Al-Mustaqbal University
College of Science
Second stage
Intelligent Medical Systems Department

جامعة المستقبل
AL MUSTAQBAL UNIVERSITY

Data Acquistion for Medical Application

Digital Image Acquisition
X-ray Imaging, Magnetic Resonance Imaging, Ultra Sound, PET and SPECT images

By

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1. Medical Images

Medical images are pictures of distributions of physical attributes captured by an image acquisition system. Most of today's images are digital. They may be post-processed for analysis by a computer-assisted method. Medical images come in one of two varieties: Projection images project a physical parameter in the human body on a 2D image, while slice images produce a one-to-one mapping of the measured value. Medical images may show anatomy including the pathological variation of anatomy if the measured value is related to it or physiology when the distribution of substances is traced. X-ray imaging, CT, MRI, nuclear imaging, ultrasound imaging, photography, and microscopic images are types of medical images.

Concepts, notions and definitions

- Imaging techniques: x ray, fluoroscopy and angiography, DSA, x-ray CT, CT angiography, MR imaging, MR angiography, functional MRI, perfusion MRI, diffusion MRI, scintigraphy, SPECT, PET
- Reconstruction techniques: filtered backprojection, algebraic reconstruction, EM algorithms
- Image artefacts: noise, motion artefacts, partial volume effect, MR-specific artefacts, ultrasound-specific artefacts

A major difference between most digital medical images and pictures acquired from photography is that the depicted physical parameters in medical images are usually inaccessible for inspection (see Fig. 2.1). Features or quantities determined by computer-assisted analysis cannot easily be compared with true features or quantities. It would be, e.g., infeasible to open the human body to verify whether a tumor. volume measured in a sequence of CT images in some posttreatment confirmation scan corresponds to the true volume. Fortunately, the physical property depicted, its diagnostic value, and possible artefacts are usually well known. Furthermore, the imaging technique has been chosen on purpose because it is known to produce images that depict diagnostically relevant information. The development of efficient analysis techniques often uses this knowledge as part of the domain knowledge to make up for the inaccessibility of the measured property. A physical property measured by an imaging device and presented as a picture must meet three conditions to be useful. It has to penetrate the human body, it must not unduly interfere with it, and it must be meaningful for answering some medically relevant question.

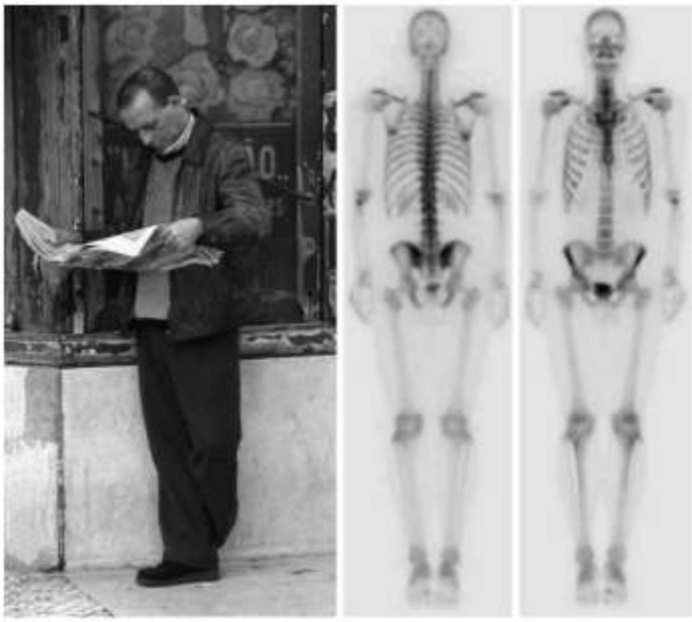


Fig. 2.1 Information from a photography is quite different from that of a medical image (in this case a bone scintigraphy, published under Creative Commons license). While the human depicted in the photo looks familiar, interpretation of the image on the right requires expertise with respect to the meaning of the intensities. On the other hand, specific domain knowledge exists as to how to interpret image intensity in the scintigraphy and the image is acquired in a way that makes analysis as easy as possible, all of which cannot be said about the picture on the left. Obviously, the kind of task for computer-based image analysis is different for these two pictures

With respect to digital imaging, four major and several minor imaging techniques meet these requirements. The major techniques are as follows.

- **X-ray imaging** measures the absorption of short wave electromagnetic waves, which is known to vary between different tissues.
- **Magnetic resonance imaging** measures the density and molecular binding

of selected atoms (most notably hydrogen which is abundant in the human body), which varies with tissue type, molecular composition, and functional status.

- **Ultrasound imaging** captures reflections at the boundaries between and within tissues with different acoustic impedance.
- **Nuclear imaging measures** the distribution of radioactive tracer material administered to the subject through the blood flow. It measures function in the human body.

Other imaging techniques include **EEG and MEG imaging, microscopy, and photography**. All the techniques have in common that an approximate mapping is known between the diagnostic question, which was the reason for making the image and the measurement value that is depicted. This can be very helpful when selecting an analysis technique. If, for instance, bones need to be detected in an x-ray, CT slice, a good first guess would be to select a thresholding technique with a high threshold because it is known that x-ray attenuation in bone is higher than in soft tissues and fluids. Many of the imaging techniques come in two varieties: Projection images show a projection of the 3D human body onto a 2D plane and slice images show a distribution of the measurement value in a 2D slice through the human body. **Slice images may be stacked to form a volume.** Digitized images consist of a finite number of image elements. Elements of a 2D picture are called pixels (picture elements) and elements of stacked 2D slices are called voxels (volume elements). We will call pixels or voxels scene elements if the dimension of the scene is not known or not important.

2D and 3D images may have an additional time dimension if the variation along the time axis provides additional diagnostic information (e.g., if normally and abnormally beating hearts are compared). Slice images are usually reconstructed from some kind of projection. Reconstruction may cause additional artefacts.

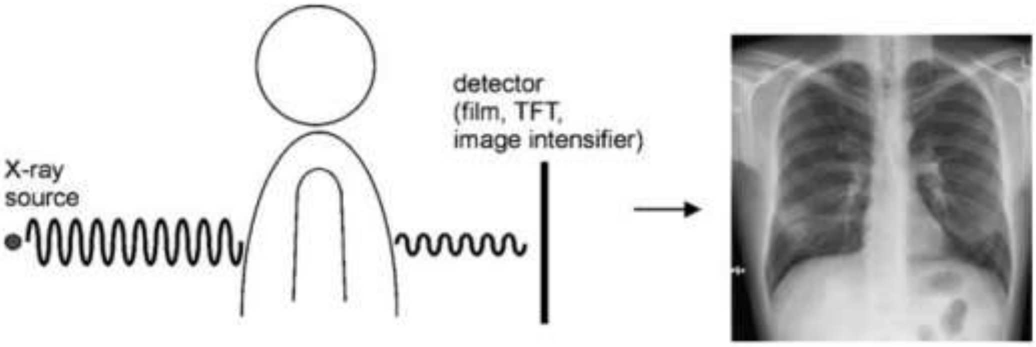


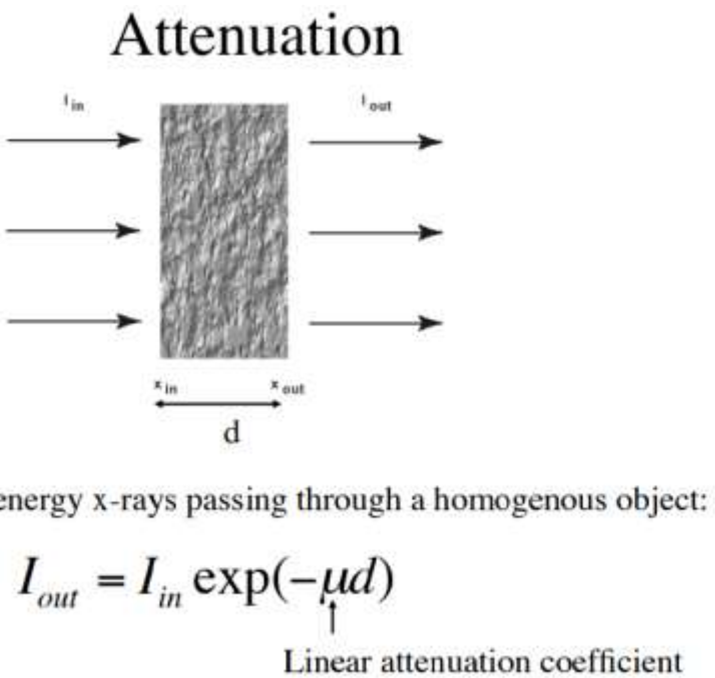
Fig. 2.2 X-rays penetrate the human body and produce an image that shows the integral of tissue-specific absorption along a path from the X-ray source

2. X-Ray Imaging

X-ray imaging uses the dependency of photoelectric absorption on the atomic number for producing a diagnostically meaningful image In this section we will only touch on the subject to give an impression of how the images are created and what kind of different x-ray imaging techniques exist.

Fig. 2.3 Two radiographs Bone structures in the two images are clearly visible. Differentiating between different soft tissues is more difficult as is the depth order of the projected structures

Diagnostic equipment for x-ray imaging consists at least of a cathode ray tube emitting x rays and a receptor with the patient placed between the emitter and *receptor*. The receptor may be film, an image intensifier, or a flat panel detector with the latter two producing digital images. If the x-ray tube is assumed to be a point source for x rays and the receptor is planar, the image intensity at every location of the receptor will be proportional to the attenuation along a ray from the x-ray tube to the receptor. The measured intensity for a monochromatic beam at a location (x,y) on the receptor is then see figure 2.4



$$I_{out} = I_{in} \exp(-\mu d)$$

Figure 2.4 Attenuation of the Iout

Images from an image intensifier suffer from a number of artefacts of which the following three are relevant for postprocessing (see Fig. 2.5)

- **Vignetting** التضليل is caused by the angle at which rays fall onto the input screen.
- **Pincushion distortion** التشويه is caused by the curvedness of the input screen and results in magnification. Magnification increases with the deviation of the input surface from a tangent plane to the center of the screen.
- **The S-distortion** is caused by external electromagnetic fields that influence the course of the electron beam between the input and output phosphor.

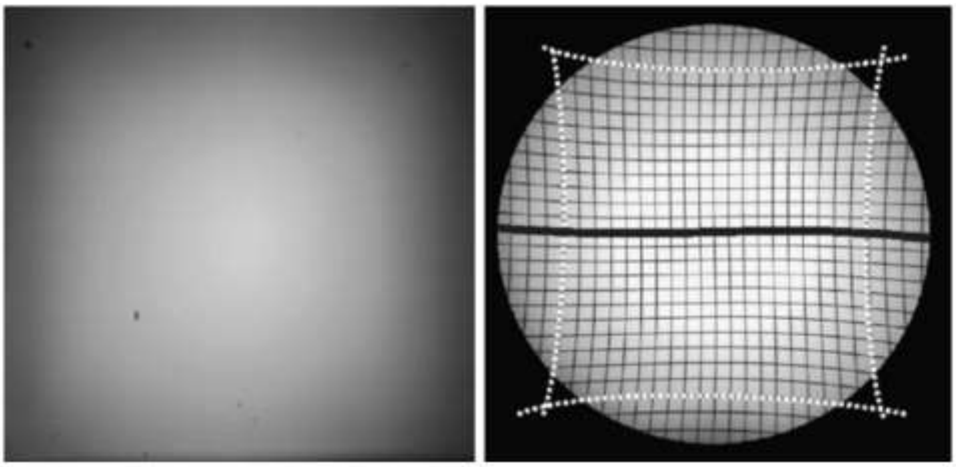


Fig. 2.5 Vignetting causes shading in an image as it can be seen in the picture of homogeneous material on the left. The location dependent magnification by a pincushion distortion of an image intensifier is seen on the test pattern of equal-sized squares on the right (dashed lines). This image also shows the much less rominent deformation due to the earth magnetic field

3. Magnetic Resonance Imaging

Protons and neutrons of the nucleus of an atom possess an angular momentum that is called *spin*. These spins cancel if the number of subatomic particles in a nucleus is even. Nuclei with an odd number exhibit a resultant spin that can be observed outside of the atom. This is the basis of magnetic resonance imaging (MRI). In MRI, spins of nuclei are aligned in an external magnetic field. A high frequency electromagnetic field then causes spin *precession* السبق that depends on the density of magnetized material and on its molecular binding, see figure (2.6).

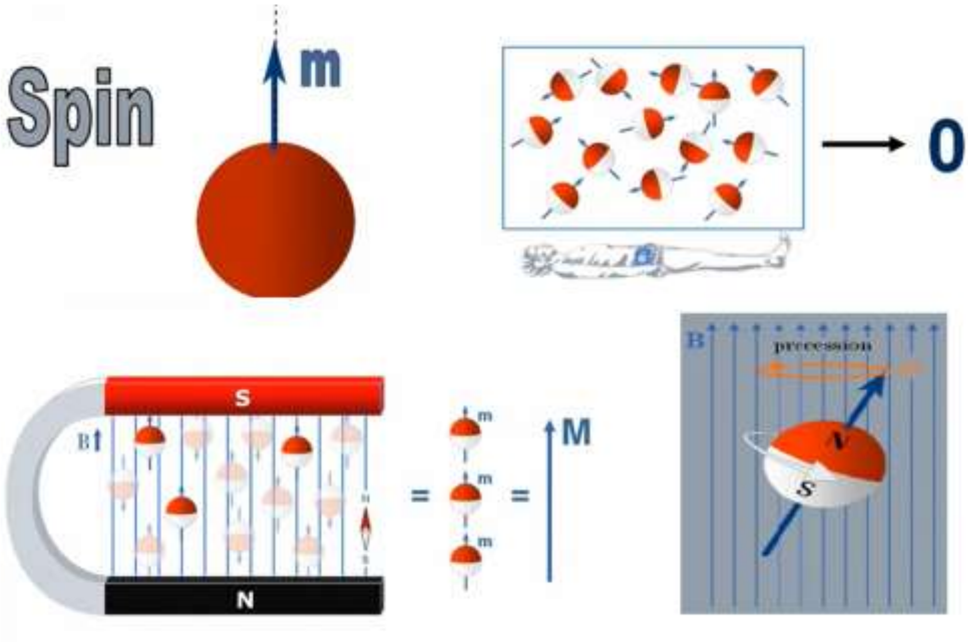


Figure 2.6 MRI Spin

4. Ultrasound Images

Sound waves will be reflected at the boundaries between materials of different acoustic impedance. An ultrasound wave sent into the human body will be reflected at organ boundaries. The locus مكان of reflection can be reconstructed if the speed of sound in the material through which the wave travels is known. For most soft tissues this speed is around 1500 m/sec. An ultrasound reflection signal is created using a transducer which acts as the sender and receiver of ultrasound waves (Fig. 2.7 shows typical ultrasound equipment). Frequencies for diagnostic ultrasound range between 1 and 20 MHz. High frequency waves attenuate faster than low frequency waves and do not penetrate the body as good as low frequency waves. High frequency waves resolve smaller structures, however, since the size of a reflecting object has to be larger than the wavelength.

Fig. 2.7 Ultrasound equipment

Figure (2.8) shows the different types of sound waves

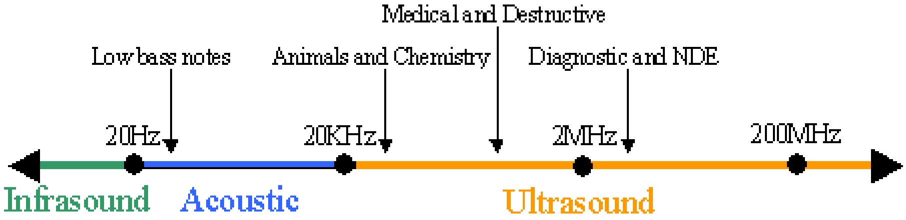


Fig. 2.8 Sound Waves

Ultrasound Imaging

An ultrasound A-scan sends a single wave with known direction into the body and records the amplitude of reflection

s as a function of travel time between sending and receiving the signal. It is a one-dimensional probe مسبار استكشاف into the body showing tissue boundaries and other boundaries between regions with different acoustic impedance مقاومة صوتية. Ultrasound (US) images (the so-called B-scans, see Fig. 2.8 and Fig.2.9) are created from a planar fan beam of differently rotated A-scans. Amplitudes are mapped to gray values for creating the image. They may also be acquired as 3D images with this fan beam rotating around a second axis perpendicular to the first axis of rotation. Ultrasound imaging (also called sonography التصوير فوق الصوتي) happens in real time and is able to show the motion of the organs being imaged.

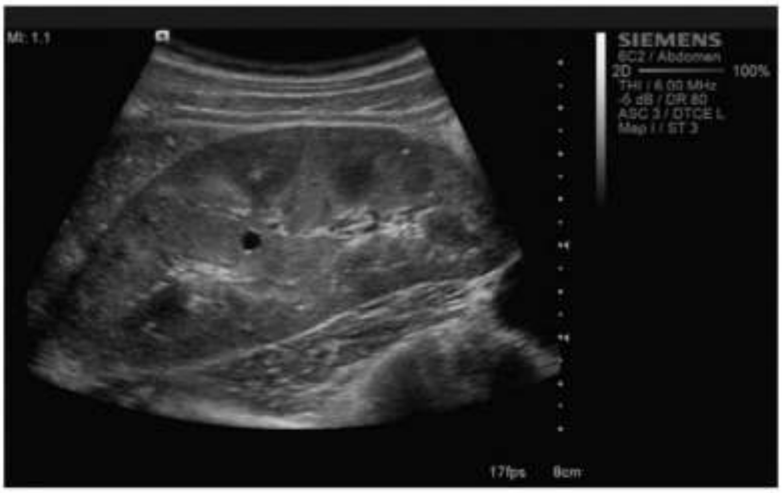


Fig. 2.8 Ultrasound B-scan of the abdomen

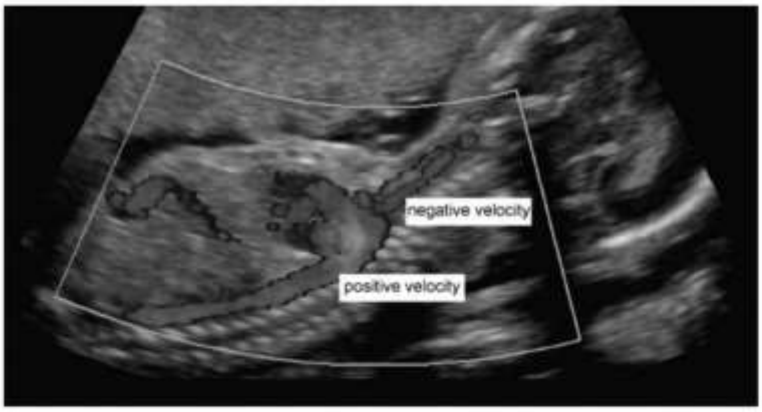


Fig. 2.9 Doppler sonography uses the Doppler effect to depict blood velocity. In its original, velocity is color-coded differentiation between flow direction and velocity

A number of effects cause **artefacts** in an ultrasound image (see Fig. 2.10).

- Sound waves are attenuated just as electromagnetic waves in x-ray imaging.

- Absorption turns wave energy into heat.
- The wave may be scattered or refracted.
- Interference and a diverging wave cause further deterioration .تدهور

Absorption causes a decrease in amplitude with increasing depth.

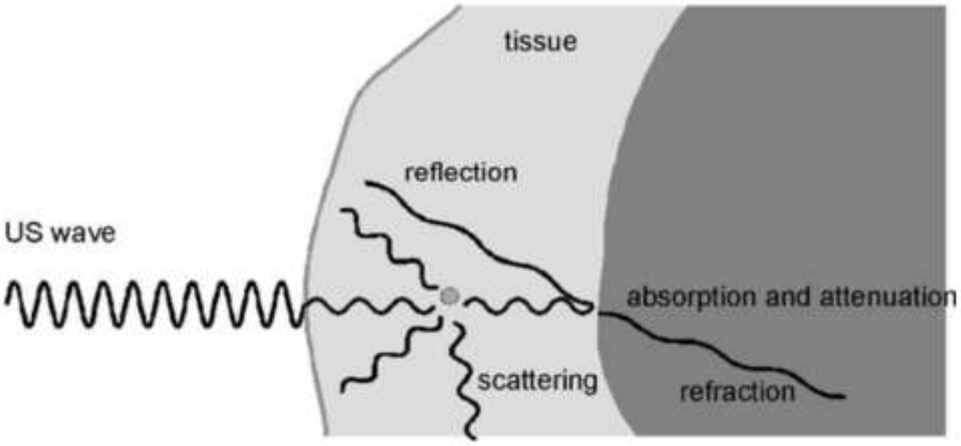


Fig. 2.10 Different effects influence the incident US wave of which only direct reflection is the wanted effect

Figure (2.11) shows the sender ultra sound waves to the detected object

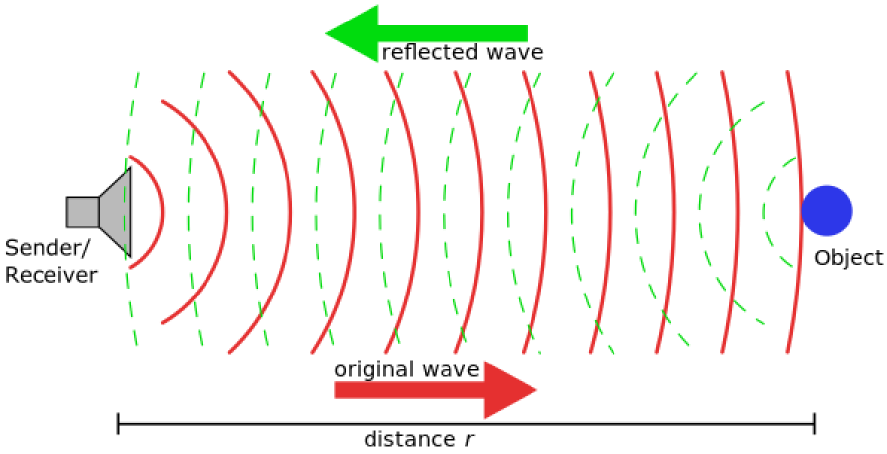


Fig. 2.11 Ultrasound Waves to detect Object

5. Nuclear Imaging

Nuclear imaging measures the distribution of a radioactive tracer material and produces images of a function in the human body. The tracer material is injected intravenously عن طريق الوريد prior to the image acquisition and will distribute through blood circulation. Distribution is indicative to the perfusion نضح of organs in the body. Examples for applications are measurements of brain activity, perfusion studies of the heart, diagnosis of inflammations التهابات due to arthritis and rheumatism, or the detection of tumor metastases due to increased blood circulation. Images are created from measuring photons sent by the tracer material through the body. Spatial resolution in nuclear imaging is lower than for the procedures described above since tracer concentration is very low so as to not to interfere with the metabolism. The sensitivity of imaging techniques in nuclear medicine is high since detectors are able to measure a signal from a few photons. Major imaging techniques in nuclear medicine are as follows

- ❖ Scintigraphy, which measures a projection of the tracer distribution with a geometry similar to projection x-ray imaging.
- ❖ SPECT (Single Photon Emission Computed Tomography تصوير طبي بأشعة كاما), which is a reconstruction from projections of tracer material producing a 3D material distribution.
- ❖ PET (Positron Emission Tomography التصوير المقطعي بالإصدار البوزيتروني), which is a tomographic technique as well, but uses a different tracer material that produces positrons. Radiation of positronelectron annihilation is measured and reconstructed.

6. Scintigraphy

For creating a scintigram (an image of an internal part of the body produced by scintigraphy), a molecule carrying the radioactive atom 99Tc (Technetium-99) is applied. Photons emitted by tracer radiation are measured by a gamma camera (also written as γ -camera and sometimes called Anger camera. The camera consists of a collimator that restricts measurements of photons to those who hit the detector approximately at a 90◦ angle, a scintillator crystal وميض that turns incident radiation into visible light, and photomultipliers المضاعفات الضوئية for amplifying the signal. The camera is usually mounted on a gantry that enables the camera to rotate (around various directions) around the patient. The collimator is a thick lead plate with drilled cylindrical holes whose axes are perpendicular to the scintillator crystal. Photons reaching the detector on a path perpendicular to the detector plane will reach the scintillator at a location that is given by the positioning of the detector hole through which it passes. Photons on a path with any other angle are reflected or attenuated by the lead collimator. If they reach the detector crystal through scattering, they have lost too much energy for being detected. Hence, the collimator causes the image to be an approximate parallel projection of photons from tracer material in the body onto the image (see Fig. 2.12)

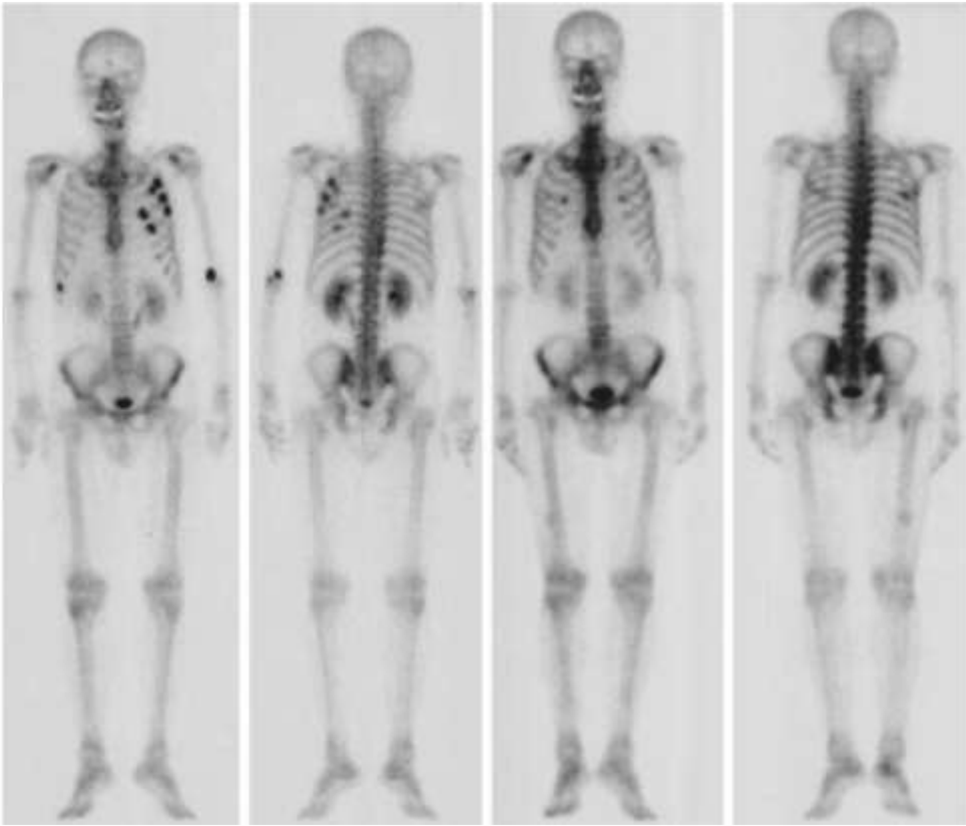


Fig. 2.12 Bone scintigraphy (in this case before and after-treatment bone scintigraphy

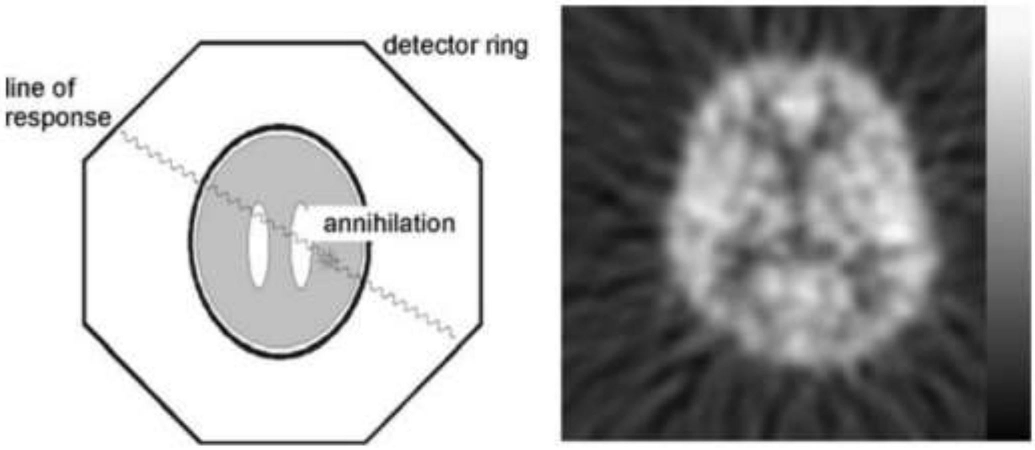


Fig. 2. 13 Schematic view of a PET scanner (left) and resulting image of measured activity in the brain

MCQ

1.What is the primary focus of Medical Image Analysis-II in the context of digital imaging techniques?

- A) Surgical procedures
- B) Computer-assisted analysis of medical images
- C) Microscopic analysis
- D) Radiographic interpretation
- E) Patient diagnosis

Correct Answer: B) Computer-assisted analysis of medical image

2. Which of the following is NOT a major digital imaging technique discussed in the context of Medical Image Analysis-II?

- A) X-ray imaging
- B) Magnetic resonance imaging
- C) Ultrasound imaging
- D) Electroencephalography (EEG) imaging
- E) Nuclear imaging

Correct Answer: D) Electroencephalography (EEG) imaging

3.What property does X-ray imaging measure for producing diagnostically meaningful images**?

- A) Acoustic impedance
- B) Molecular binding
- C) Density
- D) Spin precession
- E) Radioactive tracer distribution

Correct Answer: C) Density

4. What is the primary advantage of Magnetic Resonance Imaging (MRI) over X-ray CT?

- A) Higher resolution
- B) Lower cost
- C) Use of ionizing radiation
- D) Arbitrary slice orientation
- E) Better visualization of bone structures

correct Answer: D) Arbitrary slice orientation

5.What causes Vignetting in X-ray imaging, resulting in shading in the image?

- A) External electromagnetic fields
- B) Pincushion distortion
- C) Angle of incident rays
- D) Earth's magnetic field
- E) Magnification

Correct Answer: C) Angle of incident rays

6. What is the primary principle behind Ultrasound Imaging?

- A) Measurement of radioactive tracer distribution

- B) Reflection of sound waves at organ boundaries
- C) Detection of positron emission
- D) Ionizing radiation absorption
- E) Magnetic resonance of hydrogen nuclei

Correct Answer: B) Reflection of sound waves at organ boundaries

7. What type of ultrasound scan sends a single wave into the body and records the amplitude of reflection as a function of travel time?
   - A) B-scan
   - B) C-scan
   - C) D-scan
   - D) A-scan
   - E) M-scan

Correct Answer: D) A-scan

8. What can Doppler imaging in ultrasound be used for?
   - A) Estimating speed and direction of moving objects
   - B) Creating 3D images
   - C) Measuring radioactive tracer distribution
   - D) Detecting bone abnormalities
   - E) Imaging internal organs in real time

Correct Answer: A) Estimating speed and direction of moving objects

9. What causes acoustic shadowing in ultrasound imaging?
   - A) Absorption of sound waves
   - B) Refraction of waves
   - C) Interference between waves
   - D) Mirror echoes
   - E) Scattering of waves

Correct Answer: A) Absorption of sound waves

10. In Nuclear Imaging, what does PET (Positron Emission Tomography) use for imaging?
   - A) X-rays
   - B) Magnetic resonance
   - C) Positron emitters
   - D) Ultrasound waves
   - E) Gamma rays

Correct Answer: C) Positron emitters