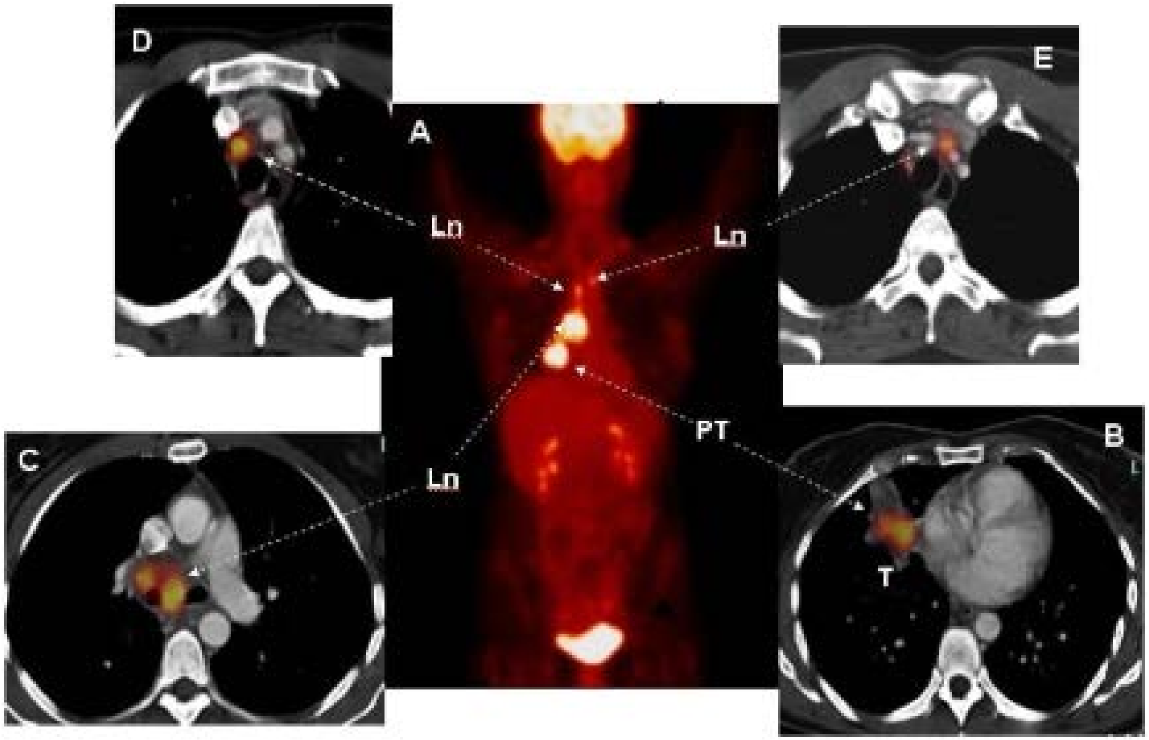
Diagnosis

Main application of medical imaging techniques in **disease diagnosis**, e.g.:

- cancer
- cardiovascular disease
- neurological disorders (e.g., Alzheimer's disease)

and in **drug development** (small animal imaging with microPET or microSPECT, microCT, microMRI, bioluminescence and fluorescence imaging systems)

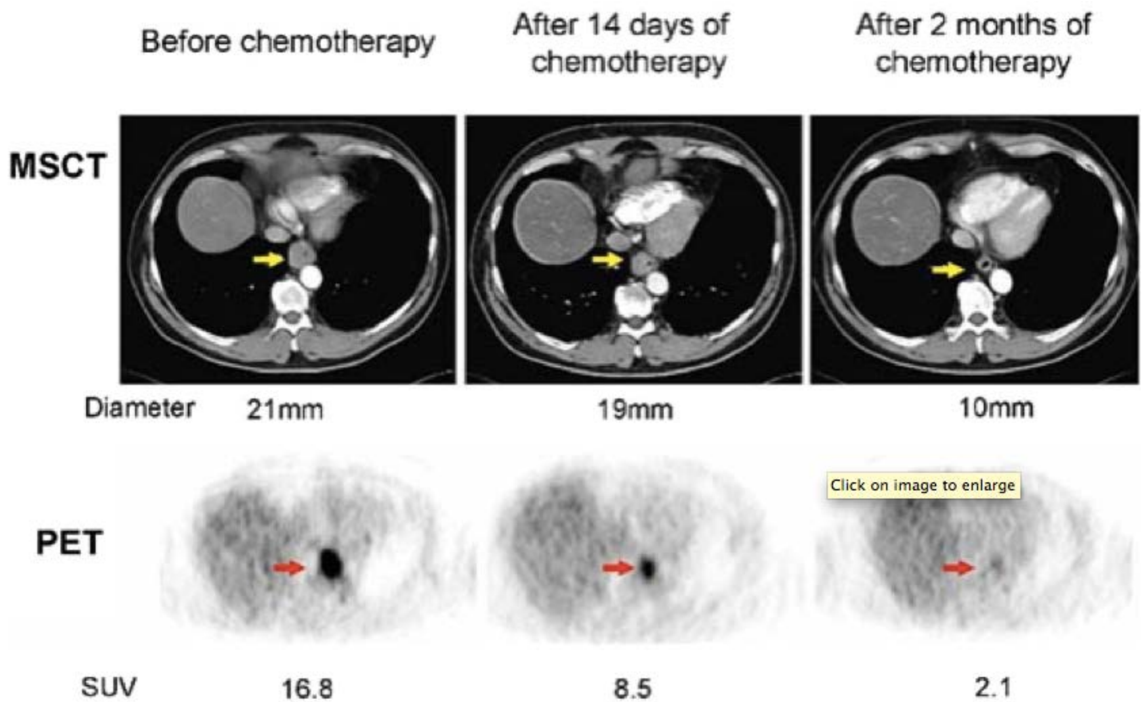
Diagnosis



Staging of lung cancer with Fluorodeoxyglucose (FDG) and Positron Emission Tomography – Computed Tomography (PET/CT.) The whole-body image (Panel A) shows normal FDG uptake in the brain and the urinary bladder. In addition, several regions of intensely increased FDG uptake are seen in the chest. On the cross-sectional images of chest (Panels B through E), the primary tumor (PT, Panel B) is seen in the right lung (Ln) (arrow) with several malignant lymph nodes on the same side. There are additional malignant lymph nodes on the opposite side of the patient's chest (Panel E, arrows).

http://www.desy.de/

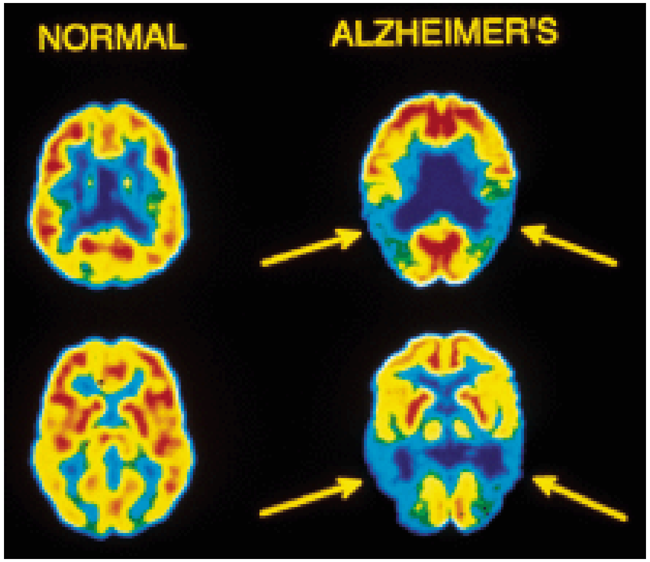
Diagnosis



Monitoring the effects of chemotherapy on tumor volume and glucose uptake with serial multislice computed tomography (MSCT) and PET imaging in a patient with cancer of the esophagus. The large tumor seen on the MSCT image (yellow arrow) is associated with intense FDG uptake on the pre-treatment PET image (red arrow). At 2 weeks, the tumor volume decreased only mildly (decrease in diameter from 21 mm to 19 mm), while the FDG uptake declined by about 50 percent (reflected by the decrease in the standardized uptake value of FDG from 16.8 to 8.5). At 2 months, the tumor volume has strikingly decreased and the FDG uptake is only faintly visible.

http://www.desy.de/

Diagnosis



DFG - PET brain images in a normal volunteer (left panel) and in a patient with Alzheimer's disease (right panel). Tomographic slices through the brain at the level of inferior parietal/superior temporal cortex are shown. The color displayed in each part of the brain reflects the concentration of FDG corresponding to the metabolic activity of the neurons in that region. Red, orange, and yellow areas are (in decreasing order) the most active, while green, blue, and violet areas are progressively less active. Note that in neurologically healthy individuals, the entire cerebral cortex has a moderately high level of metabolism. In the patient with Alzheimer's disease, the arrows indicate areas of diminished metabolic activity in the patient's parietotemporal cortex, a region important for processing of language and associative memories.

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Radiotherapy

After diagnosis some diseases like hyperthyroidism, cancer, blood disorders, etc... can be treated using radiotherapy.

Three main methods:

- Unsealed source radiotherapy
- Brachytherapy (sealed source therapy)
- External beam: x-rays, electrons, p, n, heavy ions

Stages in the radiotherapy process:

QA, imaging, planning, simulation, treatment,

verification, modelling outcome

Physics, engineering, imaging, technology based

"seeds"- small radioactive rods implanted directly into the tumor.

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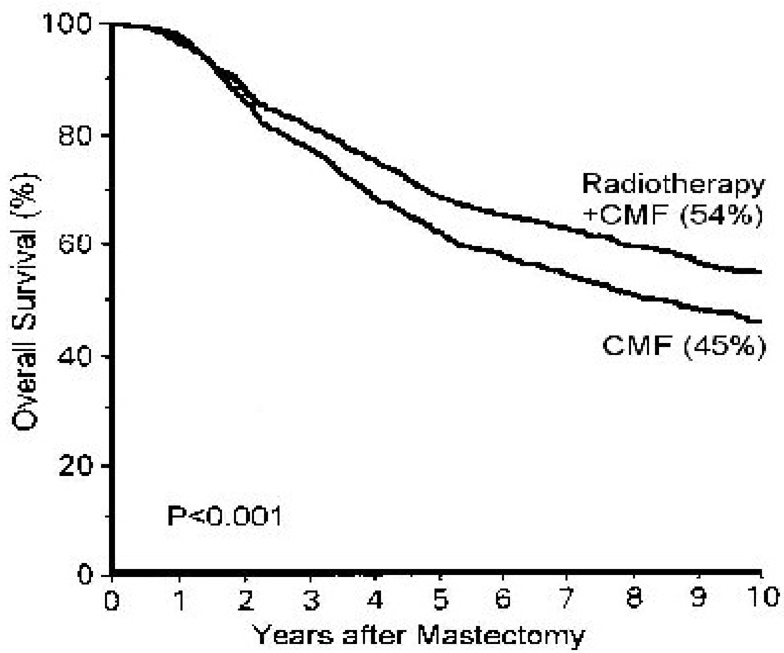
Benefits of Radiotherapy

- Breast Cancer
- Mastectomy
- Compare surgery and chemotherapy (CMF) with and without radiotherapy
- 10 year survival improved by 10%



What is medical imaging?

Every non-invasive technique that allows to look *inside* the human body.

Invasive techniques — *surgery, endoscopy*

Non-invasive techniques — Magnetic resonance imaging, ultrasound
Projection radiography, computed tomography, nuclear medicine ***(but exposure to radiation)***

In addition see things that are not visible to the eye (blood flow, organ metabolism, receptor binding)

Different techniques (modalities) allow to look inside the human body in different ways (looking at different signals)

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Signals and Modalities

Signal	Modality	Property imaged
X-ray transmission through the body	projection radiography or CT	attenuation coefficient to X-ray
Gamma-ray emission from within the body	Planar scintigraphy or emission tomography	Distribution of induced radio sources
Nuclear magnetic resonance induction	Magnetic resonance imaging	Hydrogen proton density, spin precession in large magnetic field
Ultrasound echoes	Ultrasound imaging	Sound reflectivity

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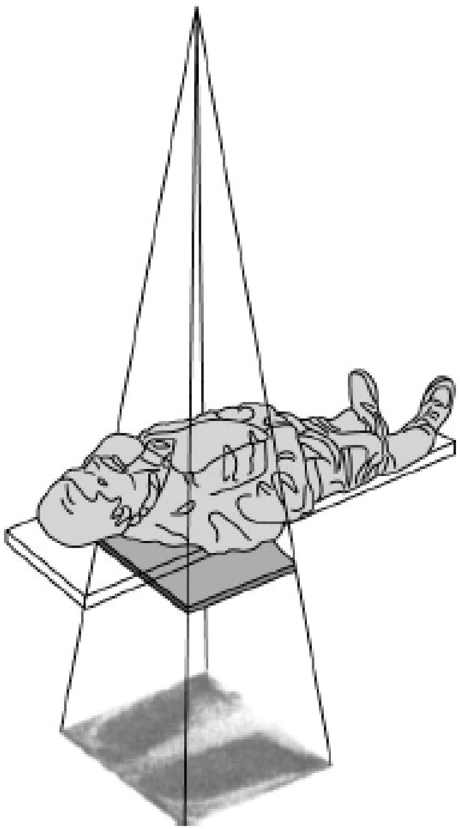
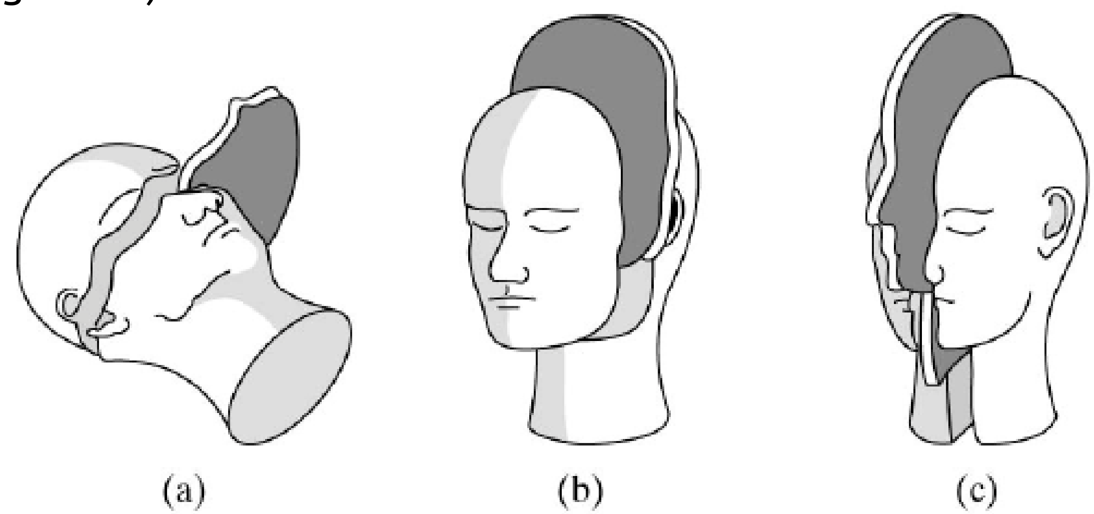
Projection vs. Tomography



Projection: A single 2D image "shadow" of the 3D body (one dimension is integrated - loss of information)

Tomography: A series of images are generated, one from each slice of 3D body in a particular direction (no integration)



axial or transverse / coronal or frontal / sagilal

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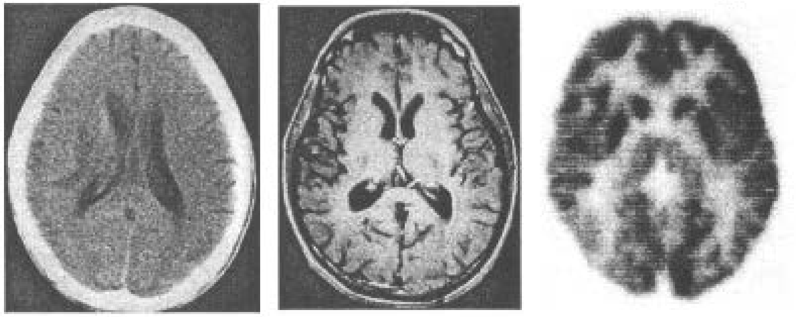
Anatomical vs. Functional imaging

Some modalities are very good at depicting anatomical structures (bones):

- X-ray and CT
- MRI

Some modalities are less good with anatomical structure but reflect the functional status (blood flow, oxygenation, etc…)

- Ultrasound
- PET, functional MRI



(a) CT (b) MRI (c) PET

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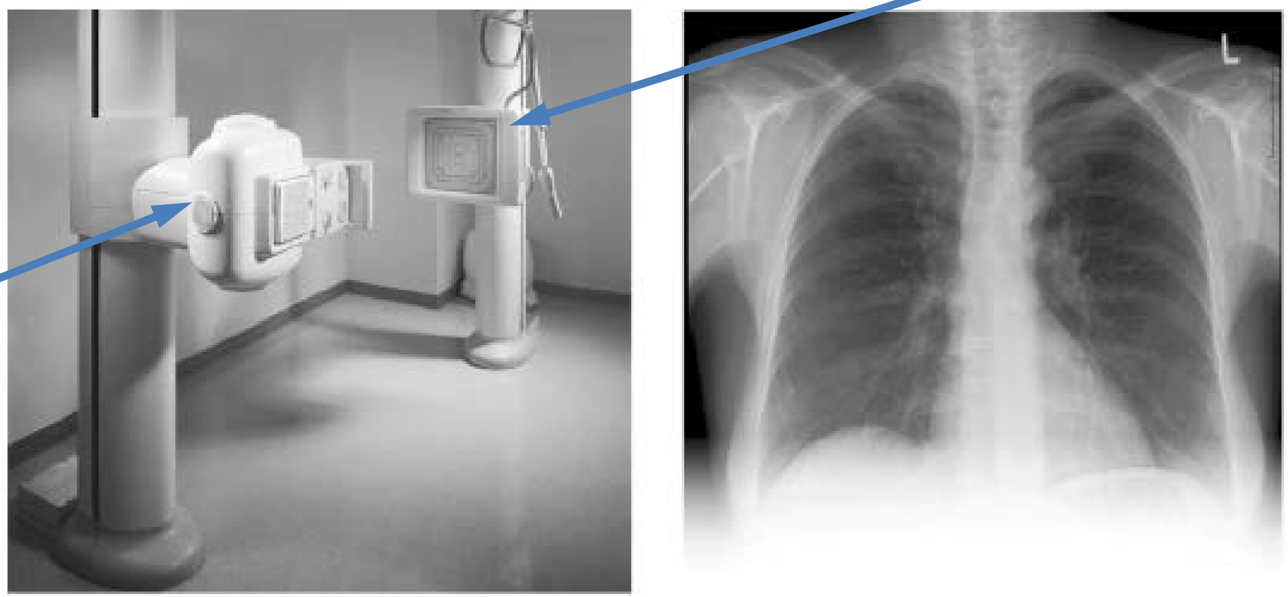
Common imaging modalities

- Projection radiography (X-Rray)
- Computed tomography
- Nuclear medicine (SPECT, PET)
- Magnetic resonance Imaging (MRI)
- Ultrasound imaging
- Optical imaging

Projection radiography

Scintillator screen and detector (film, camera, solid-state)

X-ray tube cone beam



(a) (b)

Figure 1.1

Medical Imaging Signals and Systems, by Jerry L. Prince and Jonathan Links.
ISBN 0-13-065353-5.

http://www.desy.de/

Projection radiography

• Year discovered:	1895 (Röntgen, NP 1905)
• Form of radiation: radiation	X-rays = electromagnetic (photons)
• Energy / wavelength of radiation:	0.1 – 100 keV / 10 – 0.01 nm (ionizing)
• Imaging principle:	X-rays penetrate tissue and create "shadowgram" of differences in density.
• Imaging volume:	Whole body
• Resolution:	Very high (sub-mm)
• Applications:	Mammography, lung diseases, orthopedics, dentistry, cardiovascular, GI

From Graber, Lecture Note for Biomedical Imaging, SUNY

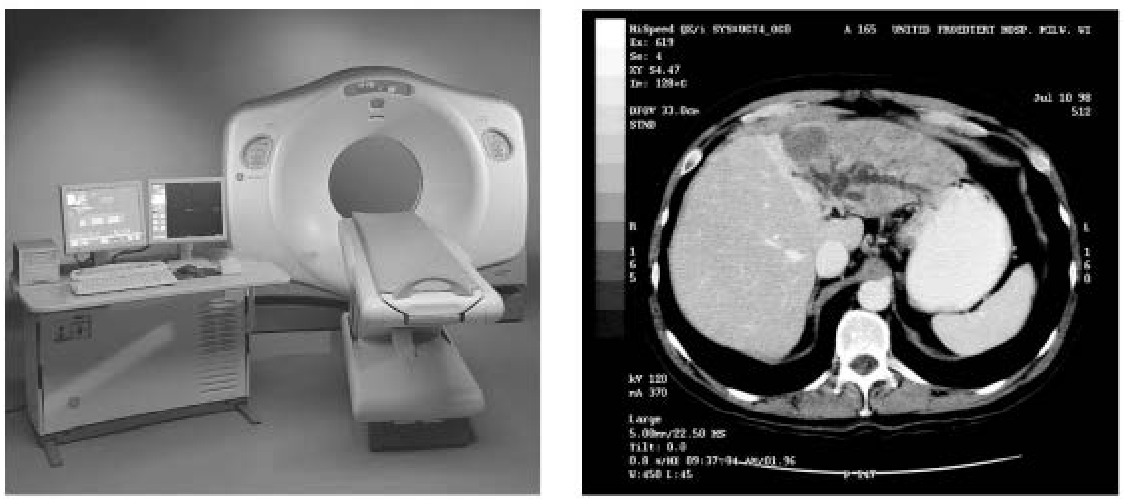
http://www.desy.de/

Computed tomography

X-ray in a 2-D “fan beam” rotated around the subject

The image of one cross-section is computed from all projections (digital)

Whole body scan in less than one minute



(a) (b)

Figure 1.2

Medical Imaging Signals and Systems, by Jerry L. Prince and Jonathan Links.

Computed tomography

• Year discovered:	1972 (Hounsfield, NP 1979)
• Form of radiation:	X-rays
• Energy / wavelength of radiation:	10 – 100 keV / 0.1 – 0.01 nm (ionizing)
• Imaging principle: views are	X-ray images are taken under many angles from which tomographic ("sliced") computed
• Imaging volume:	Whole body
• Resolution:	High (mm)
• Applications:	Soft tissue imaging (brain, cardiovascular, GI)

From Graber, Lecture Note for Biomedical Imaging, SUNY

http://www.desy.de/

Nuclear medicine

Emission images:

- Radioactive substances (radio tracers) have to be introduced into the body that emit gamma--rays or positrons.
- Radiotracers move within the body according to the natural uptake
- Investigated is the local concentration of radio tracer within the body

Functional imaging as oppose to structural/anatomical imaging

Three techniques:

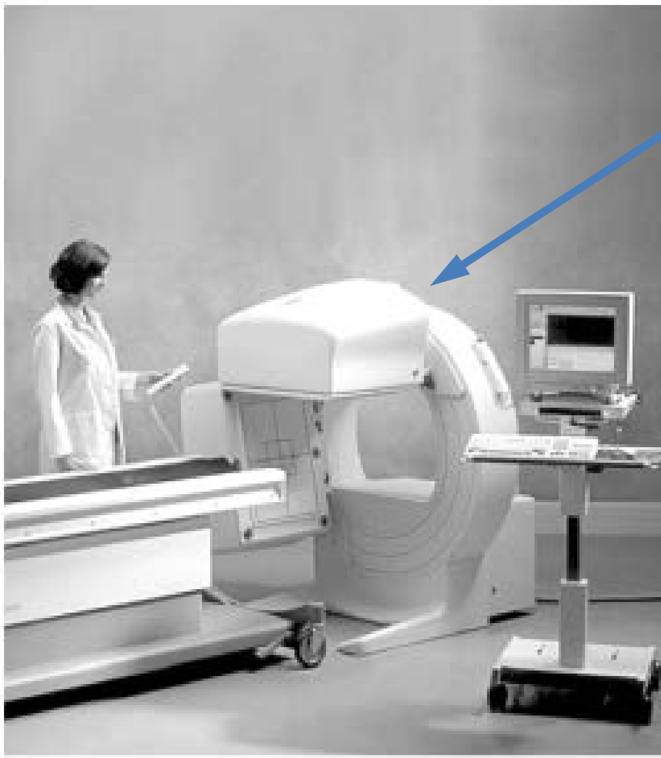
- Radionuclide imaging or scintigraphy (2D projection equivalent to projection radiography)
- Single photon emission tomography (SPECT)
- Positron emission tomography (PET)

Detect single γ-rays (rather than intensity as in CT) with a scintillator detector called Anger camera

http://www.desy.de/

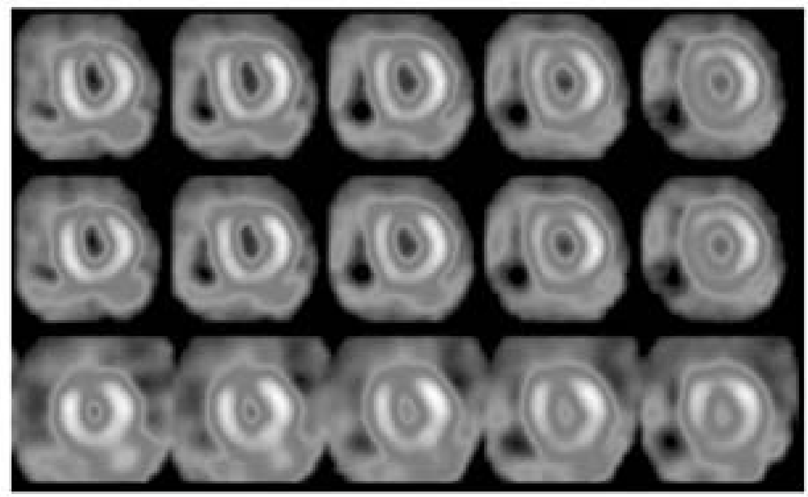
SPECT

Anger camera



(a)

Cardiac scans: the blood flows through the heart muscle



(b)

Figure 1.3

Medical Imaging Signals and Systems, by Jerry L. Prince and Jonathan Links.
ISBN 0-13-065353-5.

http://www.desy.de/

Nuclear Medicine

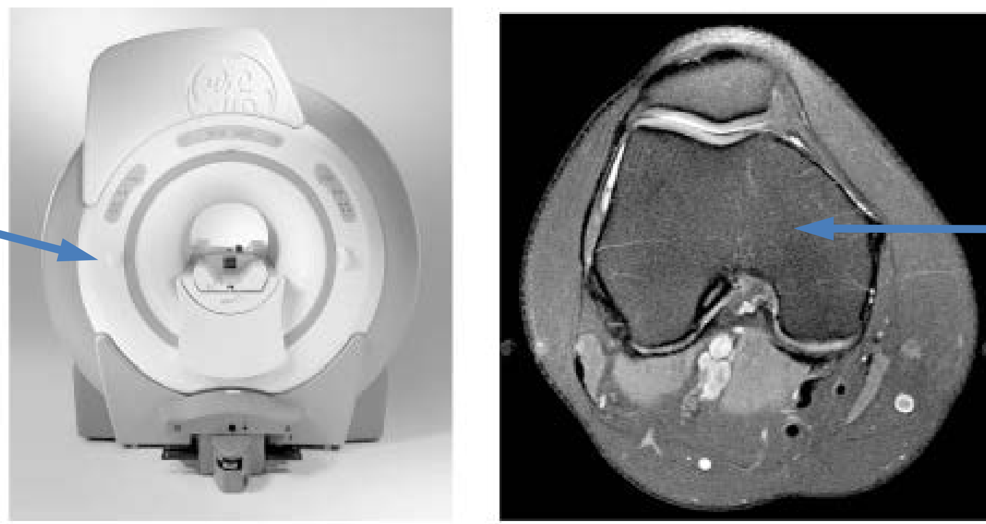
• Year discovered:	1953 (PET), 1963 (SPECT)
• Form of radiation:	Gamma rays
• Energy / wavelength of radiation:	> 100 keV / < 0.01 nm (ionizing)
• Imaging principle:	Accumulation or "washout" of radioactive isotopes in the body are imaged with x-ray cameras.
• Imaging volume:	Whole body
• Resolution:	Medium – Low (mm - cm)
• Applications:	Functional imaging (cancer detection, metabolic processes, myocardial infarction)

From Graber, Lecture Note for Biomedical Imaging, SUNY

Magnetic resonance imaging

In a magnetic field protons (H) align themselves along the field lines An additional gradient field can locally disturb the alignment To reestablish the alignment protons precess and generate detectable EM-waves

2 Tesla super-conductive magnet



Human knee

(a) (b)

Figure 1.5

Medical Imaging Signals and Systems, by Jerry L. Prince and Jonathan Links.
ISBN 0-13-065353-5.

http://www.desy.de/

Magnetic resonance imaging

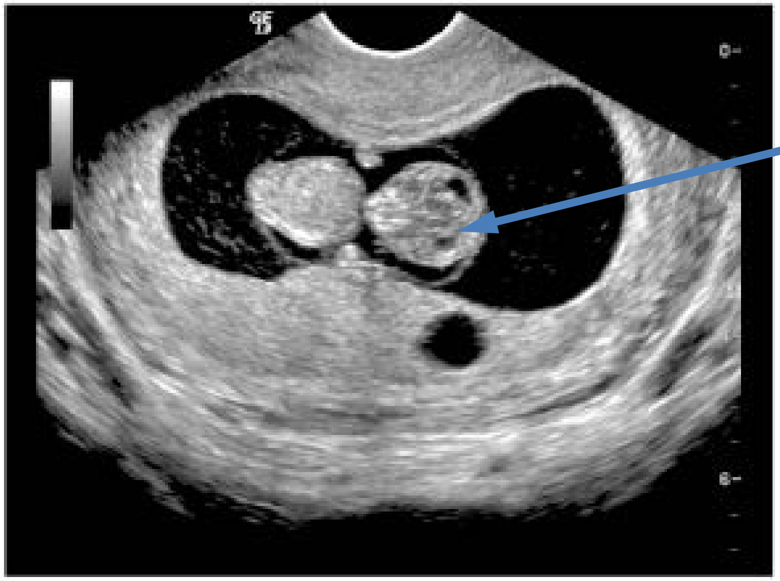
• Year discovered:	1945 ([NMR] Bloch, NP 1952) 1973 (Lauterbur, NP 2003) 1977 (Mansfield, NP 2003) 1971 (Damadian, SUNY DMS)
• Form of radiation:	Radio frequency (RF) (non-ionizing)
• Energy / wavelength of radiation:	10 – 100 MHz / 30 – 3 m (~10-7 eV)
• Imaging principle: and response	Proton spin flips are induced, the RF emitted by their (echo) is detected.
• Imaging volume:	Whole body
• Resolution:	High (mm)
• Applications:	Soft tissue, functional imaging

From Graber, Lecture Note for Biomedical Imaging, SUNY

Ultrasound imaging

- High frequency sound are emitted into the imaged body, time and strength of the returned sound pulses are measured
- Comparative inexpensive and completely non-invasive
- Image quality is relatively poor

(a)



(b)

11-weeks-old Human embryo

http://www.desy.de/

Ultrasound imaging

• Year discovered:	1952 (clinical: 1962)
• Form of radiation:	Sound waves (non-ionizing) ***NOT*** EM radiation!
• Frequency / wavelength of radiation:	1 – 10 MHz / 1 – 0.1 mm
• Imaging principle: are	Echoes from discontinuities in tissue density/speed of sound registered.
• Imaging volume:	< 20 cm
• Resolution:	High (mm)
• Applications: (Doppler)	Soft tissue, blood flow

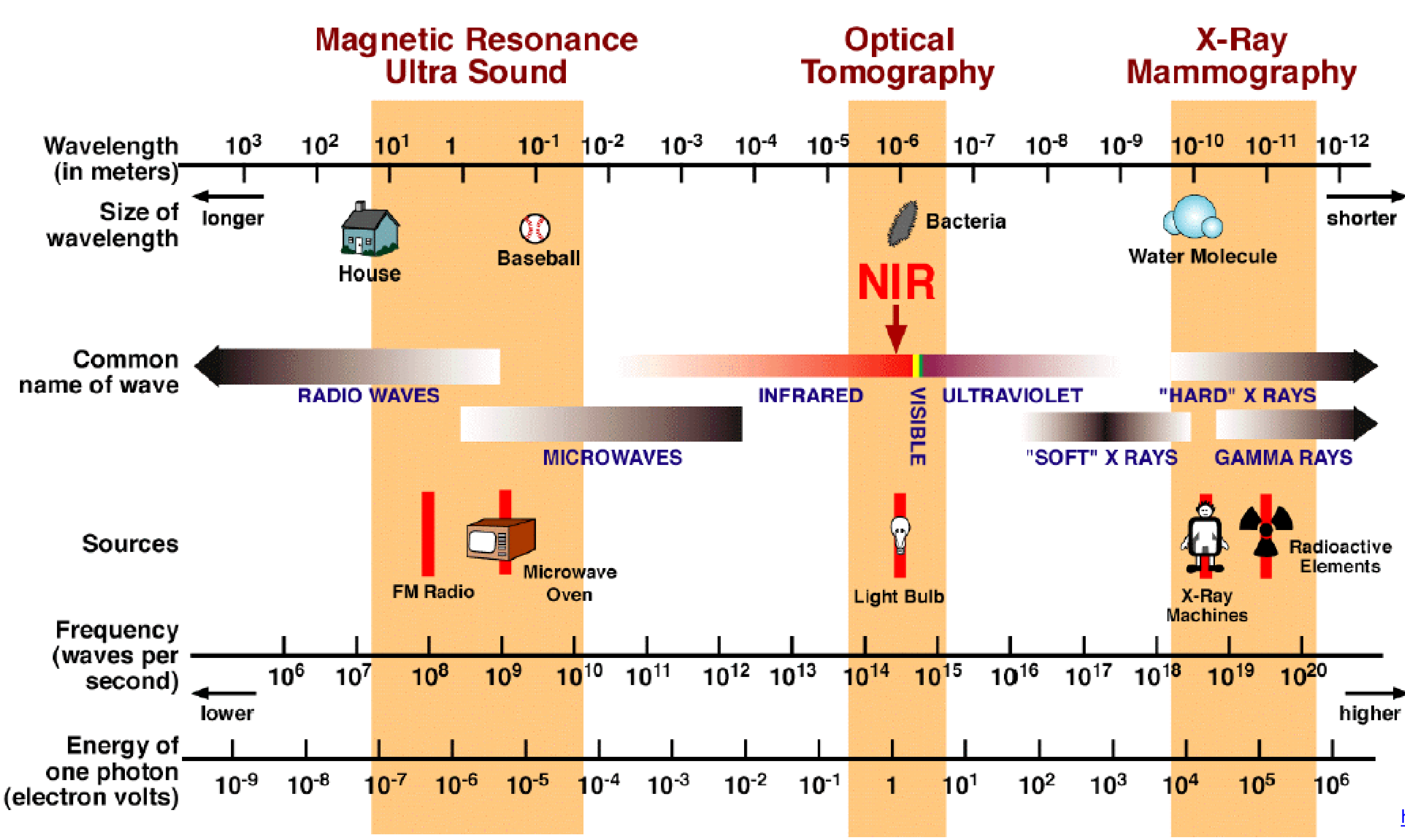
From Graber, Lecture Note for Biomedical Imaging, SUNY

http://www.desy.de/

Electromagnetic waves used in medical imaging

larger than 1 Å high attenuation from the body,

shorter than 10^{-2} Å = too high energy (>1MeV) for direct detection



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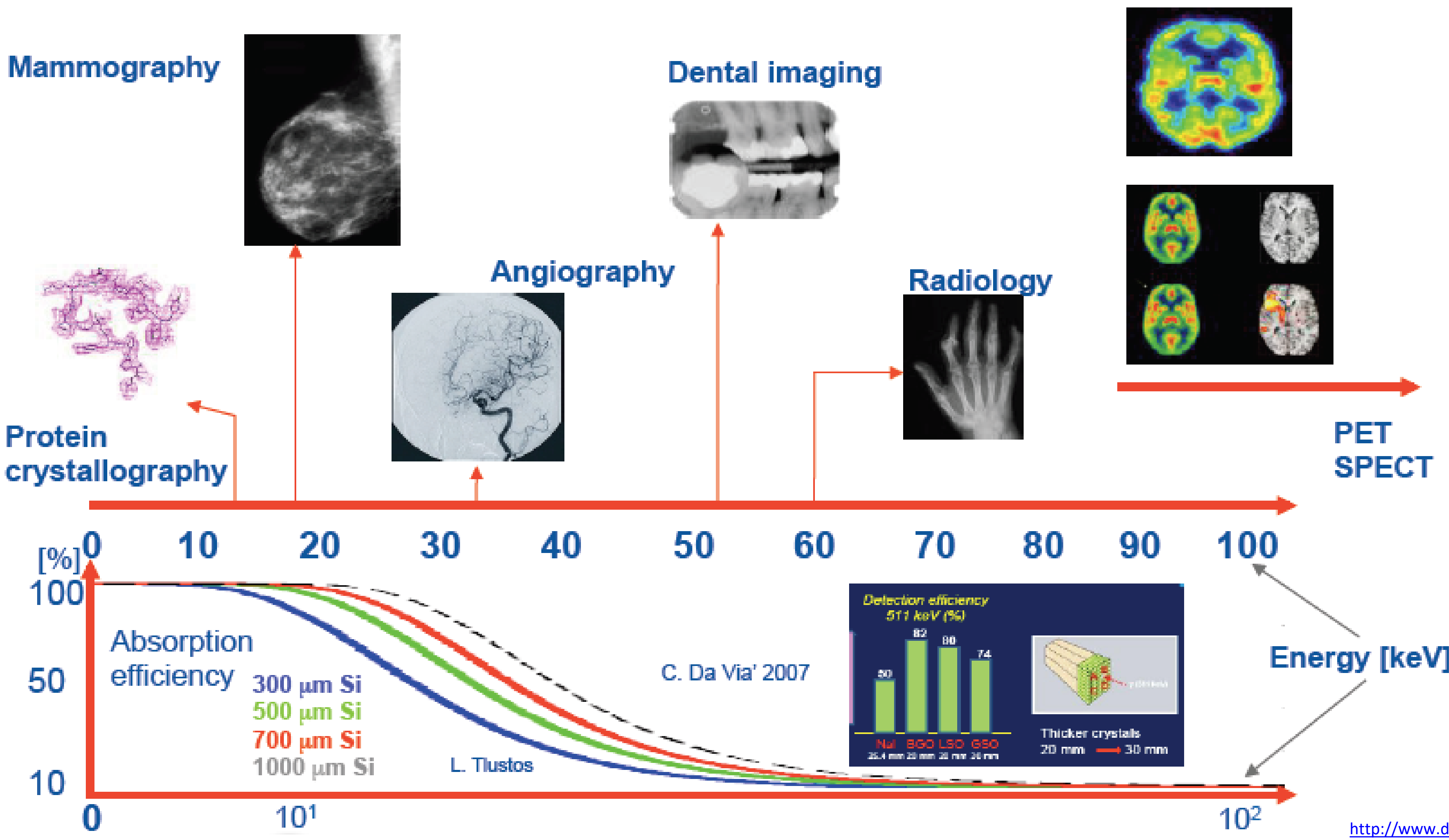
Electromagnetic waves used in medical imaging



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