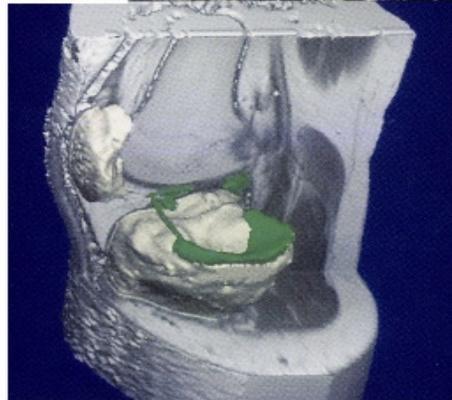
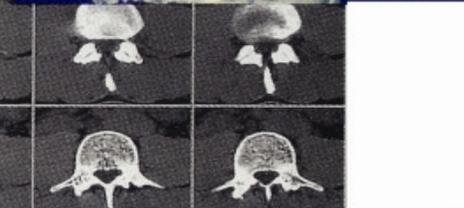
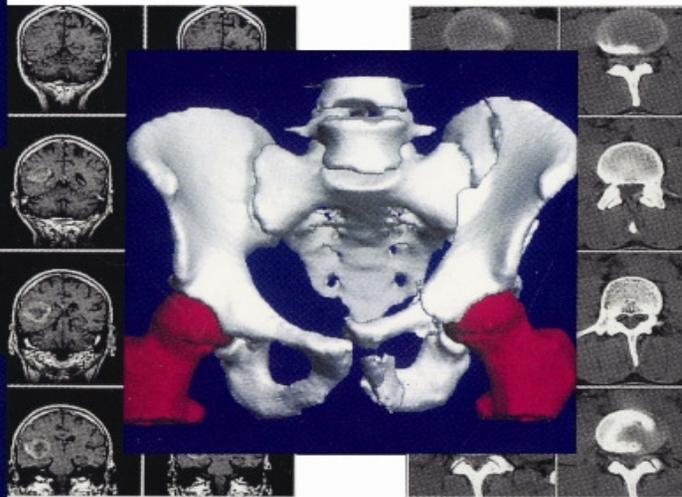
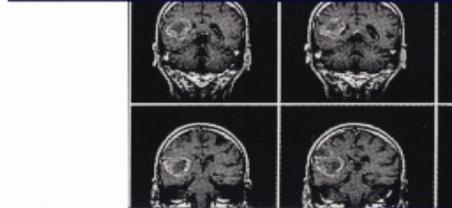
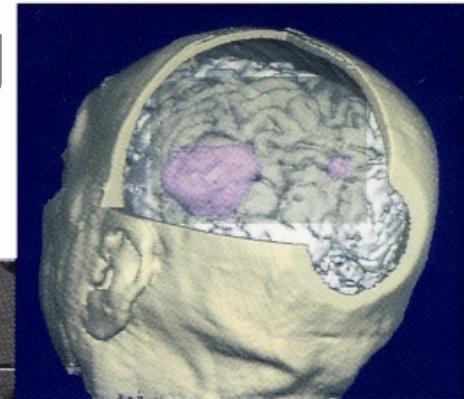




Medical Imaging *quo vadis?*



Pascal Fallavollita, PhD
Senior Research Scientist



Historical: medical imaging happened in last 100 yrs

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	<i>Germ theory of disease</i> 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	<i>X-ray contrast medium</i> . First contrast filled image of the renal system (kidneys).
1910	<i>Barium sulfate</i> 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	<i>Electrocardiograph (ECG)</i> 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	<i>Transmission electron microscope (TEM)</i> 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	<i>X-ray Image Intensifier</i> -Television units to allow dynamic x-ray imaging of moving scenes. These fluoroscopic movies provided new information of the beating h
c. 1955	<i>Panoramic x-ray</i> images of the entire jaw and teeth.
1957	<i>Fiber endoscopy</i> 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 C
1975	<i>Chronic villus sampling</i> 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.
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 fo
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 Labora
1984	<i>3-Dimensional image processing</i> using digital computers and CT or MR data, three dimensional images of bones and organs were first made.
1985	ClinicalPositron Emission Tomography (PET) scanning developed by scientists at the University of California.
c. 1985	<i>Clinical Networks</i> were first implemented to allow digital diagnostic images to be shared between physicians via computer network, allowing a doctor in Bostor
1989	Spiral CT allows fast volume scanning of an entire organ during a single, short patient breath hold of 20 to 30 seconds. S
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.
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

Historical: understanding anatomypast to present



Herophilus
335-280 BC



Galen
129-200



Da Vinci
1452-1519



Vesalius
1514-1564



Gray
1827-1861

Courtesy of Marc Niethammer, UNC, 2008

The bodies of the **great minds** could be dissected or the injured **gladiators** could be treated to learn about anatomy

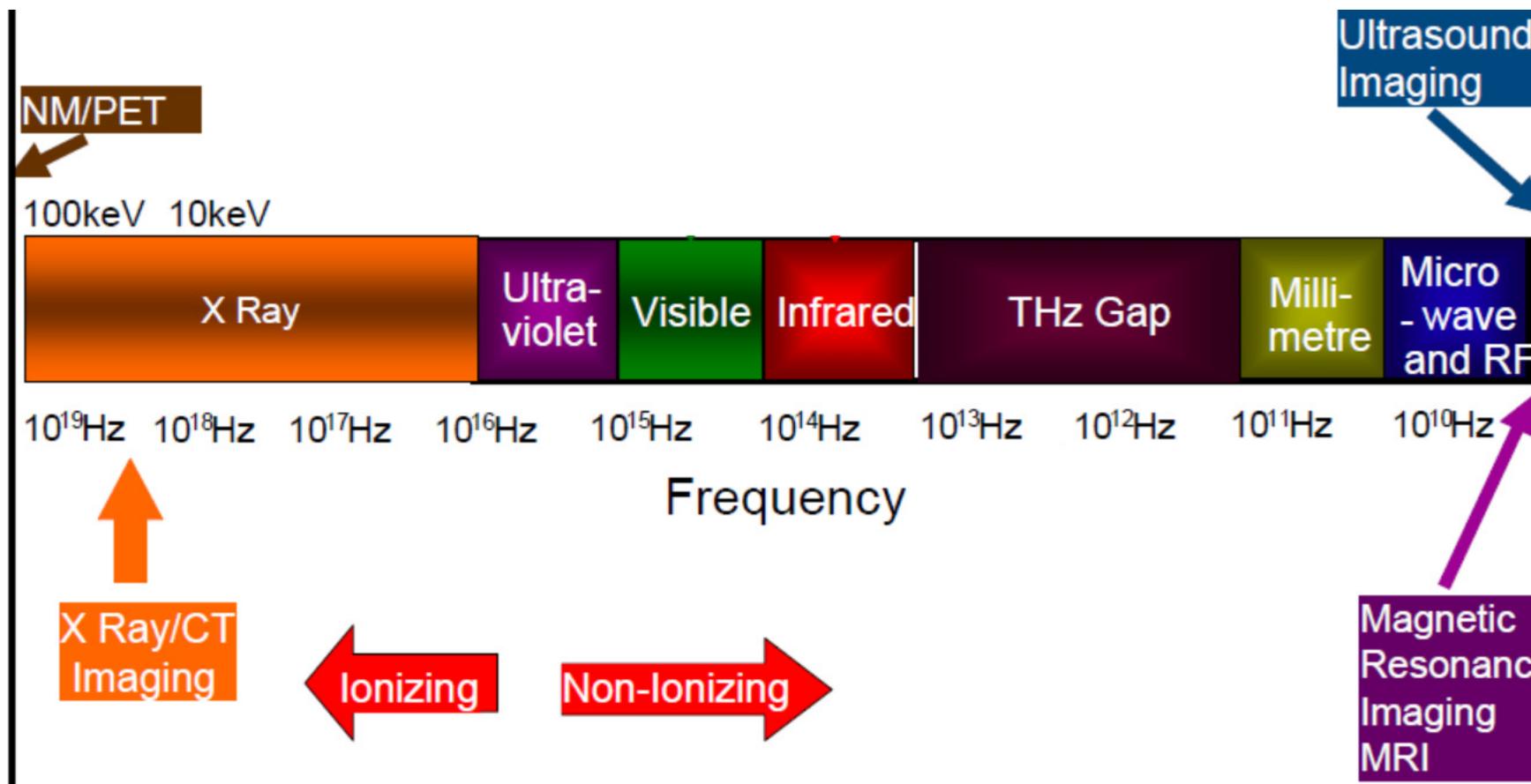
Today, we look into the human body **in vivo**.

Historical: Mayan civilization of central America



The Mayan Codex #23--- it was considered a basic right given by the **Green Jaguar God** for any Mayan with a *mallet*, a *sharp obsidian knife* and a desire to help his fellow man to find someone in need of brain surgery and **start hacking away** → for pressure relief in the brain

Preview: Imaging & Wavelengths



Courtesy of Guang-Zhong Yang, Imperial College, 2009

Different wavelengths means different interaction with tissue

X-ray: where it all began

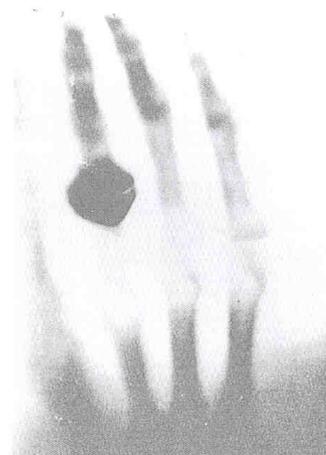
1895: Announces X-ray discovery

1896: Images needle in patient's hand, X-ray used presurgically

1901: Receives first Nobel Prize in Physics

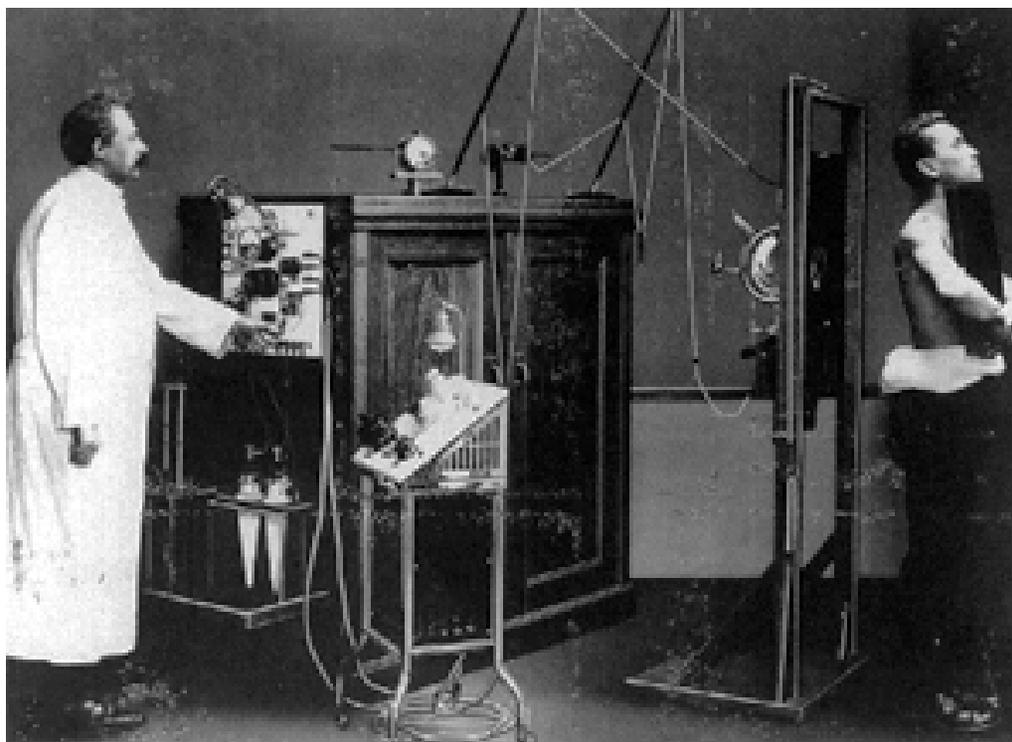


Prof. Dr. W. Röntgen



Radiograph of the hand of Röntgen's wife, 1895.

X-ray: using film cassettes



First 50 years of radiology, the primary examination involved creating an image by focusing x-rays through the body part of interest and directly onto a single piece of film inside a special cassette.

A head x-ray could require up to 11 minutes of exposure time.

X-ray typical applications

Orthopedic surgery: observe fractures and healing bones

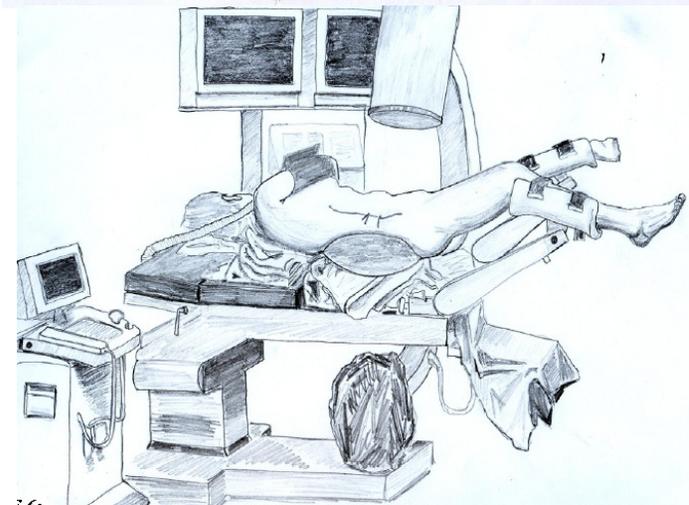
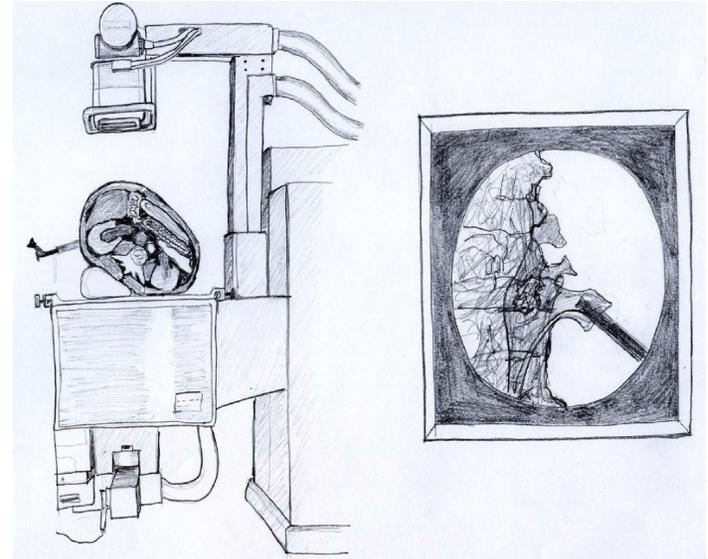
Catheterization: direct catheter placement in angiography and angioplasty

Barium X-rays: observe movement through GI tract

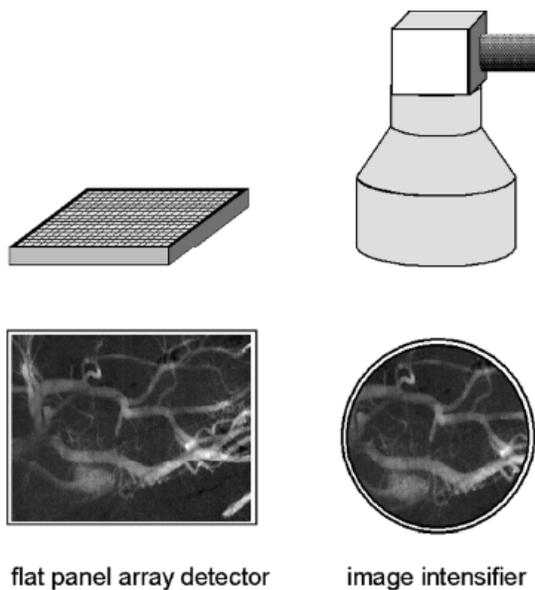
Blood flow Studies: view blood flow to organs

Locating foreign bodies

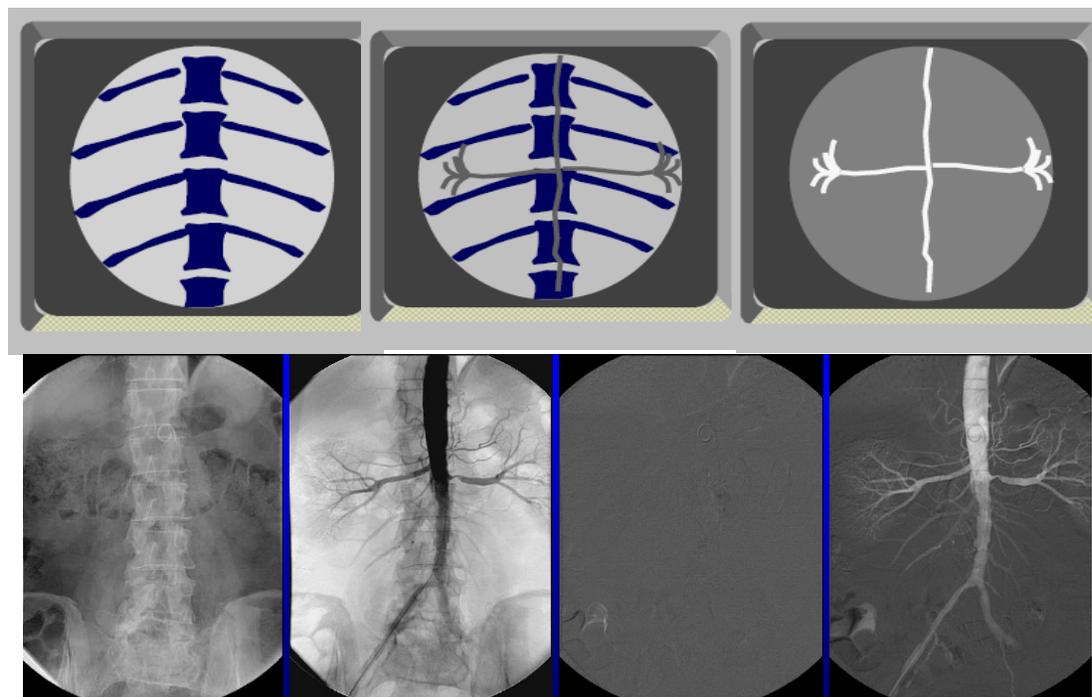
Spine and Joint injections



C-arm fluoroscopy

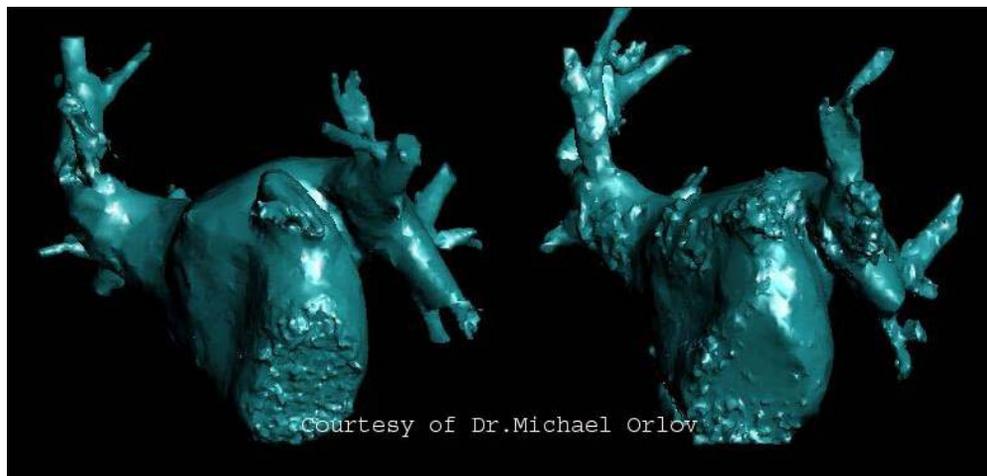


Flat Panel C-arms



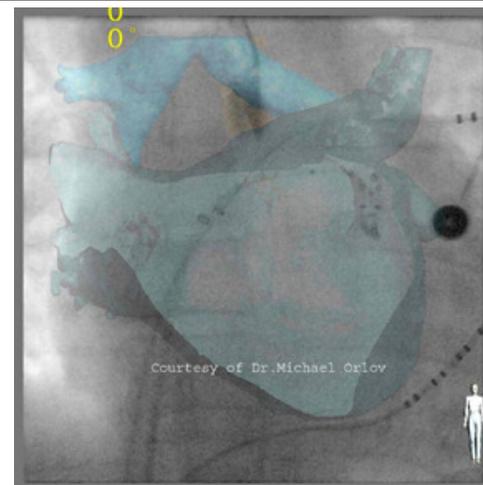
Digital Subtraction Angiography

Rotational Fluoroscopy



Rotational angiogram with 3D reconstruction is performed using **Allura Xper FD 10 system** (Philips Healthcare) immediately prior to AF ablation procedure.

Contrast is injected in the right atrium, the C-arm is rotated over 240 degrees & 3D reconstruction fused in X-ray.



Fluoroscopy & Mobile C-arms Global Market

The world market is forecast to recover poise in the short-to-medium term period to reach **US \$1.3 billion** by the year **2015**.

Continues to be dominated by developed nations (i.e. *US, Japan, and Europe*)



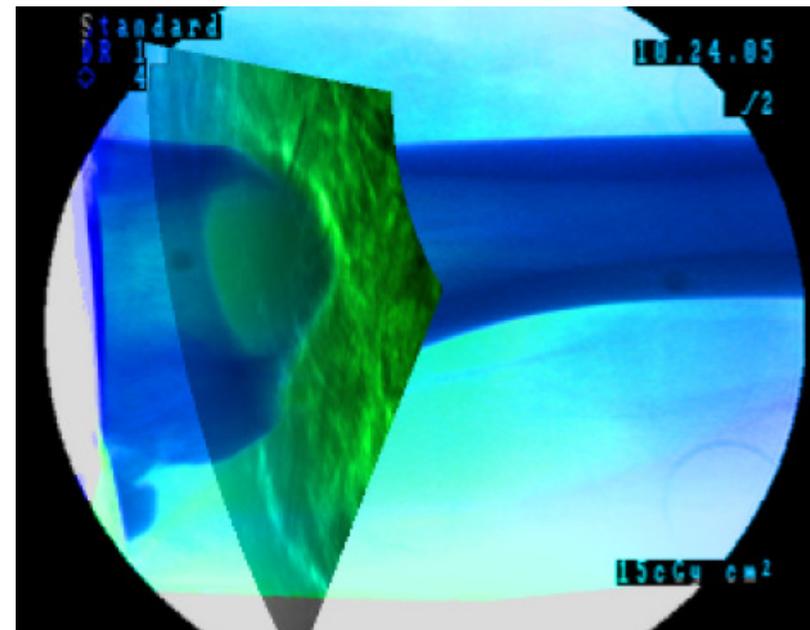
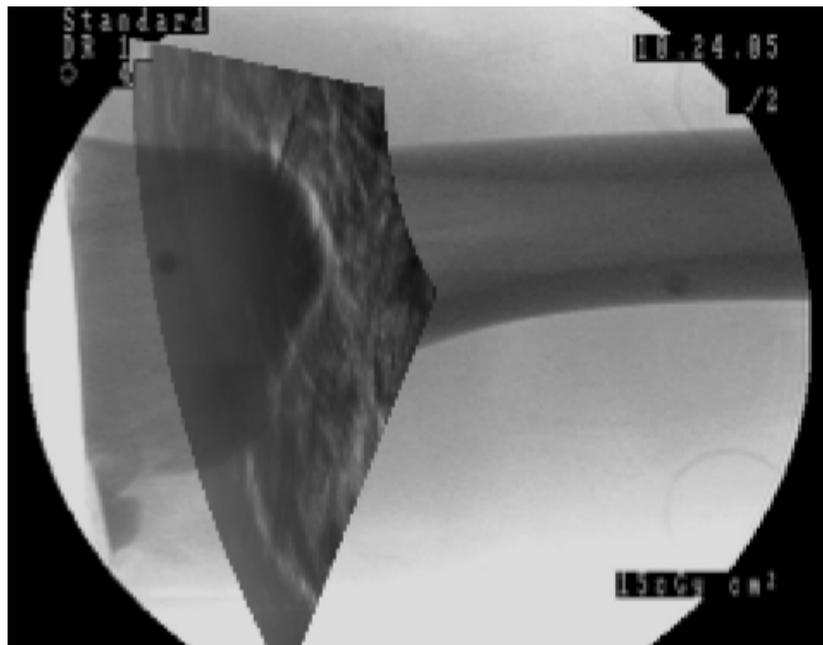
Fluoroscopy & Mobile C-arms Global Market...continued

More room to see patient and working area with the **Philips Veradius mobile C-arm system** with super thin flat detector



Bring machine to the patient using the **Siemens Artis zeego Multi-axis system**

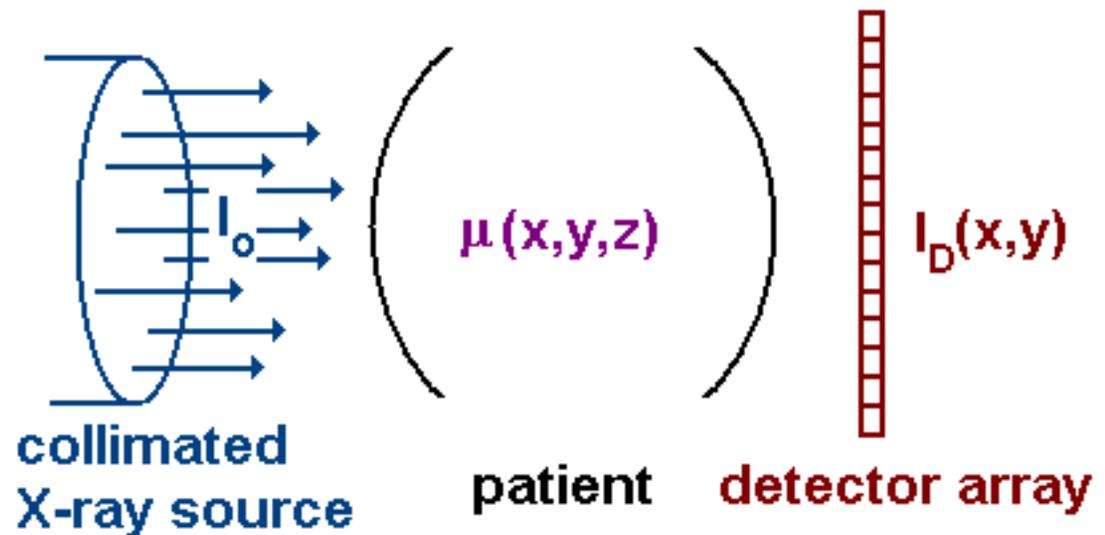
From grayscale to color?



Computerized Tomography (CT)



Godfrey Hounsfield



$$\text{Result: } I_D(x, y) \propto \mu(x, y)$$

1972 Hounsfield announces findings at British Institute of Radiology

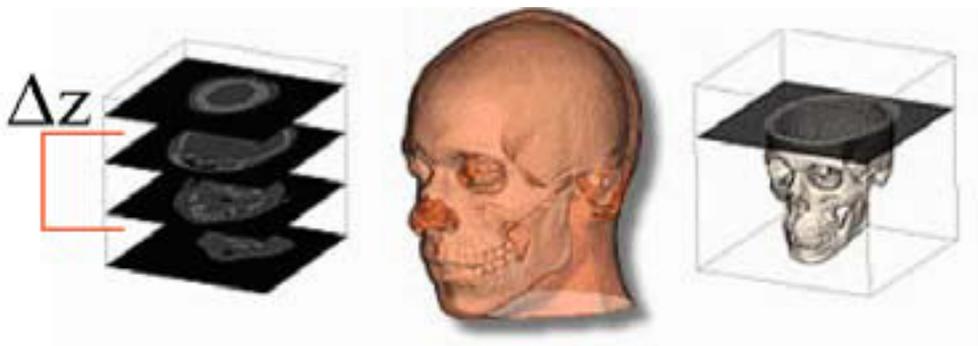
1979 Hounsfield, Cormack receive Nobel Prize in Medicine

(CT images computed to actually display attenuation coefficient)

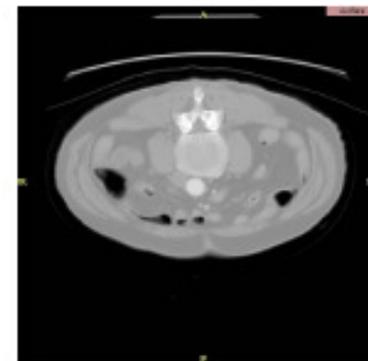
CT principles

Tomography derived from Greek: **tomos** (layer) and **graphia** (describe)

Objective is to reconstruct several image cross-sections of anatomical structures



axial



sagittal



coronal



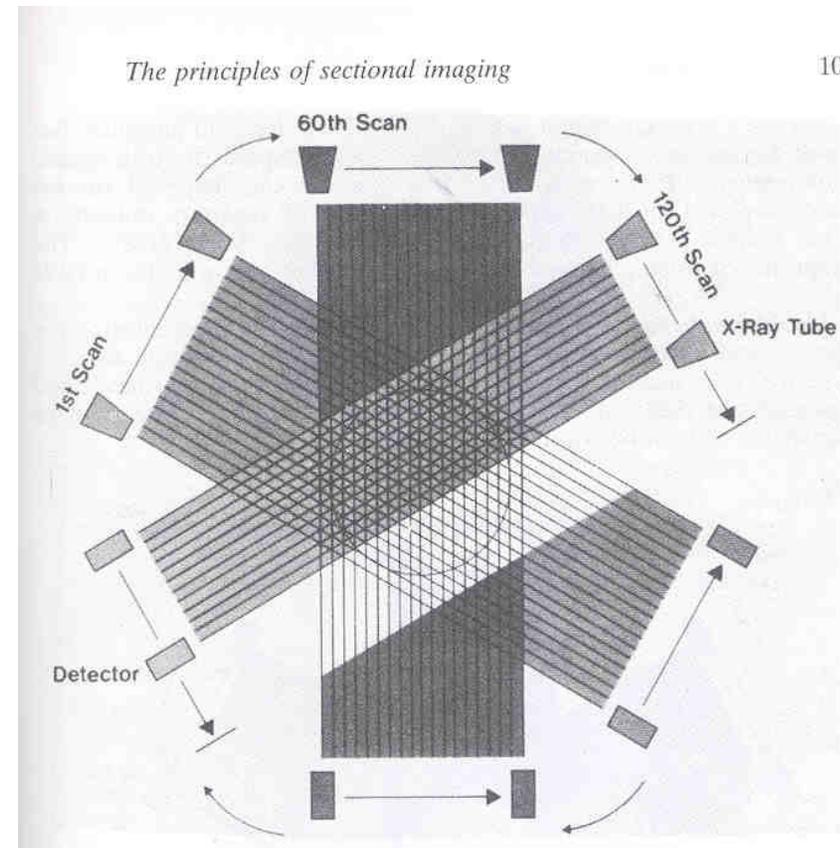
First Generation CT scanner (1971)

1. Acquire a projection (X-ray)
Translate x-ray pencil beam and detector across body and record output

2. Rotate to next angle
Repeat translation

3. Assemble all the projections

~ 5 minutes for single slice scan



CT scanner



EMI provided the first CT scanner

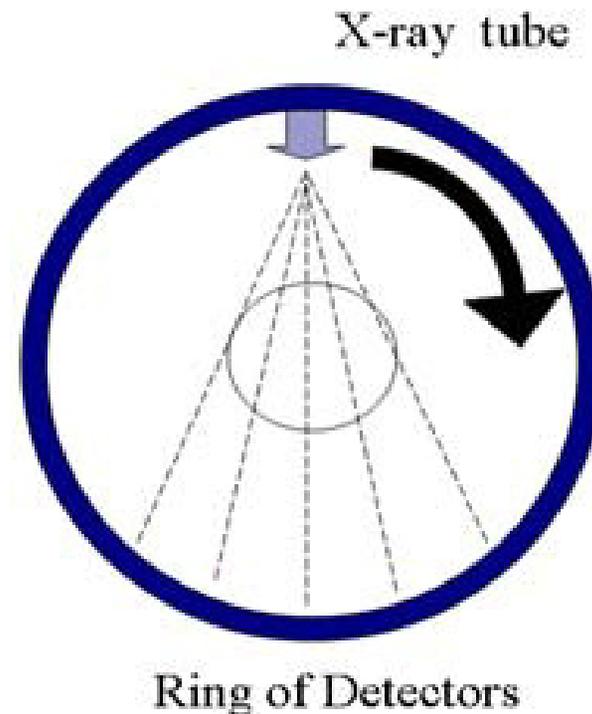
EMI also introduced The Beatles

lingering questions remain... have The Beatles financed it?

4th Generation CT scanner (1980)

1. Full ring of detectors
2. Wider fan of X-ray beams
3. Only rotation

~ 1 second for single slice scan



Courtesy of Guang-Zhong Yang, Imperial College, 2009

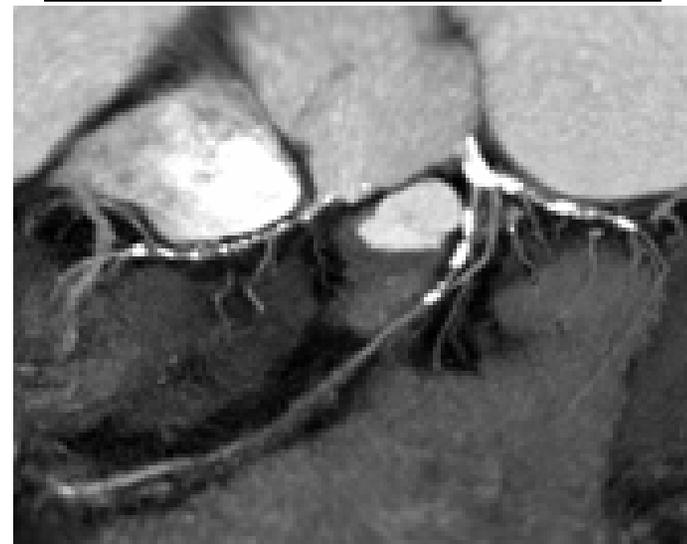
CT typical applications

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

Blockage (e.g., aneurysm)

Bleeding, fracture, infections

Cardiac assessment (e.g., stenosis)



CT Global Market

Increasing concerns over radiation exposure from CT examinations have driven a focus on dose-reduction.

In **2010**, the global CT equipment market was estimated to be worth **\$3.3 billion**.

While **GE Healthcare** was ranked first in the global CT equipment market in 2010

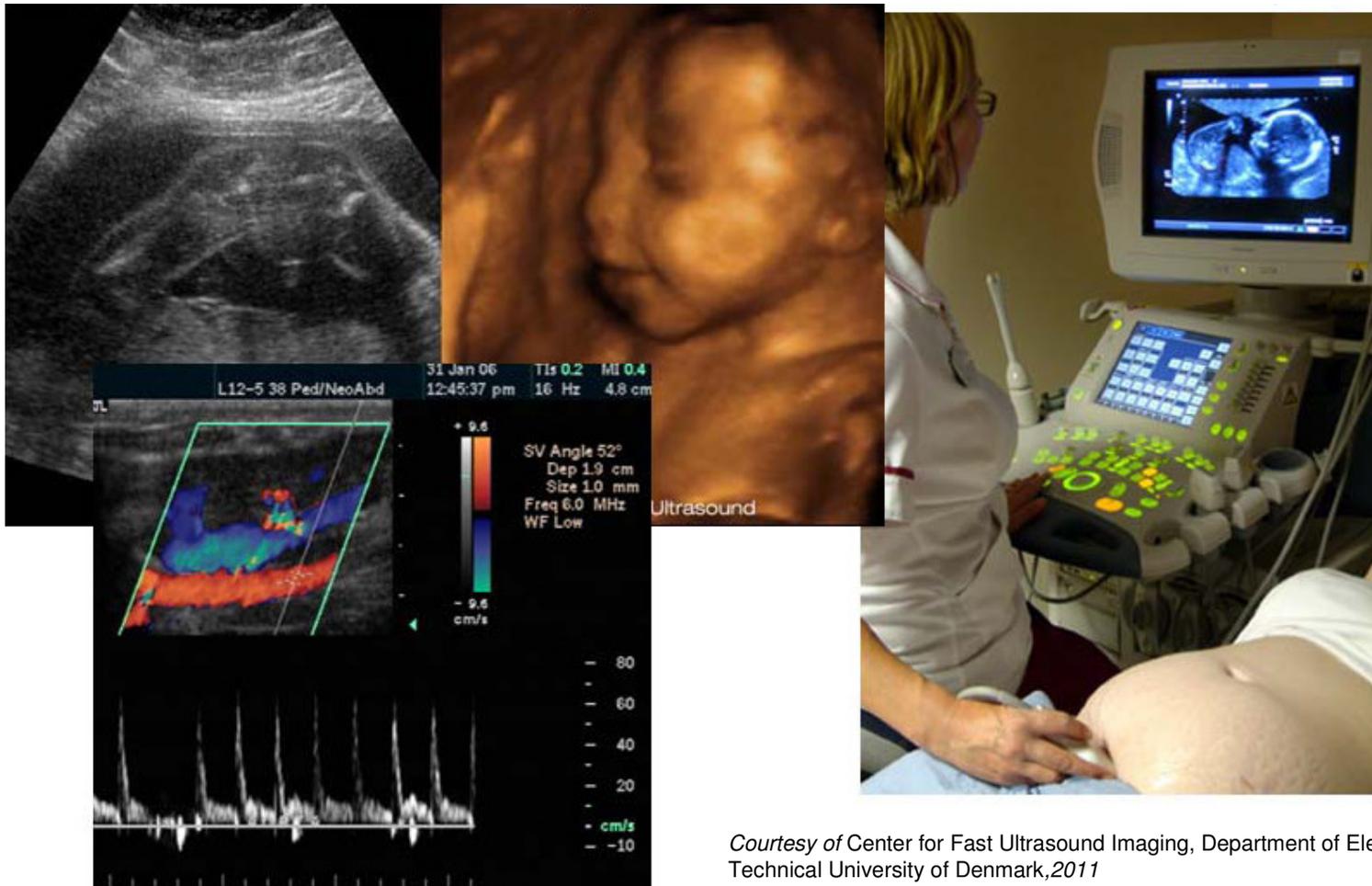
Toshiba Medical Systems, which was positioned fourth in terms of the global market, was estimated as market leader for above 64-slice systems.

CT Global Market...continued

Toshiba Medical Systems has already done this; it recently installed its first ***Aquilion One 320-slice CT system*** with dose-reduction software



Ultrasound (US) Imaging



Courtesy of Center for Fast Ultrasound Imaging, Department of Electrical Engineering Technical University of Denmark, 2011

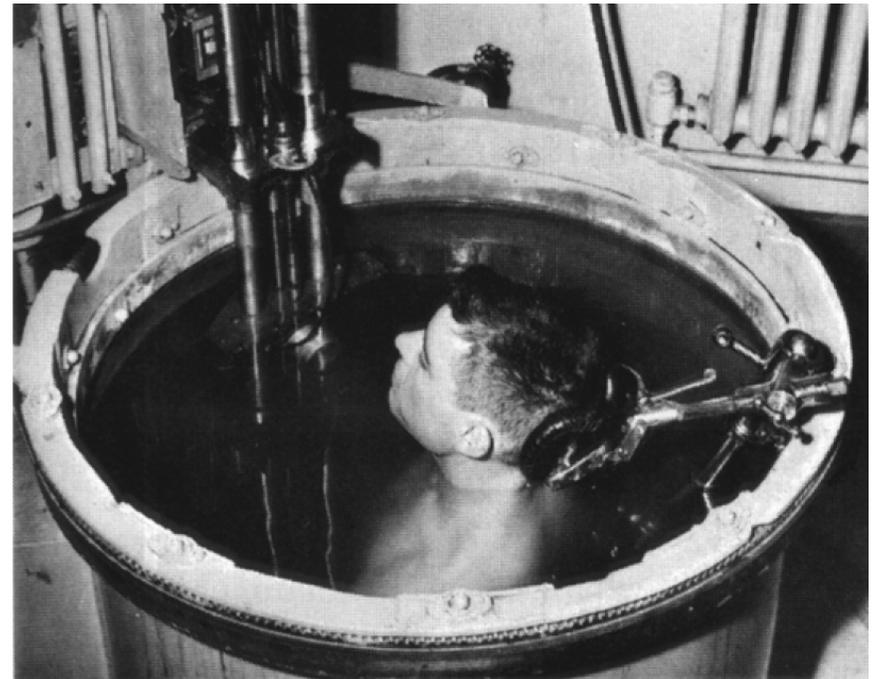
Ultrasound History

Used for many years by animals (e.g. bats)

1888 Piezoelectric effect discovered by the Curie brothers

World War I High frequency pressure waves in water (SONAR) were developed after to detect submarines.

1950s The first ultrasound system for medical imaging was made mainly by Howry and Wild.



Scanner by Dr. Howry: water filled cylinder was a gun turret from World War II B-29 bomber

Courtesy of Center for Fast Ultrasound Imaging, Department of Electrical Engineering Technical University of Denmark, 2011

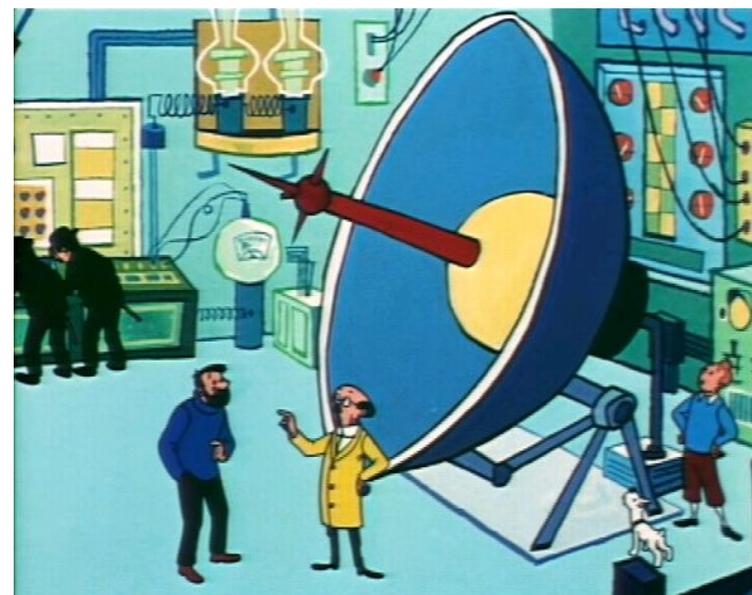
US principles

Ultrasound is defined by pressure waves that are higher than the audible range of man.

Ultrasound is non-ionizing when compared to CT or X-ray!

Herge's, The Calculus Affair (1964)

Professor Cuthbert Calculus has been working on a new device, a weapon that works on ultrasound, in a story that was once a Cold War satire.



Ultrasound modes & applications

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

Applications:

Cardiovascular: *Ventricular morphology and function, main arteries & valves*

Prostate: *specifically in guiding prostate brachytherapy procedures*

Urology: *(bladder function, testicular cancer)*

Pregnancy management: *Foetal abnormality screening, gender identification*

Quantitative Ultrasound– tissue characterization

Principle: consists in differentiating subtle changes in ultrasound speckle patterns, indicative of the tissue microstructures.

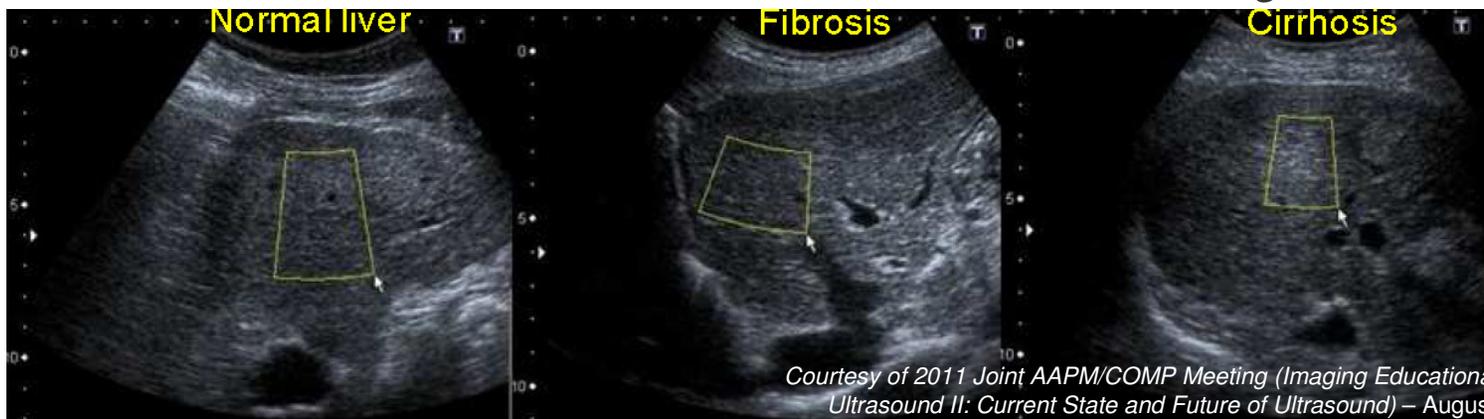
Speckle: granular pattern in images formed with coherent radiation of scatterers

Size of tissue structures < wavelength then

Probability Density function of echo amplitude = *Rayleigh distribution*

Rayleigh distribution is no longer valid in fibrosis liver tissue

size of nodules & fibrosis structures > wavelength

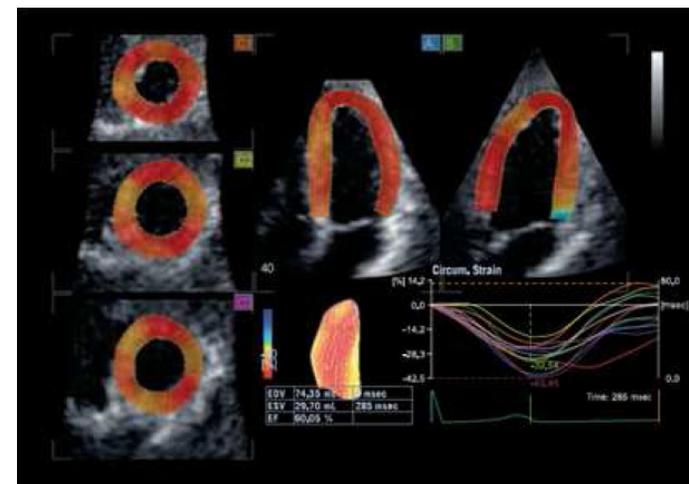
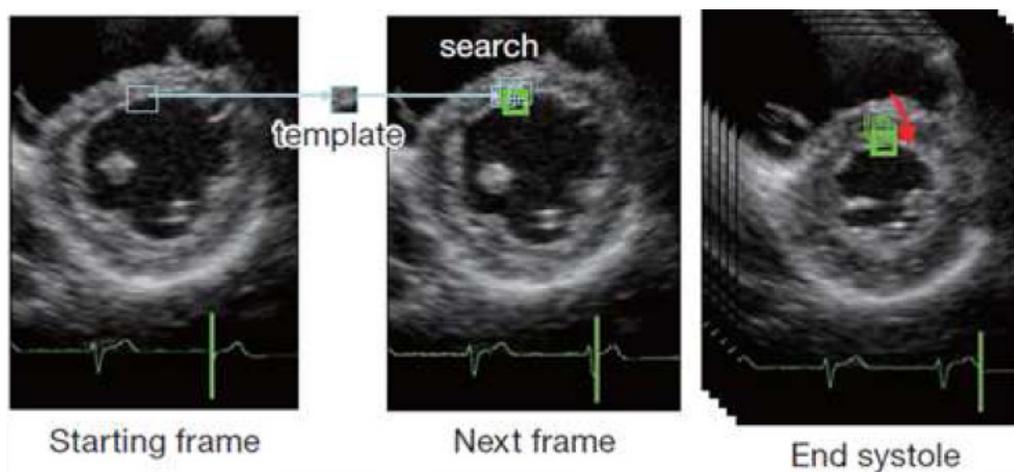


Quantitative Ultrasound– Wall motion tracking

Speckle tracking methods based on frame-to-frame correlation

Process

- Create template image in a local region in the starting frame
- Search for local speckle pattern matching the template in the next frame
- Derive a movement vector based on the displacement of the region
- Repeat the process on all frames of one cardiac cycle



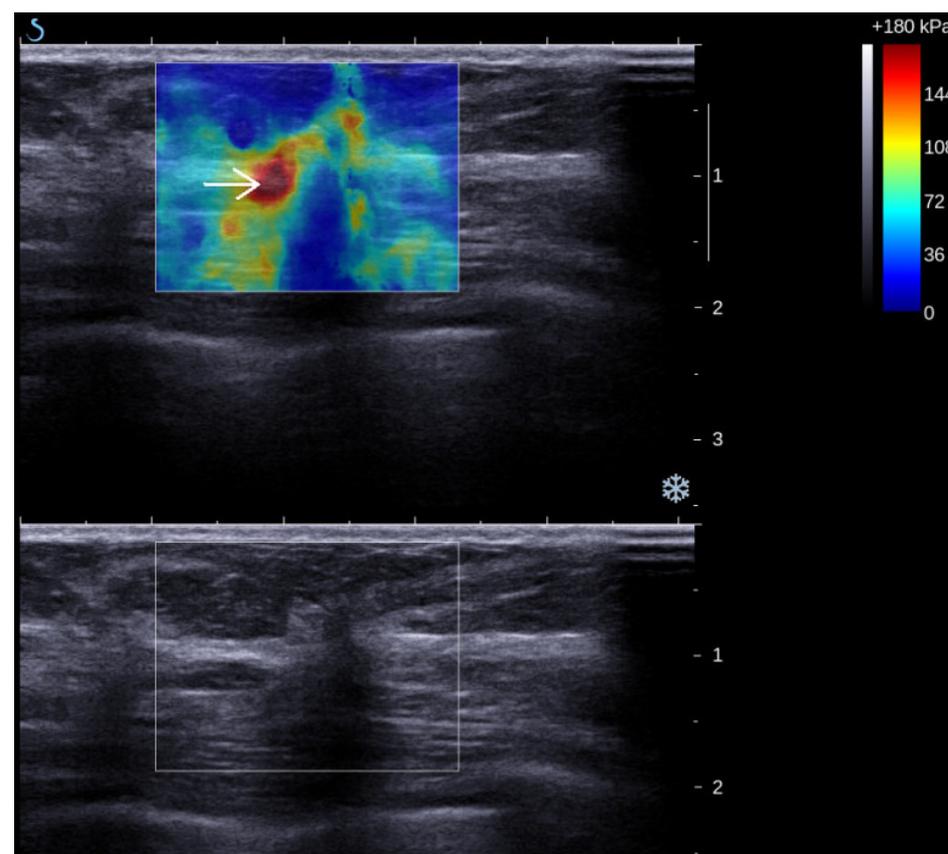
Courtesy of 2011 Joint AAPM/COMP Meeting (Imaging Educational Course - Ultrasound II: Current State and Future of Ultrasound) – August 01, 2011

Elastography

Imaging technique to detect tissue strain while compressing tissue with transducer

Elastography is based on the principle that ***malignant tissue is stiffer than non-malignant tissue.***

Some form of stress is applied to the tissue and any resulting tissue deformation is assessed.



Ultrasound and elastography images of an invasive ductal cancer showing typical peri-tumoural stiffness (arrow).

US Global Market



Medical ultrasound equipment market, which is projected to reach **\$6.2 billion** in sales by 2015.

Cardiology ultrasound equipment represents the fastest growing segment with revenues reaching **\$684 million** in **2010** in the United States.

TRENDS

Miniaturization of ultrasound devices.

Continued incorporation of system electronics into ultrasound technology.

Portable ultrasound equipment is expected to witness rapid growth in future



Magnetic Resonance Imaging (MRI)

The Nobel Prize in Physiology or Medicine **2003** was awarded jointly to Paul C. Lauterbur and Sir Peter Mansfield "*for their discoveries concerning magnetic resonance imaging*"



Principles:

Once the pulse is removed, the nuclei emits an electromagnetic signal in order to return to its initial orientation

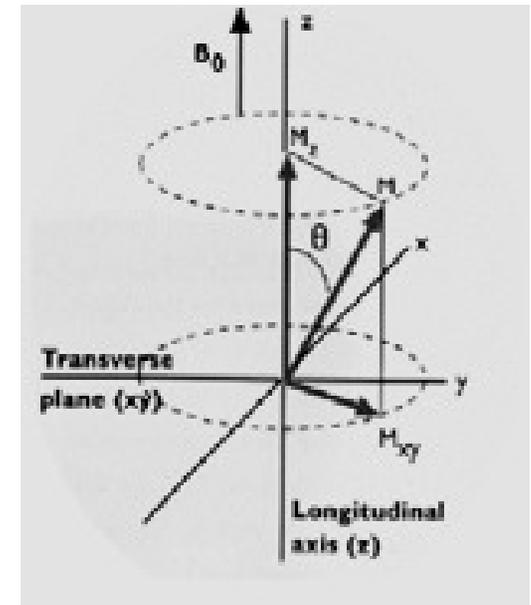
These signals are captured by a set of receiver coils and sent to the computer for interpretation

MRI theory

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



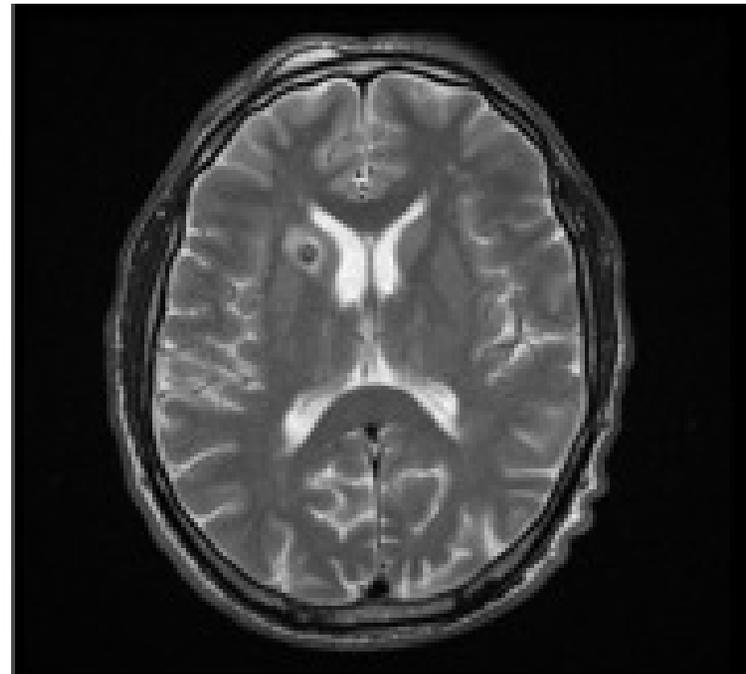
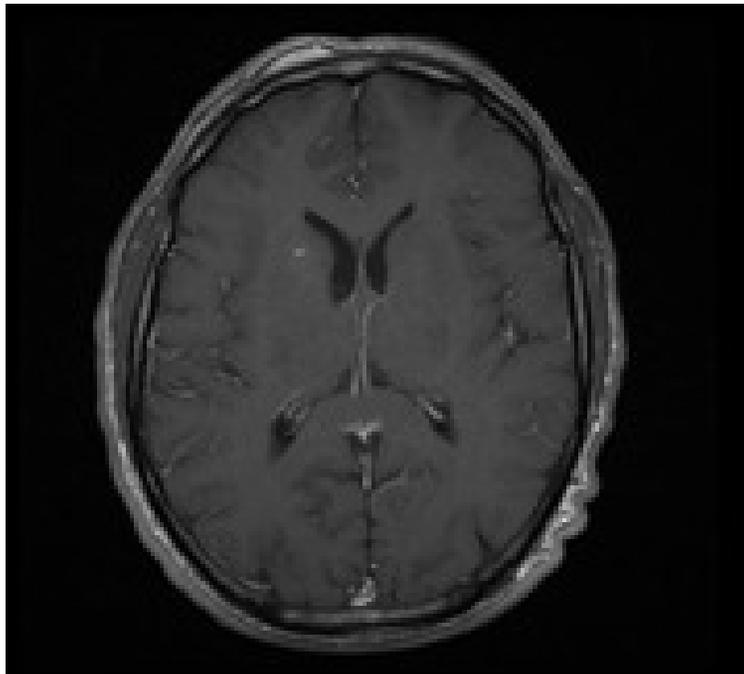
Two relaxation times are of importance to MRI:

T1: recovery of the longitudinal magnetization ($M_z = M_0$)

T2: decay of the transverse magnetization ($M_{xy} = 0$)

MRI imaging examples

T1-weighting and T2-weighting brain images



Courtesy of Guang-Zhong Yang, Imperial College, 2009

MRI applications

MRI is known to produce great contrast between different tissues

Cardiac assessment

Vessels Neurology

Brain

Respiratory

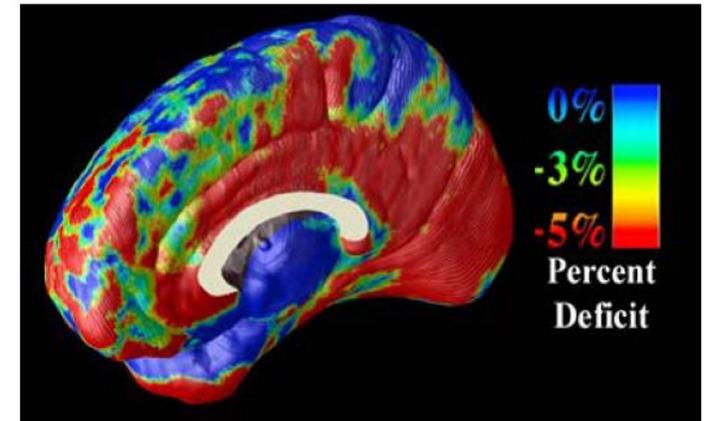
Orthopaedics (joints, bones)

Functional MRI

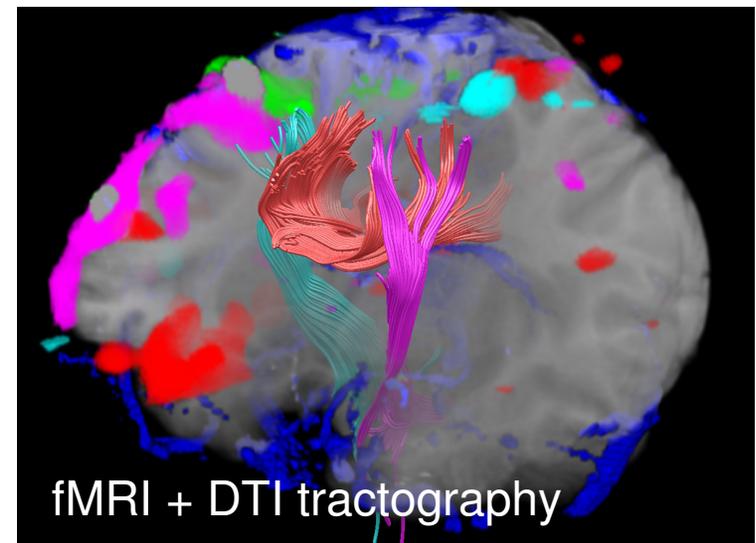
fMRI is a technique that images intrinsic blood signal change with magnetic resonance imagers.

Changes in neuronal activity are accompanied by focal changes in cerebral blood flow (CBF), blood volume (CBV), blood oxygenation and metabolism.

fMRI is also a good lie-detecting device, as it senses activity in certain regions of the brain associated with specific behaviours.



fMRI image depicting the effects of methamphetamine on brain tissue volume



fMRI + DTI tractography

MRI Global Market

In **2010**, the global MRI equipment market was estimated to be worth **\$6.6 billion**.

Expected to grow to about **\$9.7 billion** by **2015**.

MRI equipment accounts for approximately **25% of the medical imaging technologies used globally**.

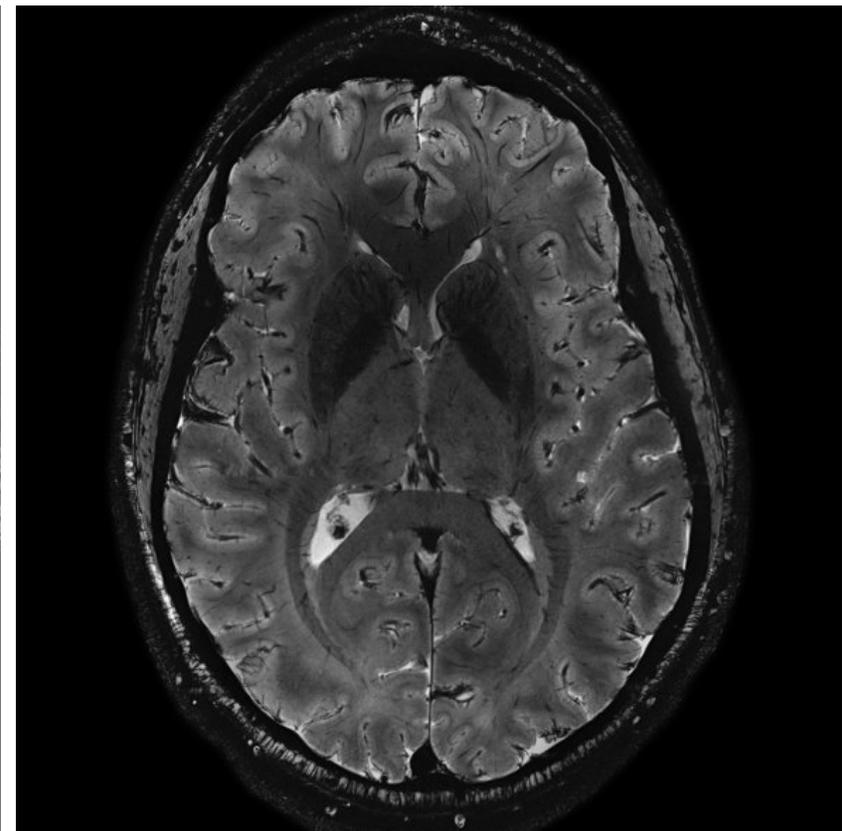


Siemens 7T MRI, 2011

7T MRI provides the potential for microscopic spatial resolution and molecular imaging methods

Enables the observation and analysis of tissue metabolism and function.

MRI Global Market...continued



Courtesy of Siemens Healthcare

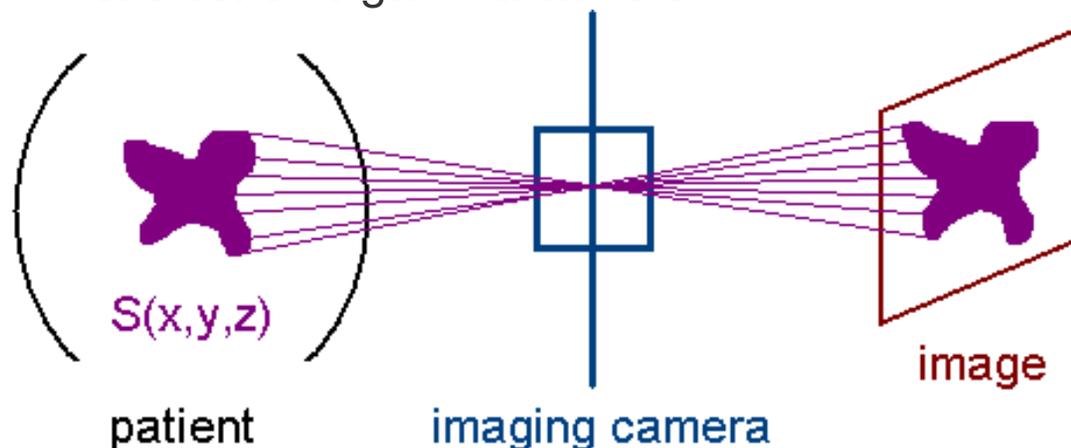
Nuclear Medicine

Grew out of the nuclear reactor research of World War II

Discovery of medically useful radioactive isotopes

1948 Ansell and Rotblat: Point by point imaging of thyroid

1952 Anger: First electronic gamma camera

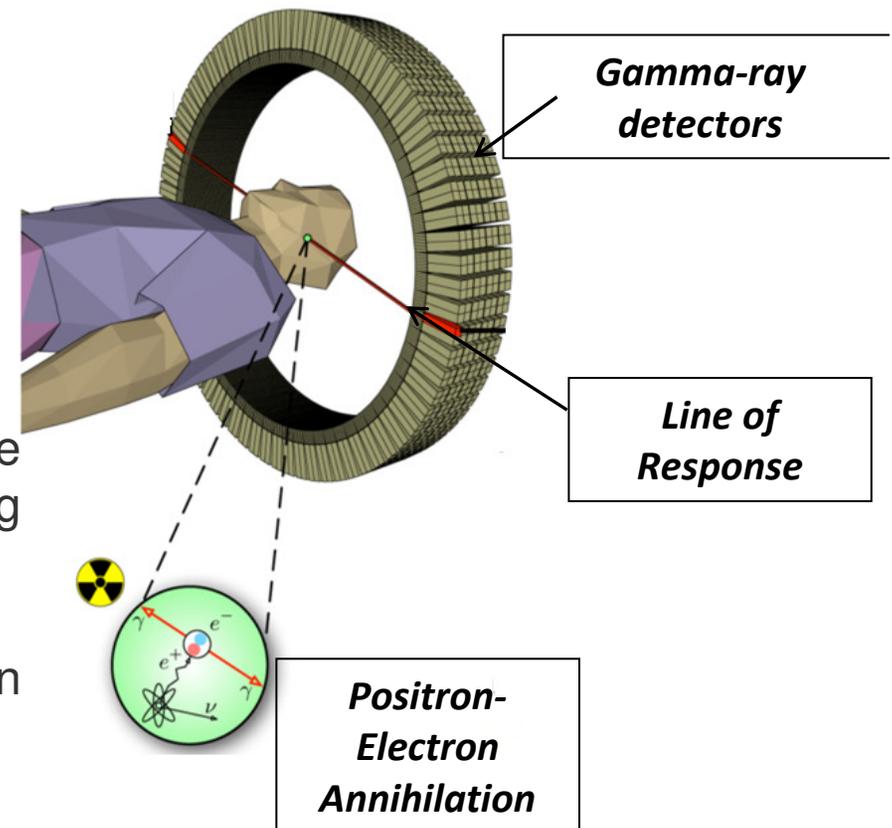


- Radioactive **tracer** is selectively taken up by organ of interest
- Source is thus inside body!
- This imaging system measures function (physiology) rather than anatomy.

Positron Emission Tomography (PET)

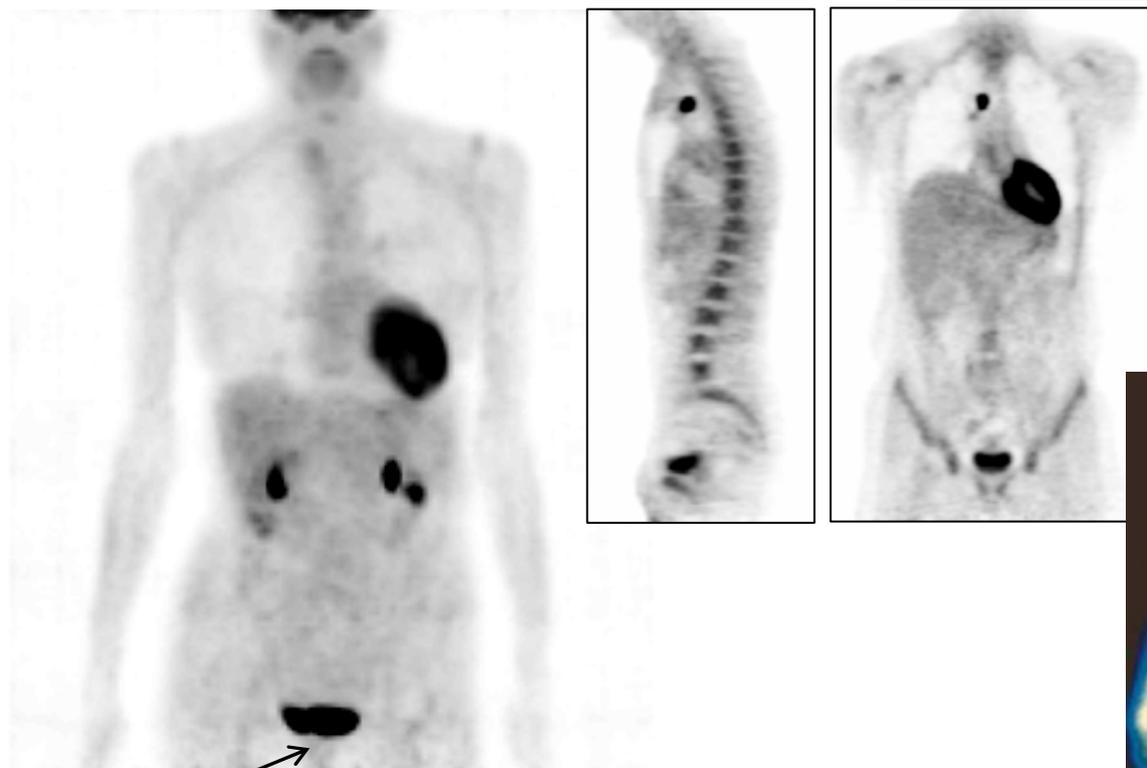
PET tracers mimic the natural sugars, water, proteins, and oxygen found in our bodies. These tracers are injected into a patient and collect in various tissues and organs.

- i) annihilation process two photons are emitted in diametrically opposing directions.
- ii) photons are registered by the PET as soon as they arrive at the detector ring.
- iii) After the registration, the data is forwarded to a processing unit and reconstructed

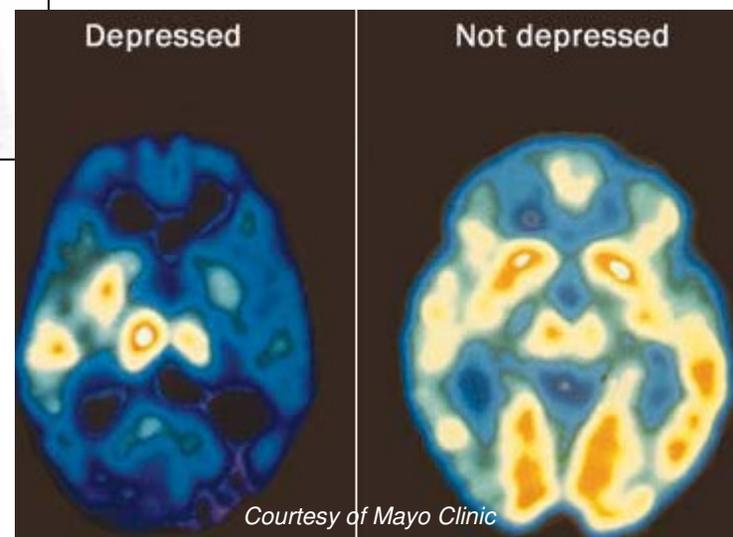


PET.....continued

Oncology



Neurology



Bladder

PET typical applications

Clinical oncology (tumours, metastases)

Neurology (certain diffuse brain diseases, such as those causing dementia)

Cardiology (in particular vascular studies)

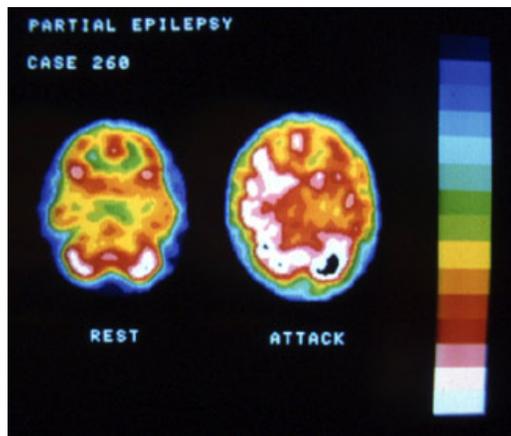
Research animal studies

Single photon emission computerized tomography (SPECT)

SPECT imaging is performed by using a gamma camera to acquire multiple 2-D images from multiple angles.

Apply a tomographic reconstruction algorithm to the multiple projections, yielding a 3-D dataset.

SPECT is similar to PET in its use of radioactive tracer material and detection of gamma rays. In contrast with PET, however, the tracer used in SPECT emits gamma radiation that is measured directly



Courtesy of GE Healthcare

Future perspectives: anatomical & functional Imaging

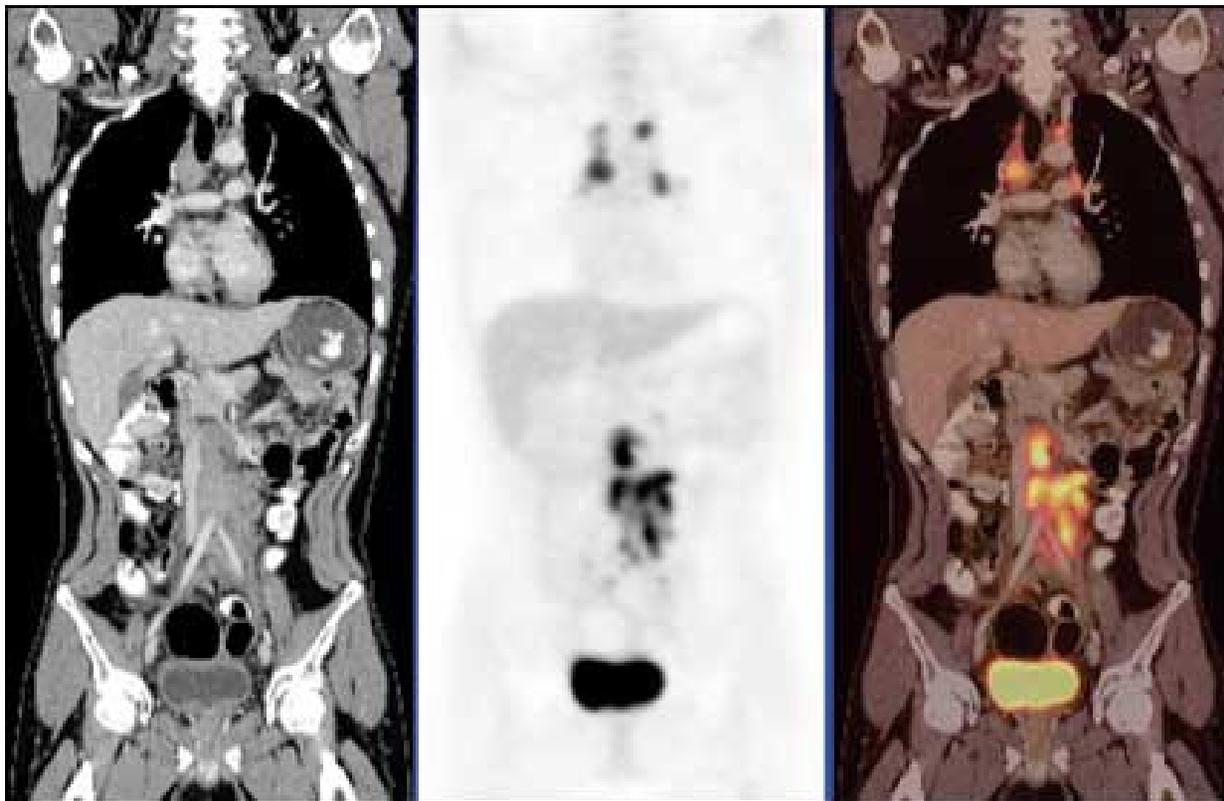
Method	spatial resolution	temporal resolution	function* mol. Imag
Ultrasound	+++ (2mm)	+++++	++
CT	+++++ (0.3mm)	++++	+
MR	++++ (0.8 mm)	+++	+++
Nuclear Medicine	+ (13 mm)	+	++++
PET	++(+) (5mm)	++	+++++

PET- CT : Combining the Best of Two Imaging Worlds

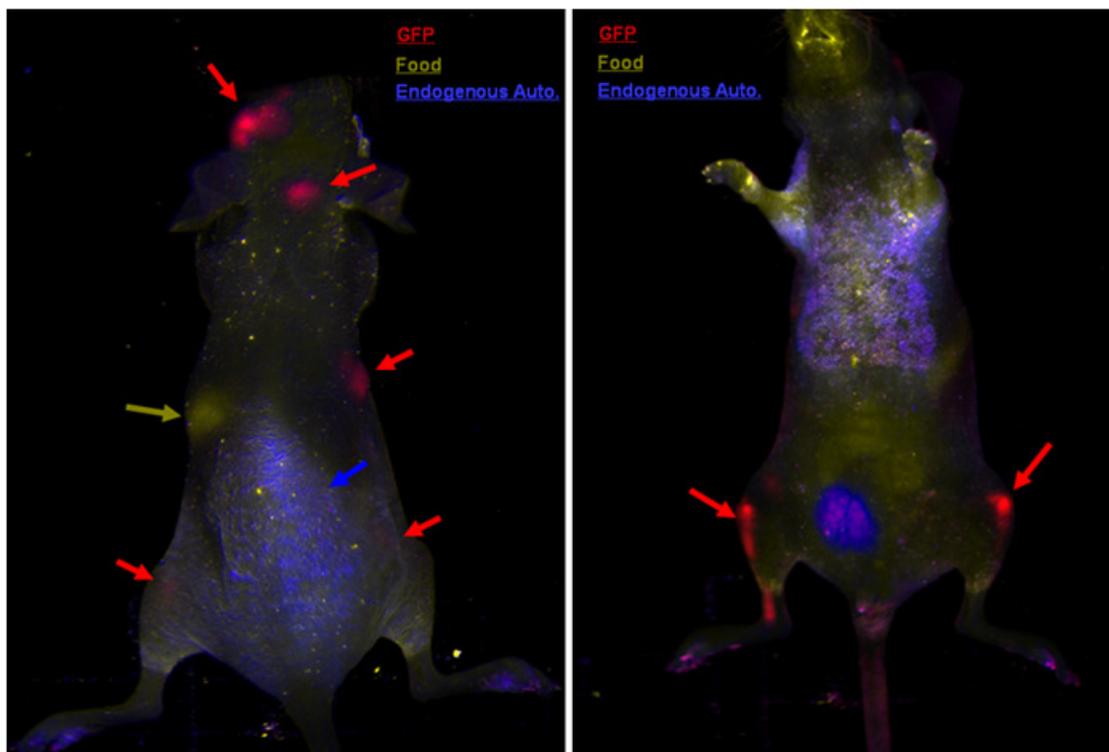
Courtesy of Guang-Zhong Yang, Imperial College, 2009

Future perspectives: anatomical & functional Imaging (2)

PET/CT integration



Future Perspectives: multispectral fluorescence imaging



Multispectral fluorescence imaging of bone metastases in vivo. **Green Fluorescent Protein** expressing tumor cells (false colored red) are visible in the skull, ribs, and legs.

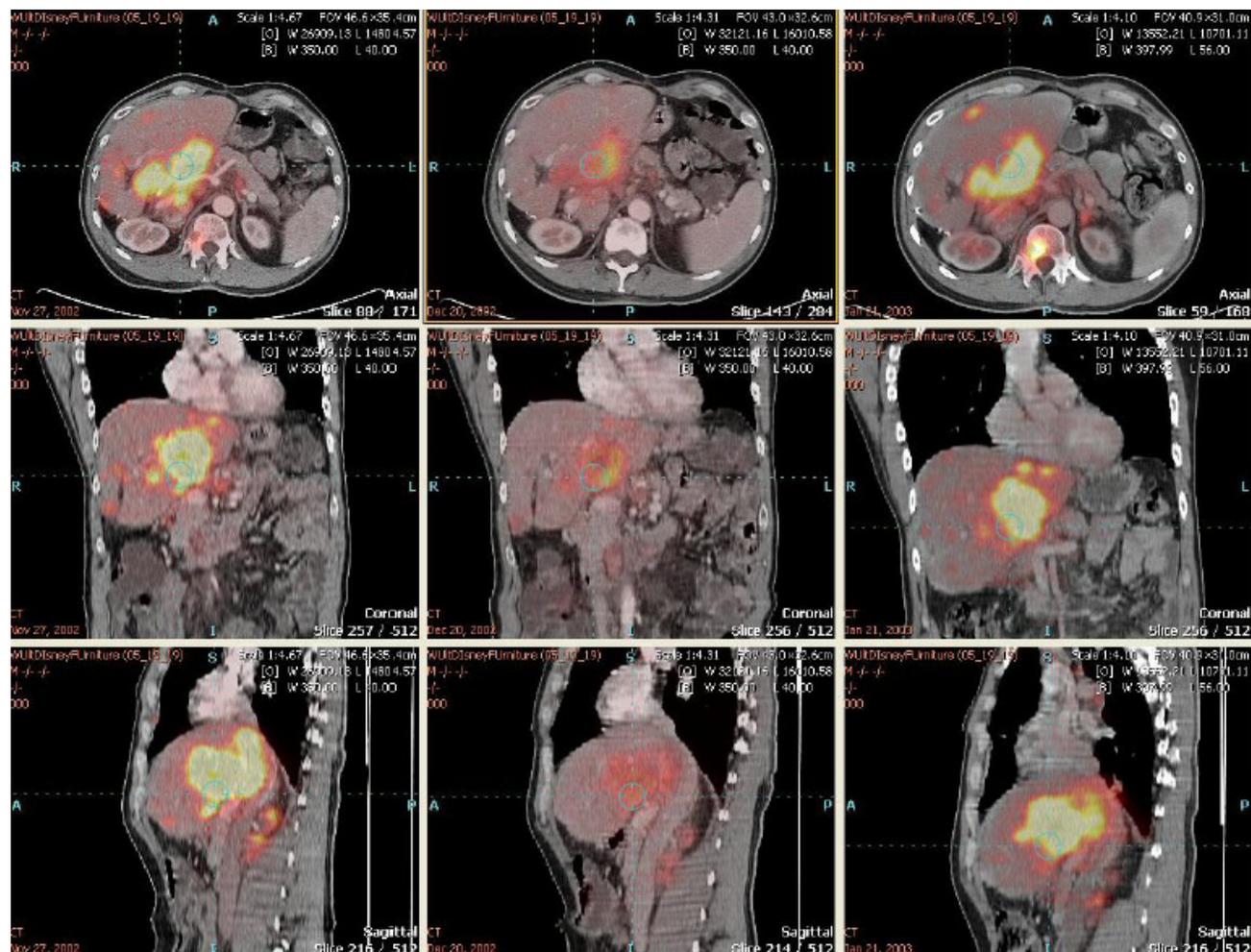
Autofluorescence from food or fat/skin are false colored yellow and blue respectively.

Image courtesy of Dr. H. Charles Manning, Ph.D., Vanderbilt University Institute of Imaging Science (VUIIS), and Dr. Greg Mundy, Vanderbilt Center for Bone Biology.

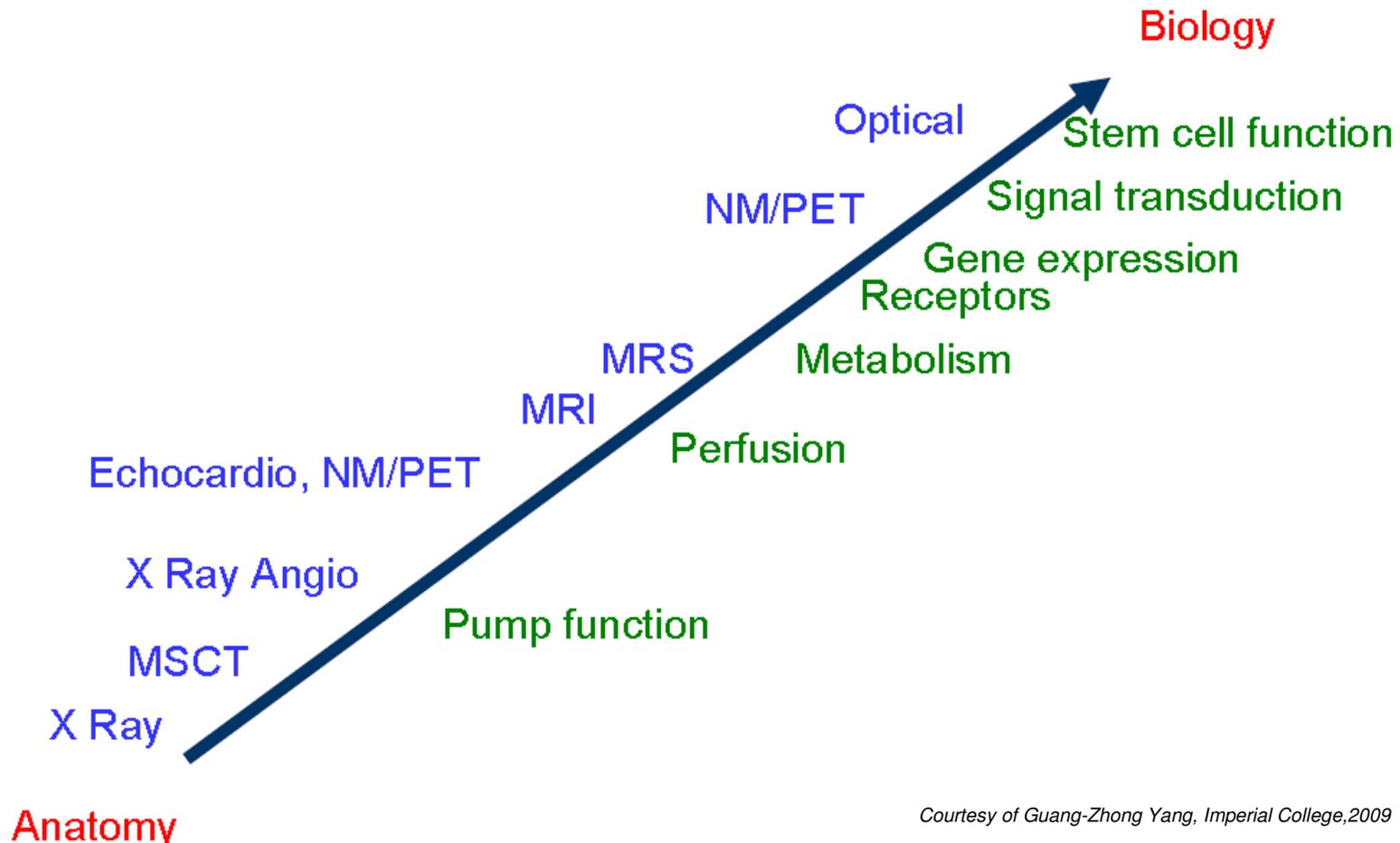
Future Perspectives: molecular imaging

We are beginning to image and model the dynamics of drug activity – and relate these to cellular and molecular processes.

The left column shows the image pre-treatment, the centre column indicates initial response to treatment, while the third shows that there has been regression



Imaging in 2020 ?



Courtesy of Guang-Zhong Yang, Imperial College, 2009

Thanks!

A simple black-and-white line drawing of a smiling cartoon character with its arms raised in a gesture of gratitude. The character has a round face, a wide smile, and a few strands of hair. A small '©' symbol is visible at the bottom right of the character's head.