructed from the various signals using an algorithm (thus Computed Tomography)



Main Hardware

X-ray tube

Detectors:
- Crystals that produce light induced by the X-ray beam
- Intensity of this light depends on tissue absorption

Motor:
- Use for rotation of the X-ray tube and detectors

First Generation

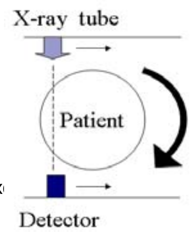
1971

Thin beam of radiation

Translate and rotate

X-ray and detector relative positions fix

Single slice scan time ~ 5 min



Second Generation

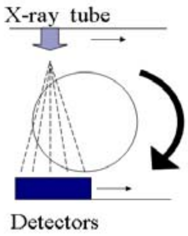
1974

Multiple beams of radiation (Fan)

Translate and rotate

X-ray and detector positions still fixed

Single slice scan time ~ 3.5 min



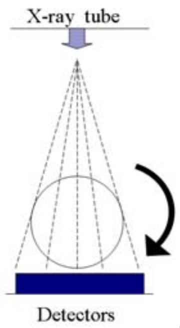
Third Generation

1977

Array of detectors

Only rotation

Scan time ~ 4.8 seconds!!



Fourth Generation

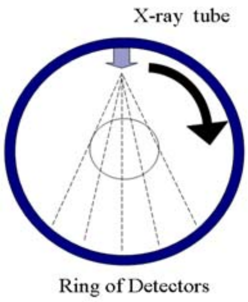
1980

Full ring of detectors

Wider fan of X-ray beams

Only rotation

Scan time ~ 1 second!!

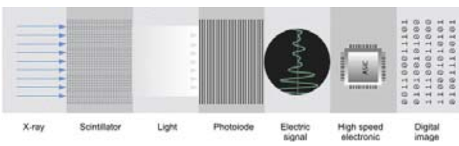


Detector Technology

The quality of the detector is critical to the quality of the scanning

A detector is composed of three main parts, scintillators, phot

Detector Technology



The scintillators convert the radiations into light signal

The photoiodes catch the light and process it into electric signals

The signal are transmitted via numerous electrical channels

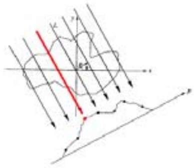
Image reconstruction follows

Detector Technology

- The more efficient the detector is in converting the radiation, the less dose is required
- For this reason, detector materials have to be effective in absorbing the X-ray and converting them to light
- To this end, the most advanced material currently used include xenon and ceramic

Image Reconstruction

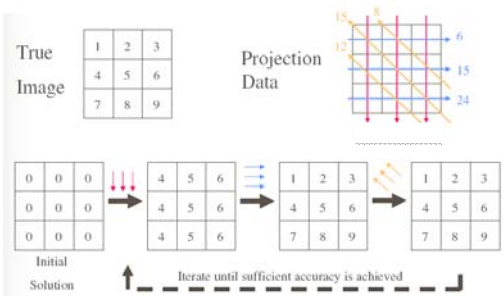
- The captured light represents the line integral of the tissue properties (i.e., sum of pixel intensity values) along the incident X-ray
- However, the individual pixel values are unknown along the line. Can we reconstruct the image using several angles



Back Projection

- Start from one X-ray angle and assign corresponding pixels equal values that sum to the line integral
- For all remaining rays, do same thing and add the values to the current estimation of the image
- Repeat until convergence of the final image. With sufficient back-projections, the structure can be somewhat restored.

Back Projection



Back Projection

- Mathematically, the back projection operation is defined as: $f_{BP}(x,y)=\int_0^{\pi} p(x\cos\phi+y\sin\phi,\phi)\,d\phi$
- where the function to integrate is the Radon Transform, whic $p(\xi,\phi)=\int f(x,y)\delta(x\cos\phi+y\sin\phi-\xi)\,dx\,dy$ lutions
- Remark $p(\xi,\phi)=-\log\left(\frac{I(\xi,\phi)}{I_0}\right)$ of the Radon transform are known:

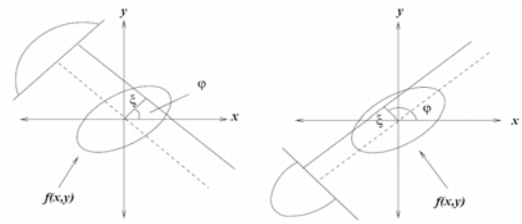
Measured intensity

X-ray position and angle

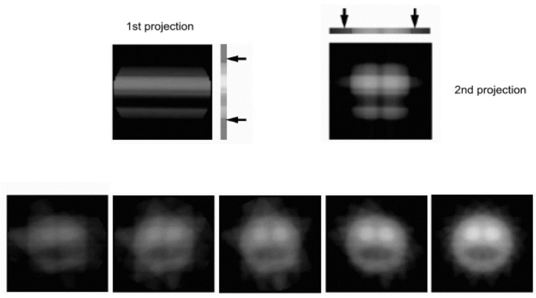
X-ray intensity

Radon Transform

- Examples showing integration along specified lines using the Radon transform:



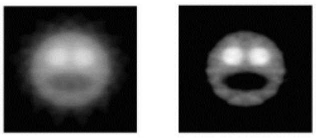
Examples



More projections until final reconstruction

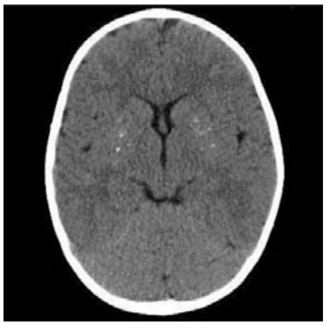
Back Projection

- The Radon transform produces a blurring effect due to low pass emphasis
- In practice, filtering is applied to address the issue (common high pass filters include Ram-Lank, generalized Hamming, Cosine filter)



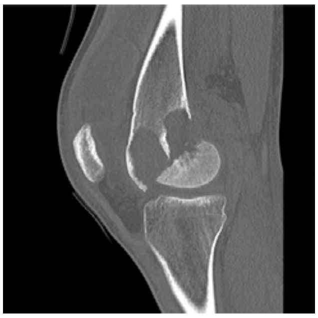
Unfiltered   Filtered

Brain



Lungs

Femur



Typical Diagnosis

Cancer (e.g., lung, brain, abdomen)

Blockage (e.g., aneurysm)

Bleeding, fracture, infections

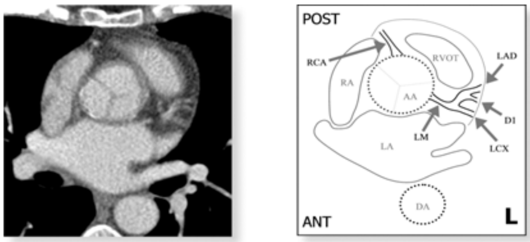
Increasingly used in cardiac assessment

Cardiac CT

- Cardiac CT has varied applications for cardiovascular assessment (chambers size, morphology, function, great vessels)
- In practice, the ionizing radiation exposure of CT reduces the clinical potential of the modality, particularly for follow-up studies
- CT has unique capabilities for coronary assessment: (Stenosis, aneurysms, Coronary bypass grafts, Coronary calcification)
- CT has inferior temporal resolution when compared to CMR

Cardiac Morphology

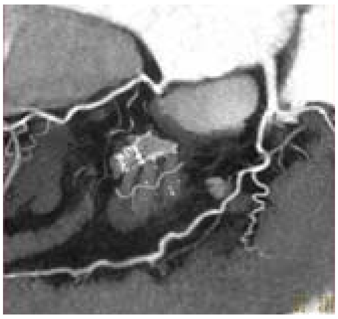
Coronary Arteries



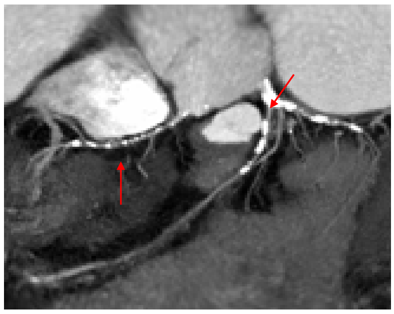
(a) (b)

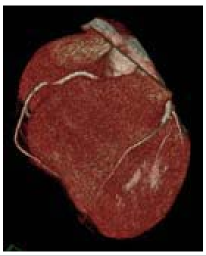
The anatomical configuration of the major coronaries depicted by CT (a) and its corresponding schematic diagram (b)

CT Angiography



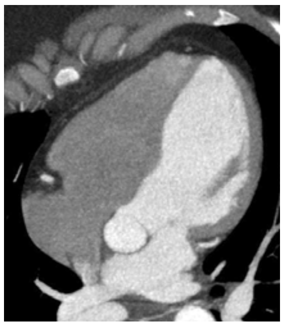
Coronary Calcification



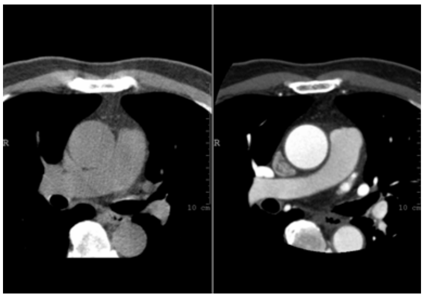


Contrast Enhancement

Example with high iodine density contrast ≥ 350 mgI/mL, for uniform enhancement of the left heart



Contrast Enhancement



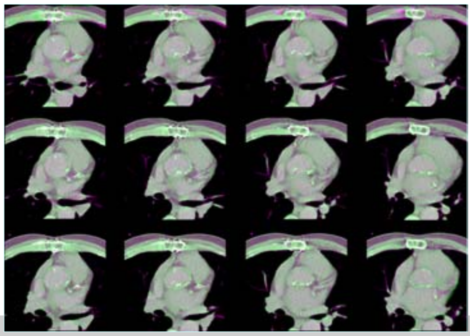
No contrast With contrast

Serial Scans Registration

6-month

12-month

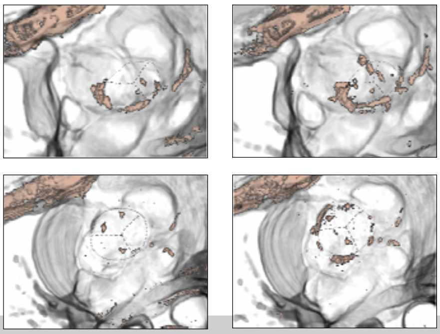
18-month



3D Reconstruction of Calcified Valve

Homograft

Freestyle



6 months 24 months

Discussion

Advantages:

- High resolution and accuracy
- Can image bone, soft tissue and blood vessels at once
- Speed (ideal in case of emergencies, lungs can be imaged in less than a minute)

Disadvantages:

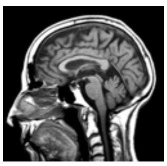
- Radiations (on average equivalent to the dose received in 3 years from background radiation)
- High costs

Conclusions

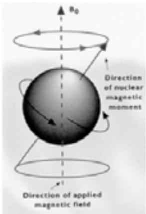
- CT is a powerful modality for imaging and diagnosis for a wide range of applications
- It provides high resolution images but involves a certain amount of radiation
- Back projection using the Radon transform and filtering is the computational core of the modality
- Future works include improving patient comfort and applicability in specific areas (e.g., cardiac)

Magnetic Resonance Imaging (MRI)

- MRI developed in 1970s by P. Mansfield (UK) and P. Lauterbur (US) (Medicine Nobel 2003)
- It is known to produce great contrast between different tissues



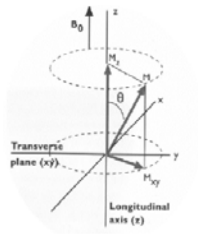
Basic Principle



- Once the pulse is removed, the nuclei emits an **electromagnetic signal** in order to return to its initial orientation
- These signals are captured by a set of **receiver coils** and sent to the computer for interpretation

Basic Principle

- The magnetization created M has two components:
  - Longitudinal (M_z) along B_0
  - Transverse (M_{xy})
- Their physical properties govern the sequence design in MR

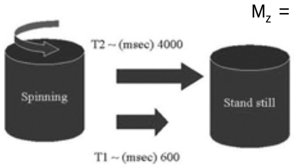


Relaxation Times

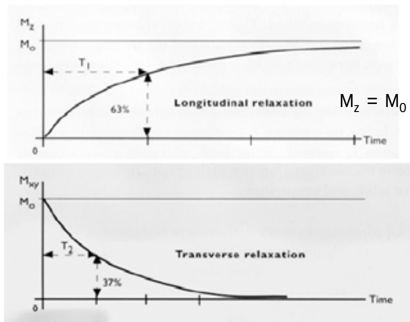
Two relaxation times are of importance to MRI:

- T_1: recovery of the longitudinal magnetization ($M_z = M_0$)
- T_2: decay of the transverse magnetization ($M_{xy} = 0$)

$M_z = M_0\,(1\text{-exp}(-t/T_1))$



Relaxation Times



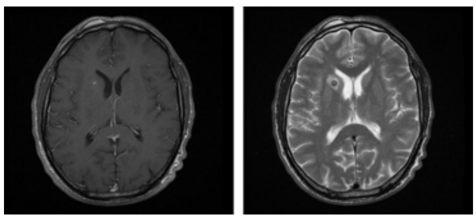
$M_z = M_0\,(1\text{-exp}(-t/T_1))$

Acquisition Parameters

- T_1 and T_2 as well as the proton density are important parameters used to differentiate the tissue constituents
- Careful sequence design can allow to emphasize one particular parameter or tissue constituent
- Furthermore, by using weighted combinations, it is possible to obtain a multi-spectral imaging modality relevant to the study

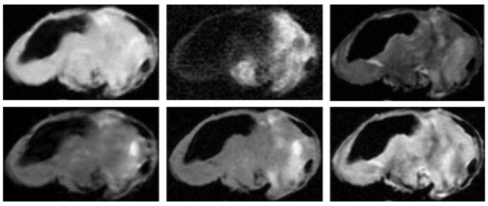
Example

T_1-weighting and T_2-weighting brain images



Example

Carotid bifurcation with 6 MR sequences



Z.A. Fayed, Mount Sinai MC

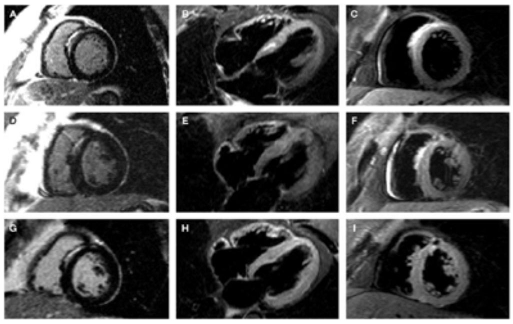
Contrast Agent

- Contrast agents can be administered to enhance the appearance of blood, tumours and other structures
- E.g., it can be simple water taken orally for imaging the stomach or small bowels
- Most contrast agents are selected for their magnetic properties

Gadolinium

- The most common contrast agent
- Gadolinium enhanced tissues appear bright on T_1 weighting images
- This provides higher sensitivity for analysis of vascular tissues and perfusion

Examples

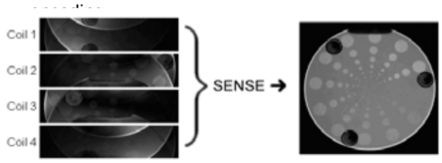


Parallel Imaging

- Recent sequence design in MRI focuses on parallel techniques
- The aim is to achieve significant scanning speeding-up
- To this end, various schemes are developed based on a set of array coils
- Parallel imaging in MRI can recover larger than usual portions of the measurements in every encoding iteration

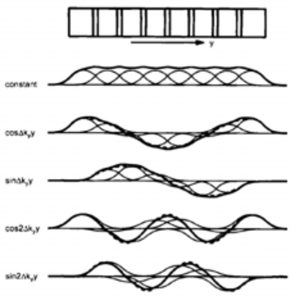
SENSE

- Sensitivity Encoding (SENSE) is one the most established fast MR imaging techniques, using a set of coil receivers
- The spatial information related to the coils of a receiver array are utilized for reducing conventional Fourier



SMASH

- Simultaneous Acquisition of Spatial Harmonics (SMASH) uses a partially parallel measurement scheme
- With this technique, several spatial harmonics are used to approximate the multiple coil sensitivities



MR Applications

Cardiac assessment (very established in clinical practice)

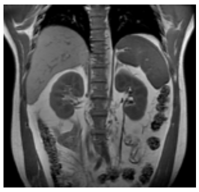
Vessels (increasingly used to study big arteries)

Neurology

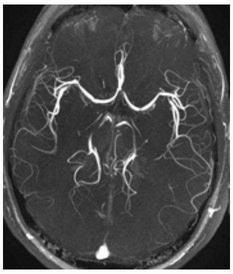
Respiratory

Orthopaedics (joints, bones)

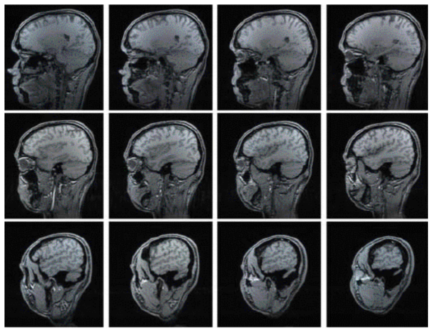
And many other applications...



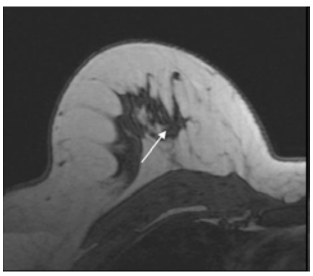
Angiography



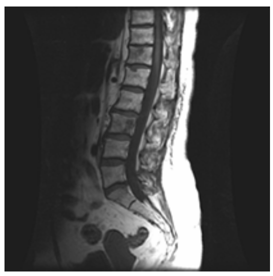
Brain



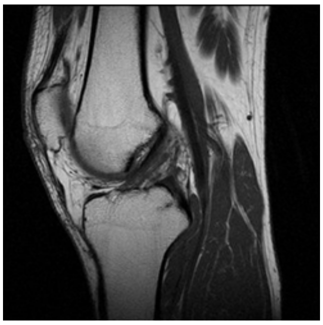
Breast



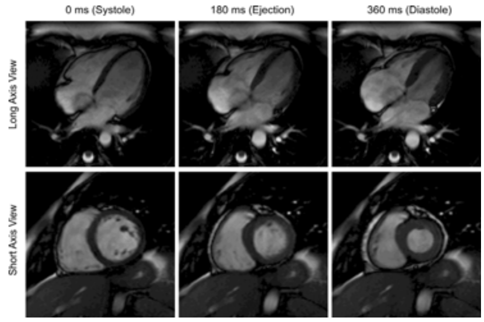
Spine



Knee

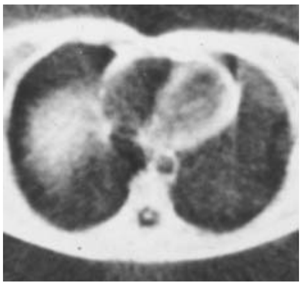


Cardiac Assessment

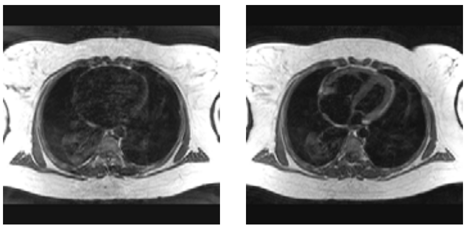


Cardiovascular MR

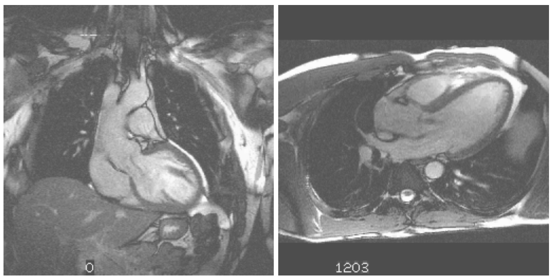
- CMR is the reference for the assessment of ventricular dimensions, function and mass
- It is highly accurate and reproducible
- A wide range of CMR sequences have been developed for various purposes (e.g., mass, perfusion, blood flow, arteries)

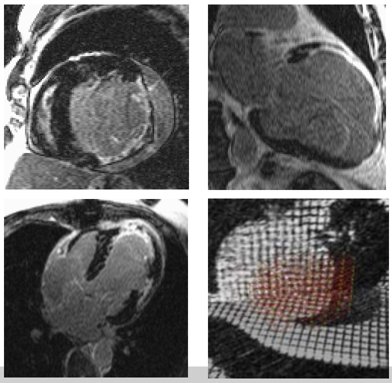


Heart - Hammersmith 1981

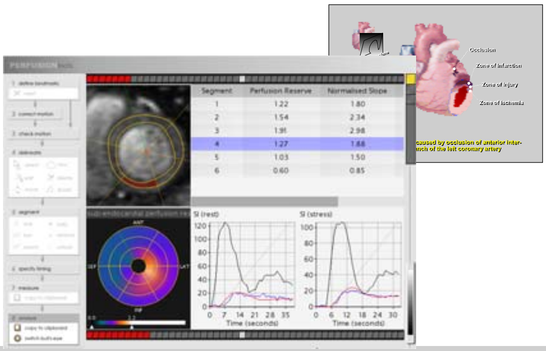


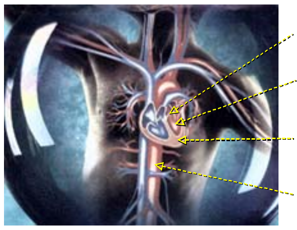
re-positioning of electrodes





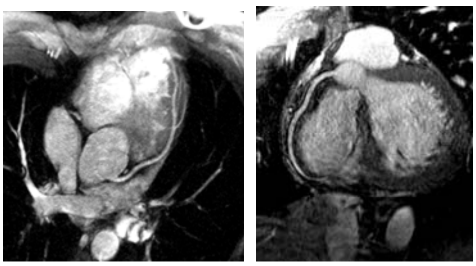
Myocardial Perfusion Imaging



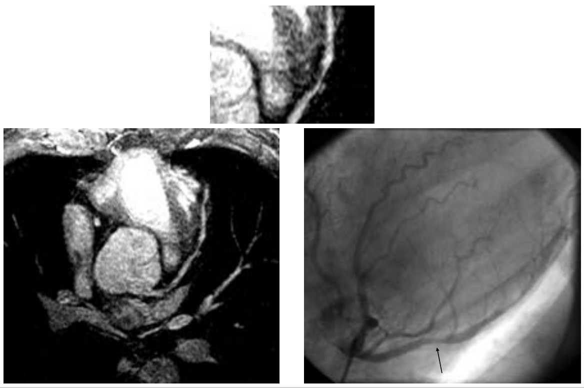


3D True-FISP breath-hold imaging

(normal volunteers)



D Li et al

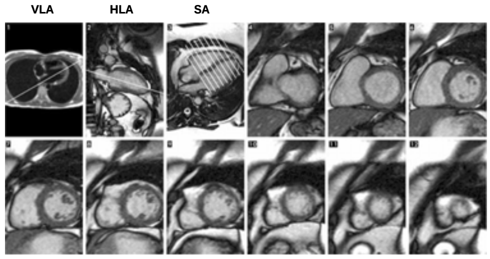


MRA conventional angiography

Standard Protocol

- Two long axis images and a stack of about 10 short axis images
- A cine image can be acquired in one breath hold in about 10 seconds (a typical conventional study requires about 5 minutes)
- Electrocardiographic gating (ECG) allows adequate 4D coverage across the cardiac cycle (good temporal resolution around 60 ms)

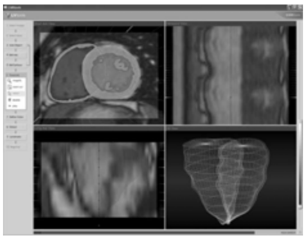
Standard Protocol



N. Keenan et al. Echocardiography, 24(2), 2007

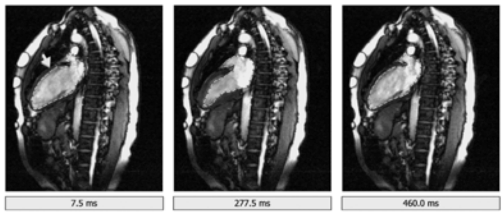
Cardiac Morphology

- Example of semi-automated analysis of left and right ventricular mass, volume, and systolic function using CMR.

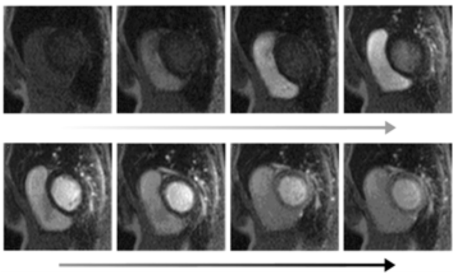


www.cmrtools.com

Cardiac Contractility



Myocardial Perfusion

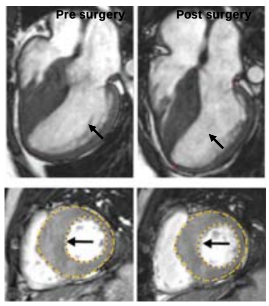


A sequence of CMR perfusion images showing the uptake of contrast agent in the myocardium.

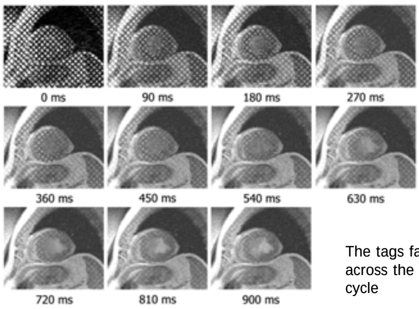
Hypertrophic Cardiomyopathy

MR long and short axis images showing pre- and post-surgery on patient with HCM

Change in septal thickness can be observed and quantified using CMR



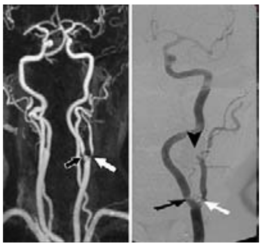
MR Tagging



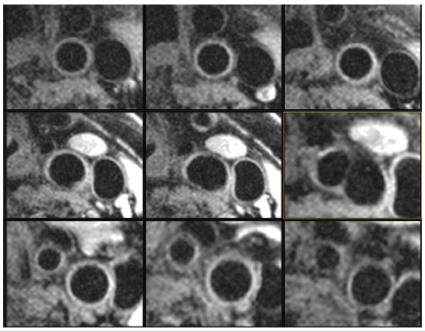
The tags fade away across the cardiac cycle

MR Angiography

MR angiography showing carotid artery abnormalities



Carotid Imaging



Discussion

Advantages of MRI:

- Great tissue contract
- Flexibility (can image boundaries, velocity, flow, perfusion)
- Safe (no radiation involved)

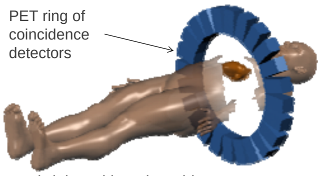
Limitations:

- Possible claustrophobia feeling
- Patient movement can affect the scan
- Patient with pacemakers cannot be studied
- Expensive to purchase, maintain and operate

Conclusions

- MRI provides great tissue contrast and a wide range of tissue measurements
- The modality is established in clinical practice and is the basis for a significant number of applications
- MRI compares favourably to most exiting imaging techniques due to its accuracy, reproducibility and flexibility
- A few developments are required, particularly to improve patient comfort, scanning speed, and sequence design

Positron Emission Tomography

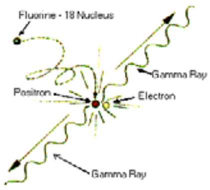


A positron emitting tracer is injected into the subject

PET generates images depicting the distribution of the positron emitting nuclides in patients

To this end, several rings of detectors surround patients in typical scanners

Photon Emission

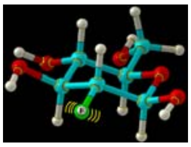


- As the radioactive atoms decay, they emit positions.
- After travelling a short distance, the positively charged positrons collide with electrons with negative charge
- The entire mass of the electron-positron annihilation is converted into two 511-keV gamma rays, emitted in nearly opposite directions

Radioactive Tracer

- The tracer is a radioactive isotope with very short half-life
- Generated on site using a cyclotron
- Administered intravenously or inhaled as a gas
- Types of isotope used in PET
  - ^{15}O – inhaled as gas, or injected as water
  - ^{11}C – inhaled as CO gas; used for imaging blood pool
  - ^{18}F – in Fluorodeoxyglucose (FDG) an analogue to glucose

Radioactive Tracer

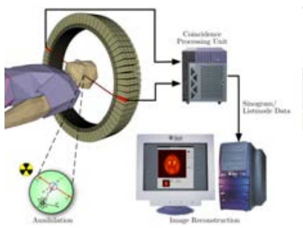


^{18}FDG

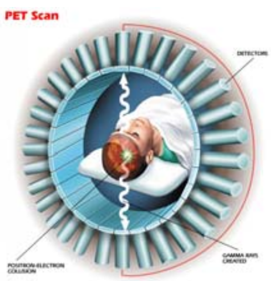
- FDG injected in dose solution into veins
- Some cells are highly metabolic and can receive more glucose than others, thus acting as a differentiation mechanism
- Used in oncology and myocardial perfusion imaging

Coincidence Detection

- PET scanners use a principle called "annihilation coincidence detection" (ACD) to obtain projections of the activity distribution in the subject



ACD



Photon Counter

- Annihilation gives
  - Two gamma photons
  - Opposite direction
- PET is a photon counter:
  - Time window ~ 1ns
  - Counts gamma ray pairs versus single rays

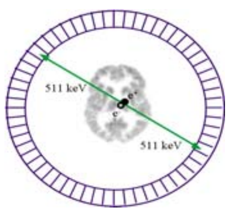
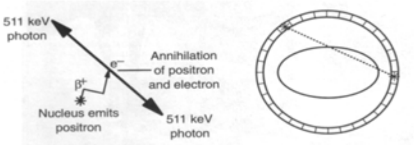
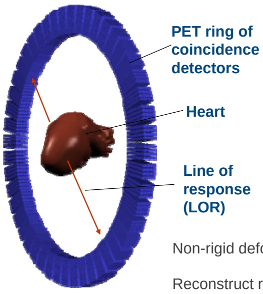


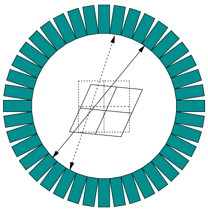
Image Reconstruction

- Uses the same computational approach than CT, hence Position Emission Tomography
- The line connecting the two photon interactions with the detectors is the basis line integral



List-mode motion correction

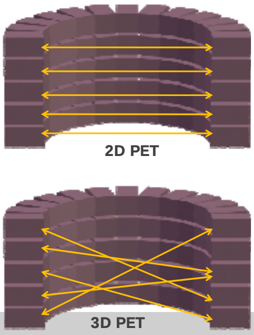




Non-rigid deformation, Affine transform of LOR

Reconstruct rebinned list-mode

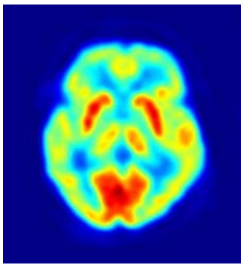
3D Image Reconstruction



2D reconstruction
- Each slice independent
- Ignore LOR events involving more than one ring

3D reconstruction
- LOR events between different rings are included
- All slices processed together
- Improved SNR

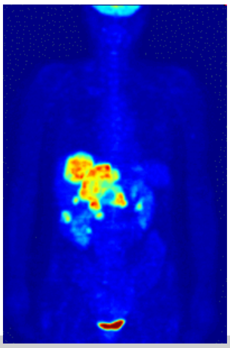
Brain Illustration



Applications

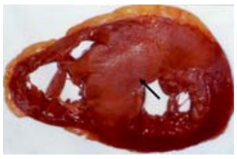
- Clinical oncology (tumours, metastases)
- Neurology (certain diffuse brain diseases, such as those causing dementia)
- Cardiology (in particular vascular studies)
- Research animal studies

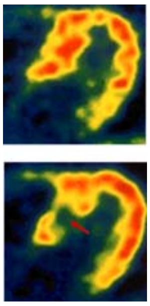
Whole Body



(Showing abnormal focal uptake in the liver)

Hypertrophic Cardiomyopathy





Rest

Stress

New England J Med 2003, 349, 1027-1035

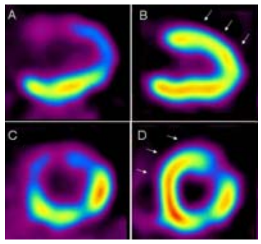
Viability Assessment

Example of ^{18}FDG-PET images of patient with myocardial infarction (defect anterior wall).

After cell transplantation, anterior wall and apex showed increased viability (arrows) in infracted area.

Pre surgery

Post cell transplant



Tossios et al., BMC Medical Imaging, 2006

Discussion

- Advantages:
  - Unique functional capabilities
  - Can image the whole body
  - Can diagnose biological disorders at the molecular level (often before anatomical change is visible)
- Limitations:
  - Involve radiation exposure (similar to CT)
  - Relatively expensive
  - Low spatial resolution (> 2 mm)

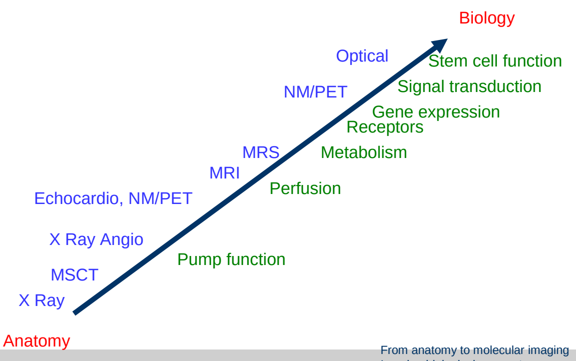
Conclusions

PET is a nuclear medicine imaging technique which can produce images of functional processes

Radioactive tracers are required, such as FDG-18 or Rb-82, depending on the application

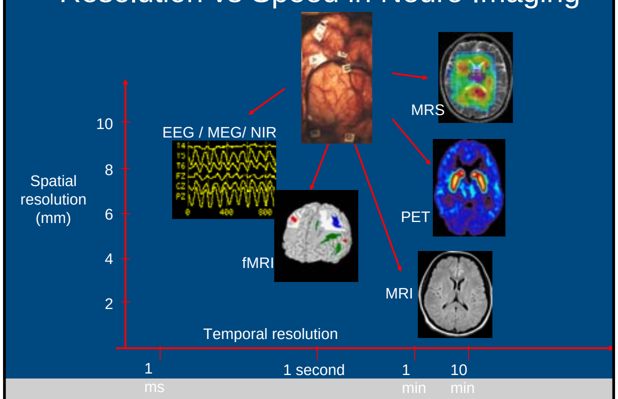
The modality allows complimentary and more detailed functional assessment of a number of diseases

While the technique is rapidly advancing, future work include decreasing exposure to radiation



From anatomy to molecular imaging
Imaging biological parameters

Resolution vs Speed in Neuro Imaging



Method	spatial resolution	temporal resolution	function* mol. Imag
Ultrasound	+++ (2mm)	+++++	++
CT	+++++ (0.3mm)	++++	+
MR	++++ (0.8 mm)	+++	+++
Nuclear Medicine	+ (13 mm)	+	++++
PET	++(+) (5mm)	++	+++++

PET- CT : Combining the Best of Two Imaging Worlds