Computed Tomography: An Introduction to Scanning & Data Capture

Superimposition

- Objects above and/or below the object of interest can confuse the image
- Especially when structures differ only slightly in density

Slices of 3D Object making 2D images

What does tomography mean?

TOMOGRAPHY = The process for generating a tomogram, a two-dimensional image of a slice or section through a three-dimensional object.

WHO IS CREDITED WITH INVENTION OF THE CT SCANNER?

- **SIR GODFREY HOUNSFIELD**
  WON THE NOBEL PRIZE FOR MEDICINE IN 1979
  - ONE OF THOSE MACHINE IN THE BRITISH SCIENCE MUSEUM BEHIND THE LUNAR MODULE

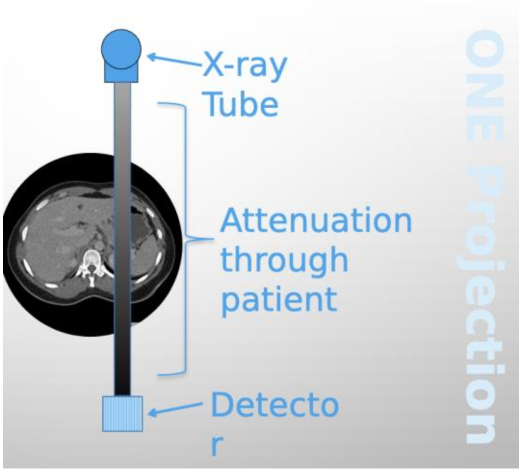
What are we measuring? (Attenuation Coefficient)

What is Attenuation?

- Attenuated x-rays are those that are absorbed, transmitted with a lower energy or scattered.
- It is an exponential process and therefore, the beam intensity never reaches zero.
- There are two main methods through which attenuation occurs:
  • Compton scatter – incident x ray photon is deflected from its original path by interaction with a electron.
  • Photoelectric effect – where a X-ray photon interacts with an atom transferring its energy to the inner shell electrons ejecting it from its atom.

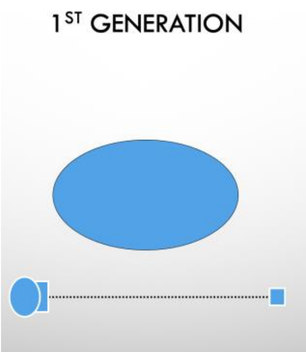
Data Acquisition

- Measures attenuation of x rays between tube and detector
- Through Non-homogenous matter
- Sum of total attenuation
- Projection



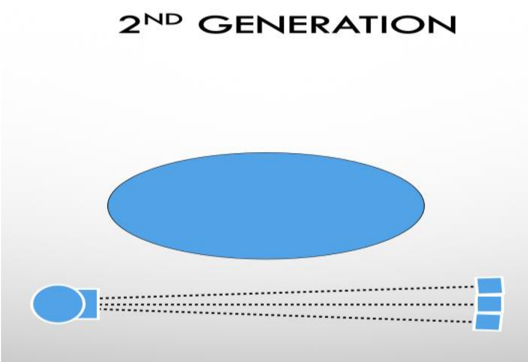
1st Generation - Translate and rotate

- single pencil beam of x rays and measured by a single detector
- The tube-detector assembly is moved across the scan field of view (translation) and a series of measurements of transmitted intensity are made.
- It is then rotated 1 degree to a next position and translation takes place again
- 4 and half minute a slice.



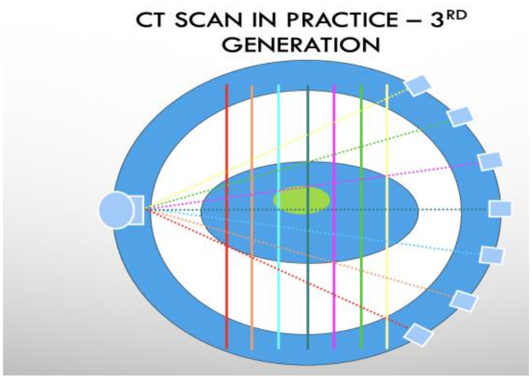
2nd Generation Translate and rotate multiple detectors

- **2nd generation**- Similar to the above but a **narrow fan beam** (instead of a pencil thin beam) and multiple detectors were used.
- Results in faster scans due to more data being acquired
- 30 secs a slice



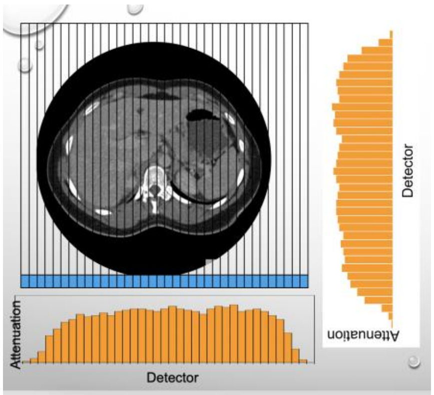
3rd Generation translate and rotate - multiple detectors

- 3rd generation - Wide fan beam with multiple detectors (up to 1000) Removing the need to translate
- The tube and detectors are rigidly coupled together and rotate jointly about the patient.
- More detectors, more money (cost of production). More processing power. Most modern scanners are based on this one
- 0.5 secs a slice



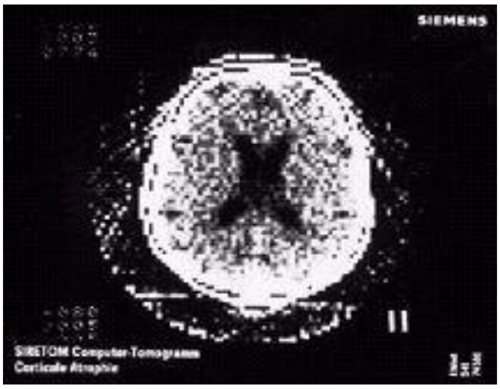
Data Acquisition

- Total attenuation between tube & detector
- Sum of attenuation coefficients in all planes the beam has travelled through
- Goal: To calculate attenuation within each individual voxel on the resulting images

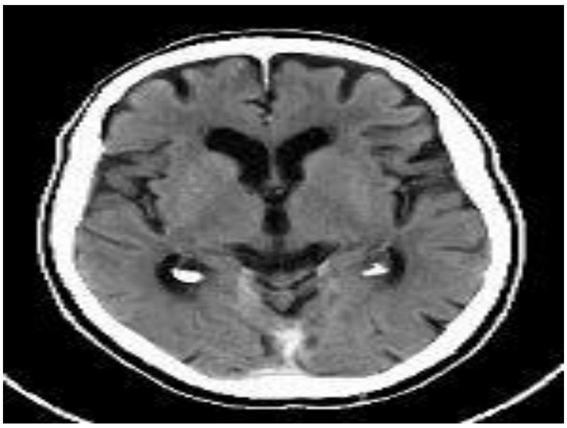


- We need to sample the whole object to determine the distribution of attenuation
- Remember: one view is ONE PROJECTION
- Modern scanners usually have about ONE THOUSAND samples per PROJECTION and about ONE THOUSAND PROJECTIONS per rotation
- The X-ray tube in modern scanners spins 3 times per second.

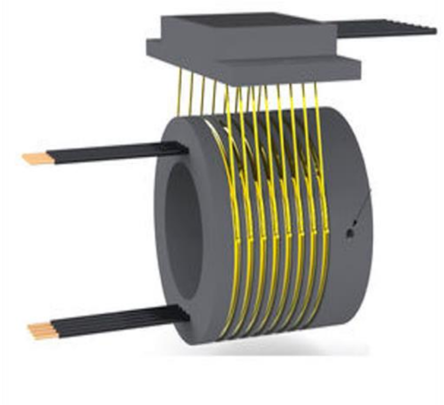
1st Generation CT image



3rd Generation CT image

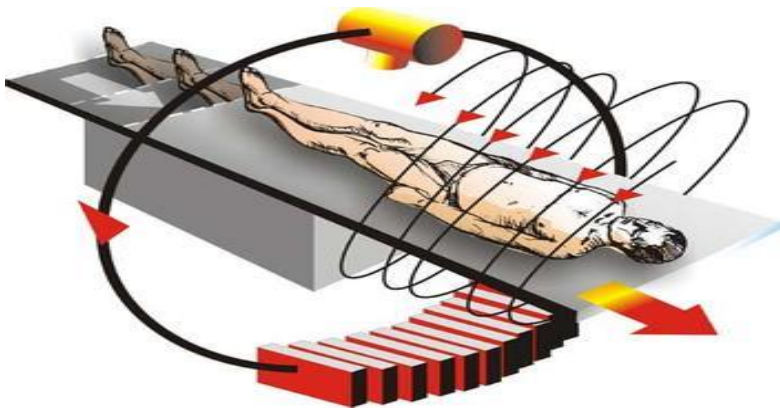


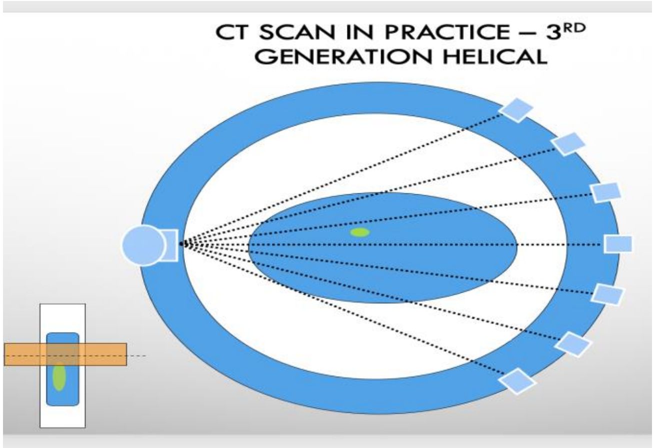
Slip Ring technology – allowed for continual scanning



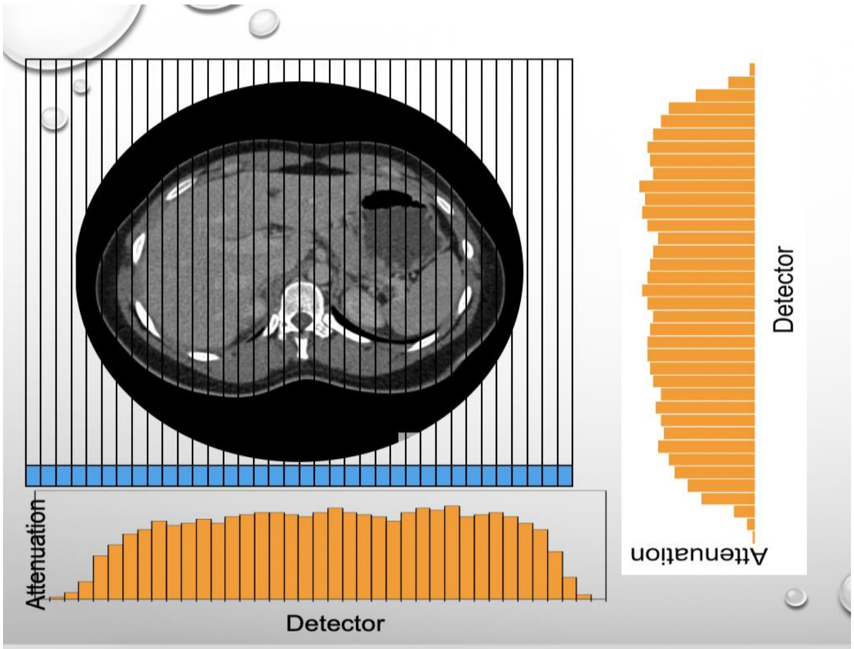
- A slip ring is electromechanical technology that enables the transmission of electrical signals from a stationary to a rotating structure.
- connections made by stationary brushes pressing against rotating circular conductors.
- CT Slip ring technology was introduced to enable **helical** (continuous rotating) scanning.
- Prior to the introduction of Slip Rings, only axial scanning was possible (which had the need to stop / reverse direction of rotation, after no more than 700 degrees rotation due to the finite length of the attached cables)
- Slip-ring technology eliminated the need for cables and enabled the continuous rotation of the gantry components

Helical scanning



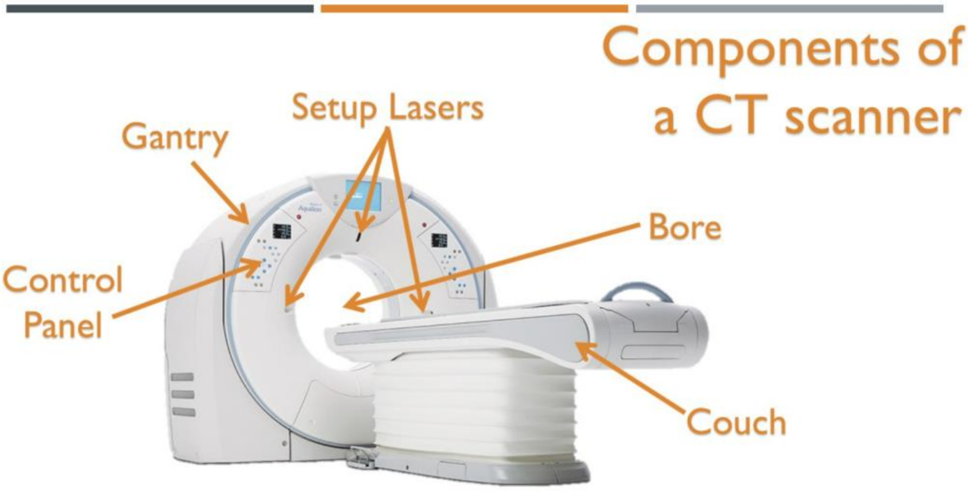


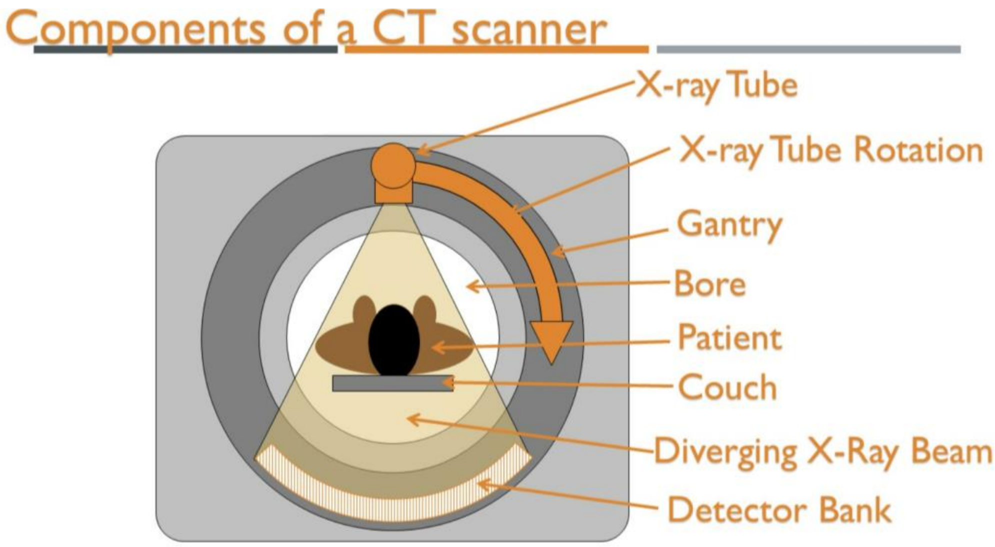
Data Acquisition



- Numerous projections at different angles around the patient
- Usually around one thousand projections per rotation
- Approximately 3 rotations of the x ray tube per second

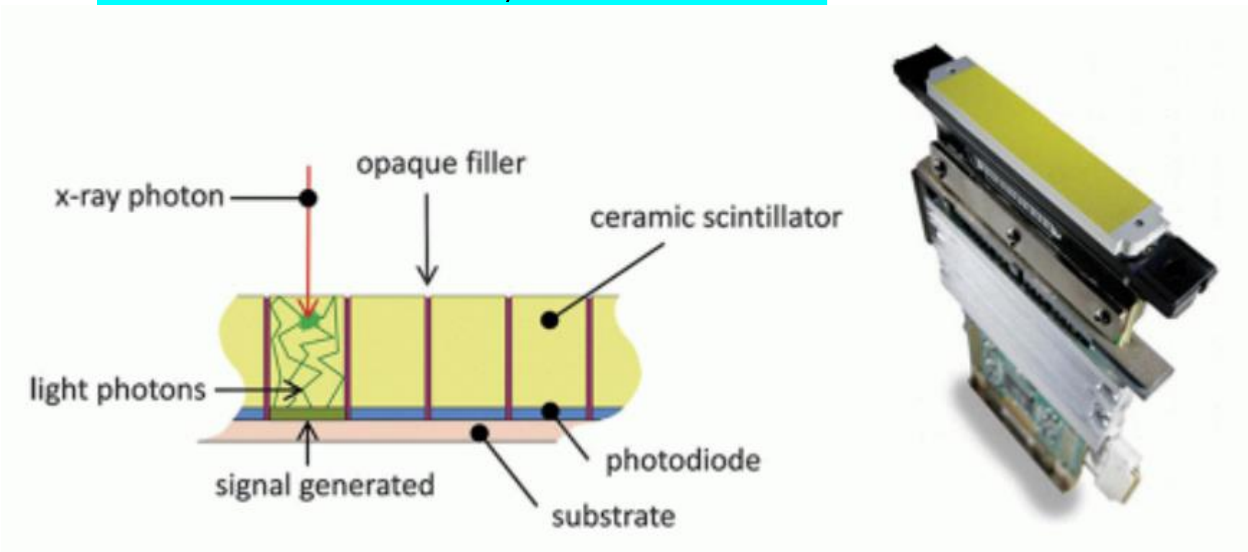
Components of a CT scanner





CT Detectors

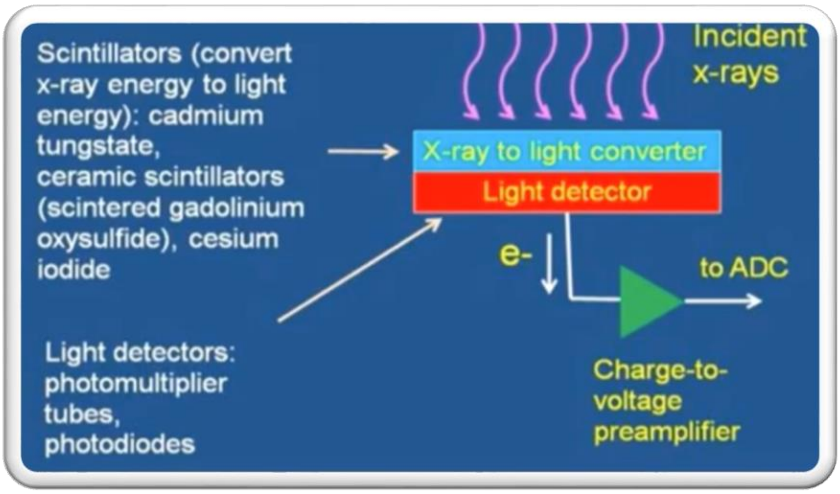
- CT detectors collect signals of how much radiation hits them i.e. the attenuation of the matter in between them and the tube
- The slice width is determined by the size of the detector.

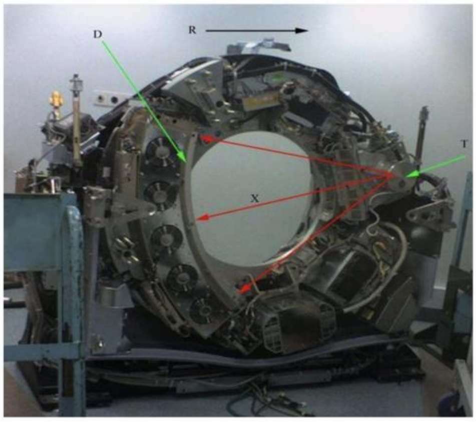


Energy conversion

What happens when emerging photons hit the detector?

- Scintillators – convert x ray energy to light energy. They can be made of cadmium tungstate, ceramic scintillators, caesium iodide
- Light detectors: photomultiplier tubes, photodiodes - converts photon input into electrical signal.

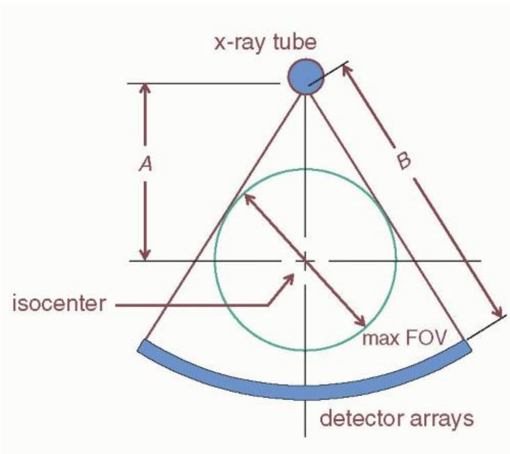




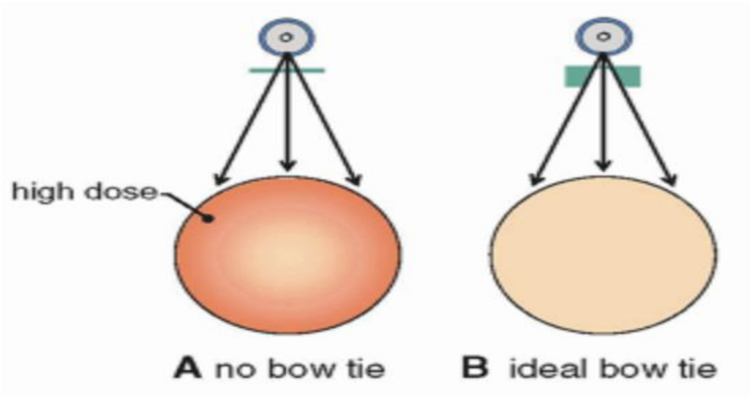
Components of a CT scanner

T	X-ray Tube
D	X-ray Detectors
X	X-ray Beam
R	Gantry Rotation

<u>The Bowtie filter & THE ISOCENTRE</u>



- The patient should be centred in the isocentre
- The isocentre is the centre of the field of view within the bore
- Bow tie filters, filter less in the centre and more on the edges.
- This accounts for the shape of the body (thicker at the centre) and allows a uniform/homogenous beam to reach the detector.



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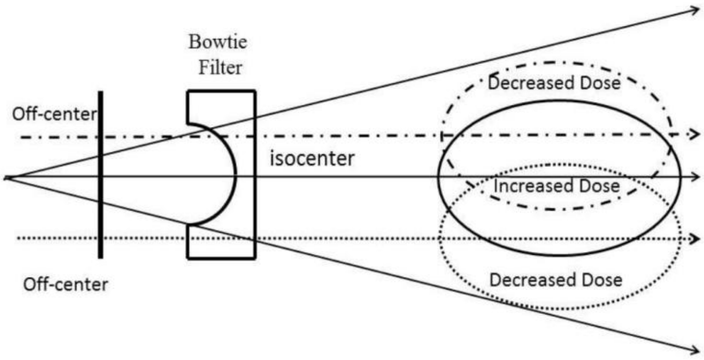
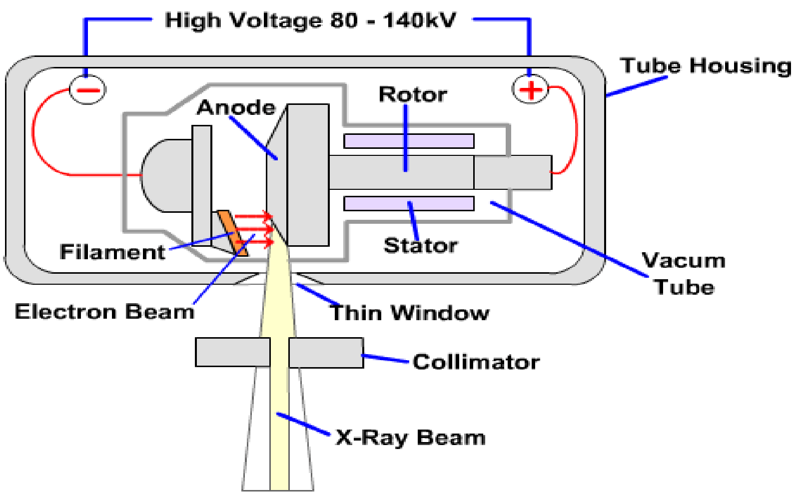


X-ray tube

- Tubes for CT have much more power than conventional x-ray tubes. They could be exchanged every 12 months.
- Anode is usually larger- approximately 1mm- To tolerate a lot of heat loading.
- Most CT scanners operate at three to four tube voltages – 80, 100, 120 and 140kV are typical.



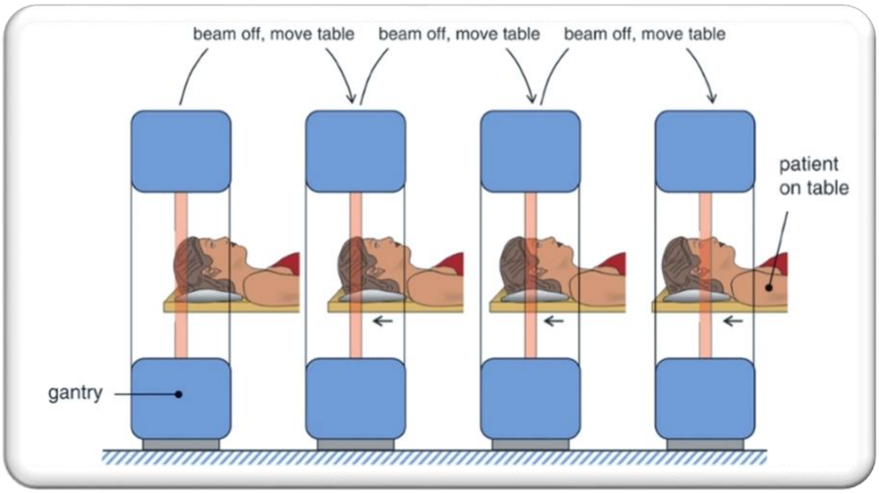
- Standard radiography= 0.3 to 0.5 megajoule (MJ)

- CT=5-7 MJ
- Reduced with the introduction of MDCT which makes better use of the produced X-rays.
- Owing to the high X ray flux required for CT, the X ray tube uses a tungsten
- anode designed to withstand and dissipate high heat loads and high atomic number.

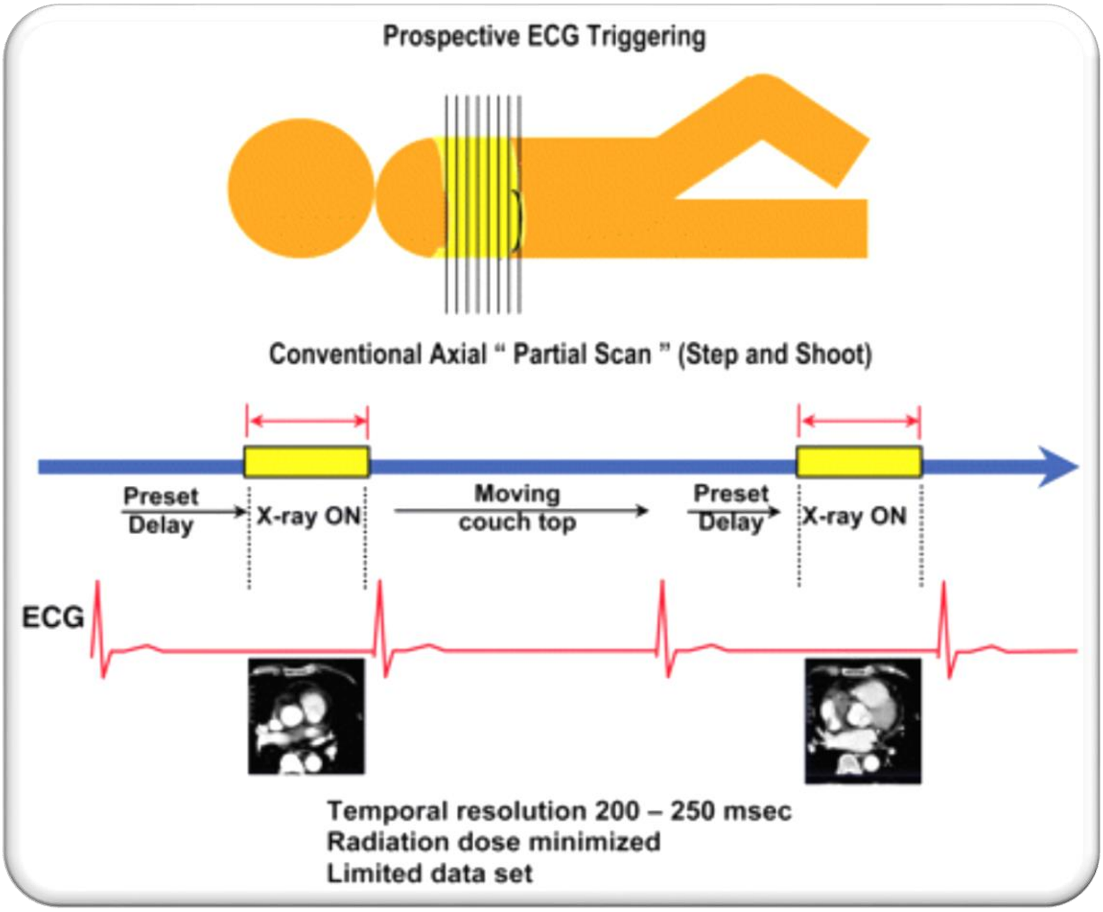
Types of image acquisition – two types

Sequential/axial/step and shoot

- The table is stationary when the tube is energised
- And then the table moves to a new position while the X-ray tube is 'off'
- A 360 degrees scan is acquired at each stage until the whole area of interest is covered
- This type of acquisition takes longer to complete
- However improvements in multidetector row CT (MDCT) technology now enables larger volumes to be scanned at a go



Sequential/axial Acquisition- Example- ECG triggering



Helical/Spiral Scaning

- The table moves at a constant speed while gantry rotates around the patient
- The X-ray source therefore draws a helix around the patient
- This scan is fast because there is no start-stop motion

Advantages of Helical/spiral

- This scan is fast because there is no start-stop motion
- High quality multi planer three dimensional image display
- Virtual studies- Bronchoscopy and Colonography
- Allows large areas to be scanned in one breath hold reduces motion artifacts
- Small areas of pathology unlikely to be missed
- More uniform with contrast enhancement
- Reconstructions possible at any level at any angle post scan

Exposure factors from the tube

KVP

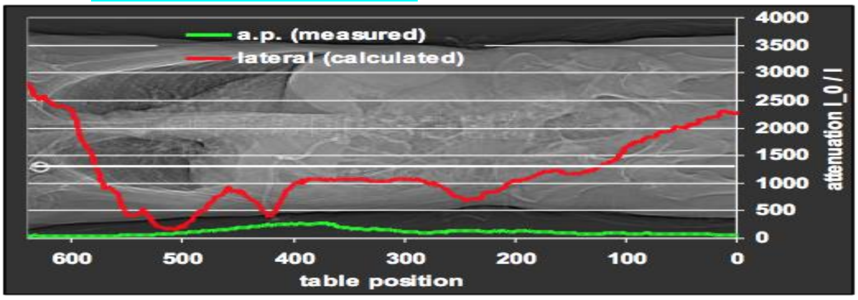
- constant for the whole scan
- The tube voltage in any CT scanner depends on the vendor, typically 120kV but includes 80,100,120 and 140 kV
- The average energy of the X-ray beam is referred to as the **effective energy**
- The effective energy for the 80kV spectrum is about 40keV and that for 140kV is 60keV

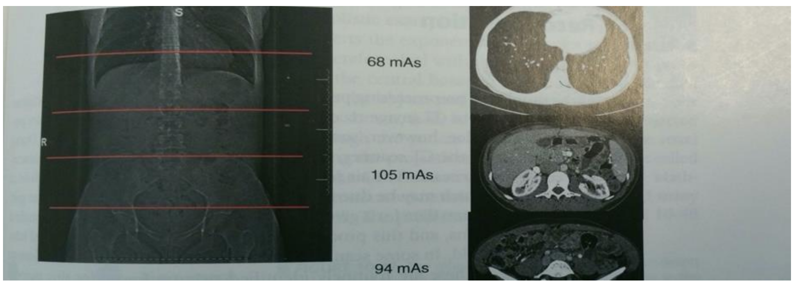
MAS

- Modulated throughout the scan
- depends on tissue thickness/density
- reduces radiation dose to the patient by using less photons when the tissue is more penetrable
- Modulation is planned by the scout/topogram/planning scan
- Tube modulation is different at various body positions
- The mA is changed depending on the composition of the body part
- Topogram used to assign mAs variations along long-axis of patient

Topogram AP and Lateral

- a two dimensional x ray image generated by tomography without being reconstructed into slices.





LOTS of Different Names

•Siemens: CareDose4D

•GE: Smart Scan, Auto mA, Smart mA

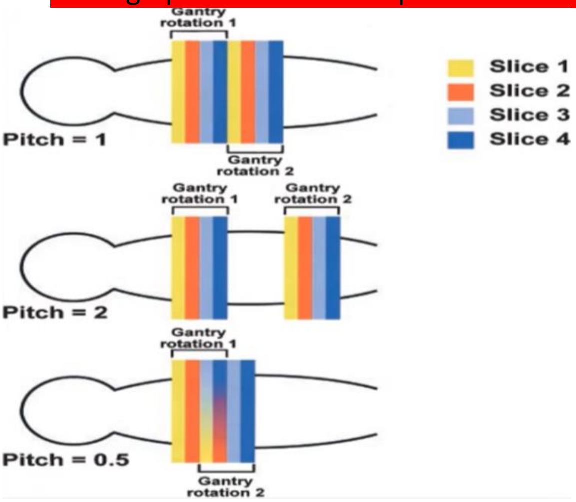
•Philips: DOM, Z-DOM

•Toshiba: SureExposure, SureExposure3D

•GE SmartmA.

Pitch

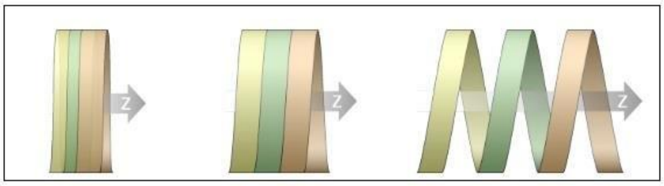
- The ratio of table movement distance to the width of the x ray beam during one gantry rotation
- influencing image quality and radiation dose.
- Low pitch = more overlap between slices
- High pitch = less overlap between slices



$$detector\ pitch = \frac{table\ feed\ per\ gantry\ rotation}{slice\ thickness}$$

- If the table feed per gantry rotation is less than the slice thickness (pitch<1). Successive rotations will overlap and lead to over-scanning and consequently increase radiation dose
- If the table feed is greater than the slice thickness(pitch>1), data from successive rotations become strung out. This leads to under-scanning and problems with image reconstruction

Pitch



Pitch < 1
Beam Width has some overlap at each view angle from rotation to rotation

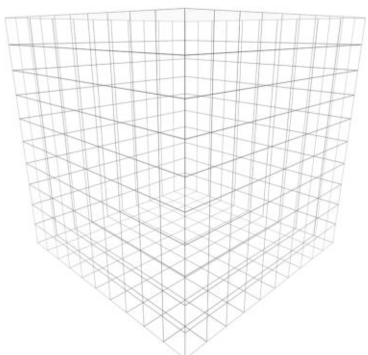
Pitch = 1
No overlap of Beam Width at each view angle and no view angles not covered at certain table positions

Pitch > 1
Some view angles are not covered by the beam width at certain table positions

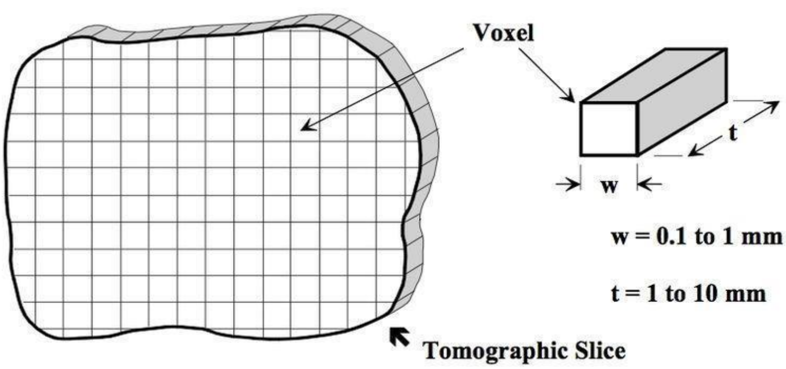
Lecture 2 – CT – image reconstruction

- Image reconstruction in CT is a mathematical process that generates tomographic images from x ray projection data acquired from multiple angles is transformed into a 3D image aiming to improve image quality and minimise artefacts.

An image Matrix

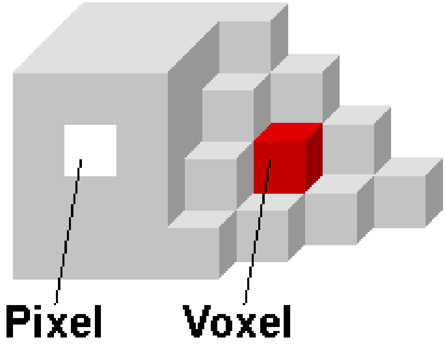


- Pixel on a flat 2D image
- Any 3D information they are rendered in voxels.



Voxels are within tomographic axial slices
W = width
T = thickness

Pixels and Voxels



- The image that is seen on the screen is a 2-dimensional representation of a 3-dimensional structure
- The image is composed of pixels on the screen but these represent voxels that also possess depth
- The depth of the voxel corresponds to the image slice thickness

- Every slice acquired is subdivided into a matrix of up to 1024x1024 volume elements.
- This volume represents the area traversed by numerous X-ray photons during the scan.
- The intensity of these photons are measured by the detectors.
- So, from these intensity readings the density (linear attenuation coefficient) of the tissue can be measured at each point in the slice.
- Attenuation values (HU) are assigned to each voxel.
- The viewed image is reconstructed as a corresponding matrix of pixels.

CT Image

- Layers acquired in a axial projection

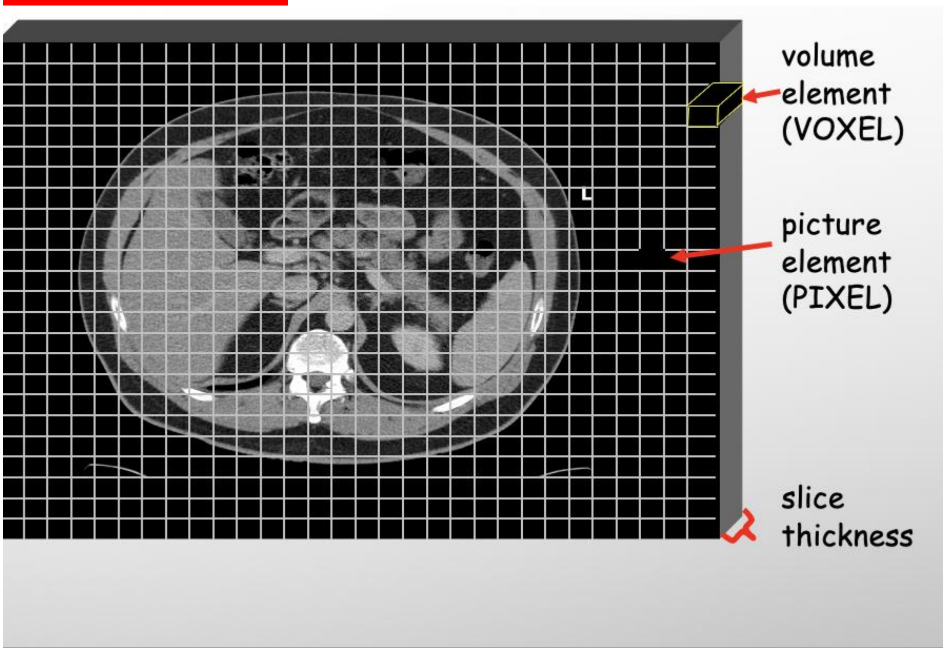
Slice subdivided into matrix of tissue voxels

Voxels correspond to locations in computer memory or pixels in image

Brightness of each pixel governed by x-ray attenuation in corresponding voxel

Pixel= Picture element=The smallest measurable part of an image that may be displayed

Siemens: CareDose4D



Hounsfield units

- We assign a value to each voxel and this is the HU or CT Number
- Water is always 0 and we calibrate around that so the other can change!

- 2000 different values that a Hounsfield unit could have

Hounsfield Units

- We measure attenuation coefficients (the degree to which the beam has been attenuated)
- These linear attenuation values are therefore normalised to the attenuation coefficient of water according to the equation;

$$\frac{\mu_{tissue} - \mu_{water}}{\mu_{water}} \times 1000 = CT\ number$$

μ=linear attenuation coefficient of material

Back projection

- CT image data is reconstructed are the sum of all back projected filtered attenuation profiles.
- Back projection; reconstructs an image by taking each view and smearing it along the path it was originally acquired. The resulting image is a blurry version of the correct image.
- First one is a standard form of image reconstruction, sinogram data, back projecting it into the image data
- Iterative reconstruction images look smoother

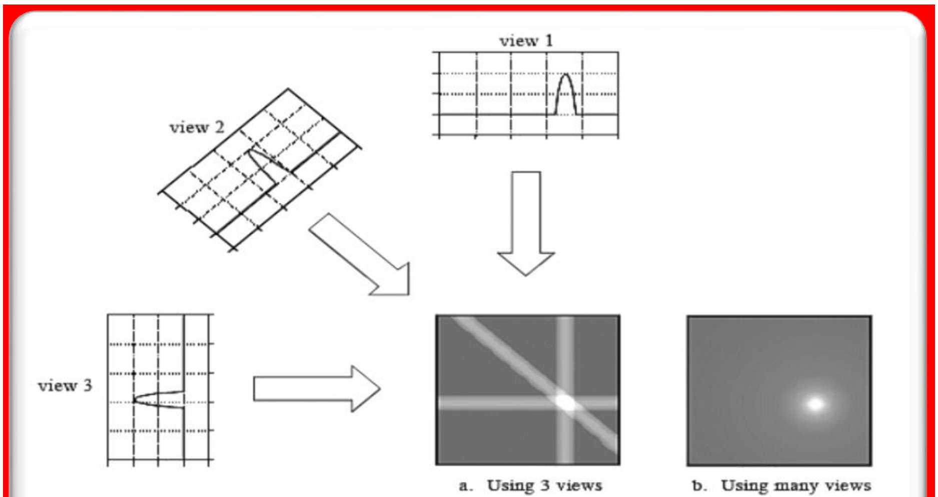
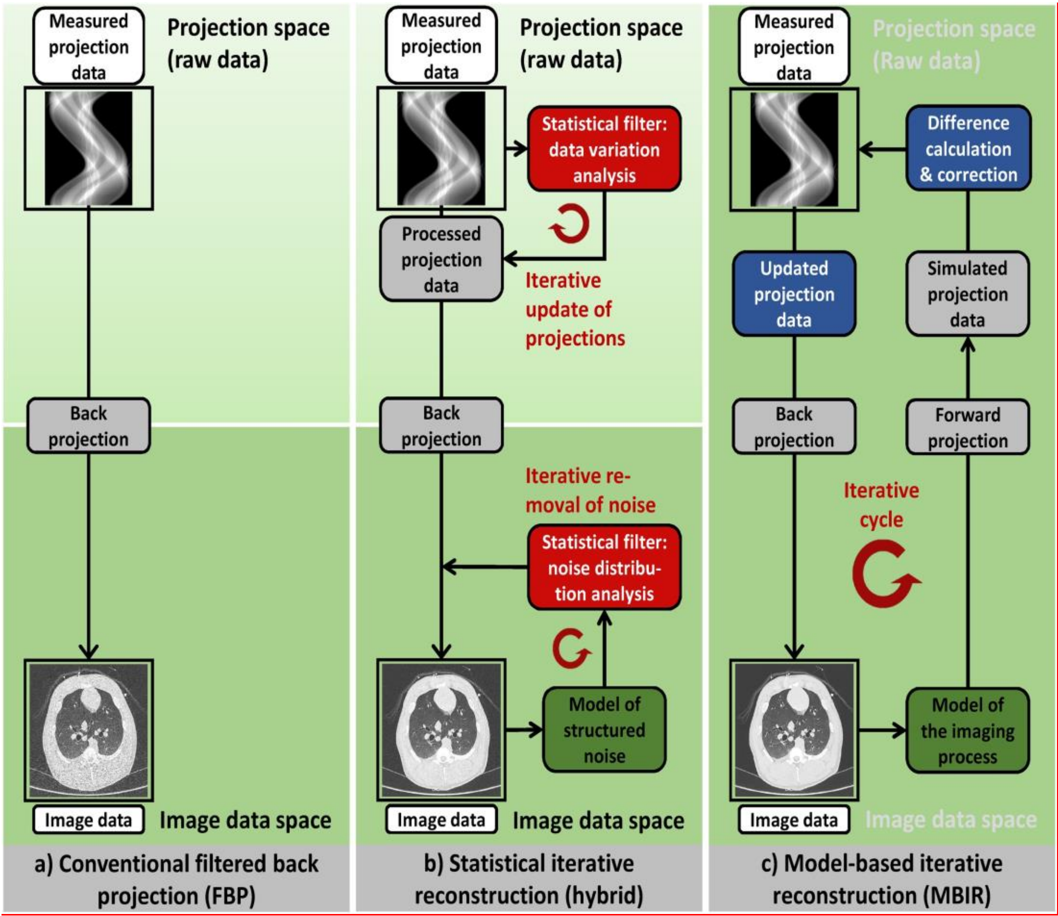


FIGURE 25-16
Backprojection. Backprojection reconstructs an image by taking each view and *smearing* it along the path it was originally acquired. The resulting image is a blurry version of the correct image.

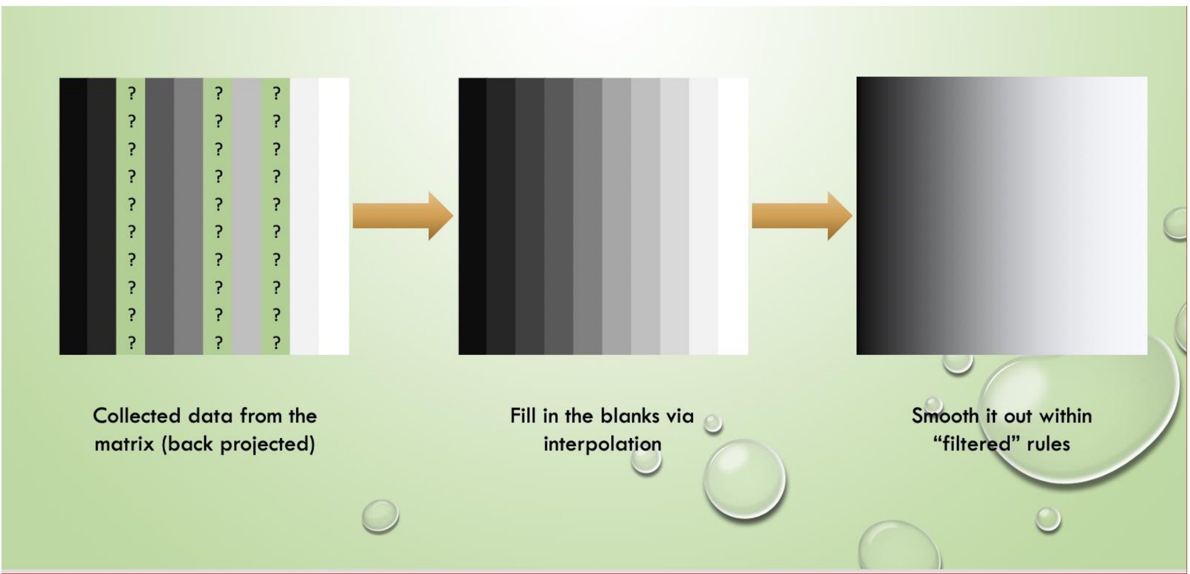
Filtered Back Projection into Iterative reconstruction

- First one is a standard form of image reconstruction, sinogram data, back projecting it into the image data
- Iterative reconstruction images look smoother

- The first one uses statistical



In mathematics, linear **interpolation** is a method of curve fitting using linear polynomials to construct new data points within the range of a discrete set of known data points.

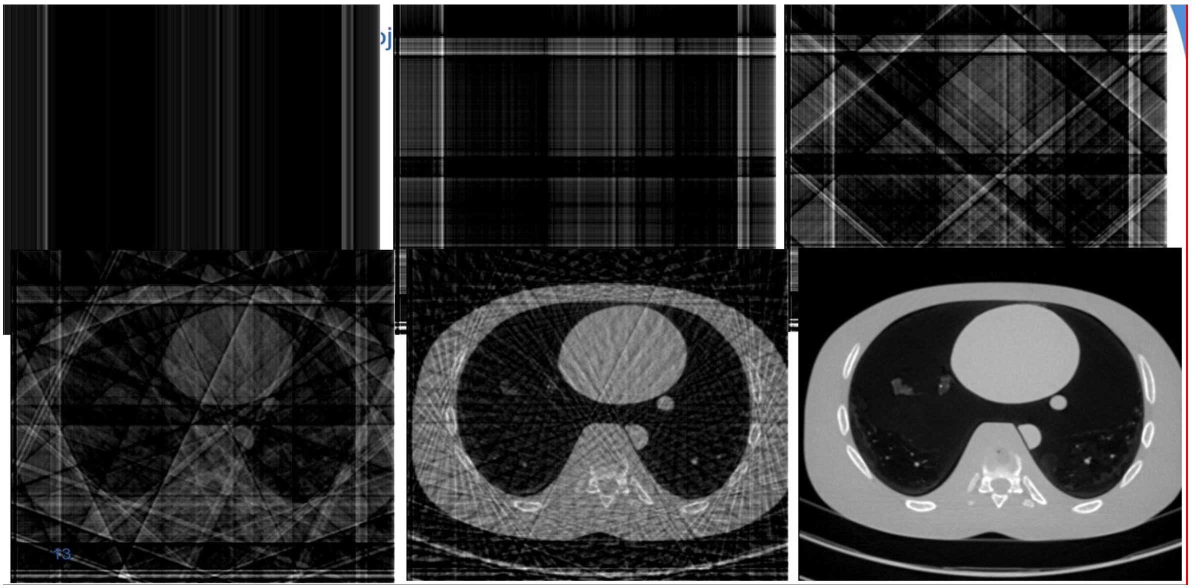


Iterative reconstruction

- Iterative algorithms are characterized by the repetition of a calculation
- **The iterative cycle is repeated until a predefined stopping criterion is met**
- We want to make sure the image data truly corresponds to acquired projection data
- The advantage of iterative reconstruction is reduced noise and artefacts so less dose

MBIr and ASIR- Types of Iterative Reconstruction

- This iterative process can be performed in the raw data domain alone, in the image domain alone (B) or in both domains (C)
- ASIR -Adaptive Statistical Iterative (e.g. filter in Instagram, make all the colours brighter performing a mathematical operation on each voxel, increasing its intensity)
- MBIR -Model-Based Iterative Reconstruction (e.g. rose cheek filters, looking for things it recognises in order to put a rose cheeks etc)
- A blend of FBP and IR is offered to prevent the image from looking artificial
- More time consuming
- Dose reduction of up to 75%



Signal to noise ratio

- When incident X-rays are detected, this constitutes 'signal' that is used to generate a CT image
- However, variations in detector element response to incident X-rays are inevitable and can lead to 'noise'

- **There is an inverse relationship between the noise in an image and the number of X-rays detected**
- The quality of a CT image can therefore be determined by the signal to noise ratio (SNR).
- Increasing tube current increases SNR as an increased number of X-rays strike the detector

Low contrast resolution

- To distinguish details of low contrast
- This allows tissue that only differ slightly in density to be distinguished from each other
- Major advantage over projection imaging
- May improve with inherent differences in tissue attenuation, e.g. iv contrast
- Improves with more mAs as it is dependent on SNR
- Thicker slices have more data so less noise to give better contrast resolution

Temporal resolution

- This is the time required by a scanner to acquire enough data to reconstruct a single image slice
- Temporal resolution depends on the gantry rotation time
- IMPROVES BY SCANNING FASTER

Spatial resolution

- This is the smallest distance at which two separate points can be distinguished as individual objects
- It is the ability of the imaging system to display fine details separately.
- This may either be in the x, y-axes (transverse spatial resolution) or in the z-axis (longitudinal spatial resolution)
- Usually, spatial resolution is similar in both direction (isotropic)
- How to improve spatial resolution;

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Windowing

- CT numbers in an image are usually mapped on an 8-bit grey scale (256 possibilities)
- In spite of the computer's ability to display 2000 shades of grey, the human eye cannot perceive all 2000. As a result only a limited number of these are displayed.
- Window Level (WL) is the central HU of all the numbers within the window
- Window Width (ww) covers all the HU of all the tissues of interest (displayed as shades of grey).
- Tissues outside the window are displayed as either black or white.

Windowing continued examples

Abdominal CT = 350/50 (soft tissue Radiodensity)

- **Ww** Range: -125 to +225 HU **wl** centred at +50 HU
- Gradations: Each 350/16 or 22 HU displays a different shade of grey on the screen

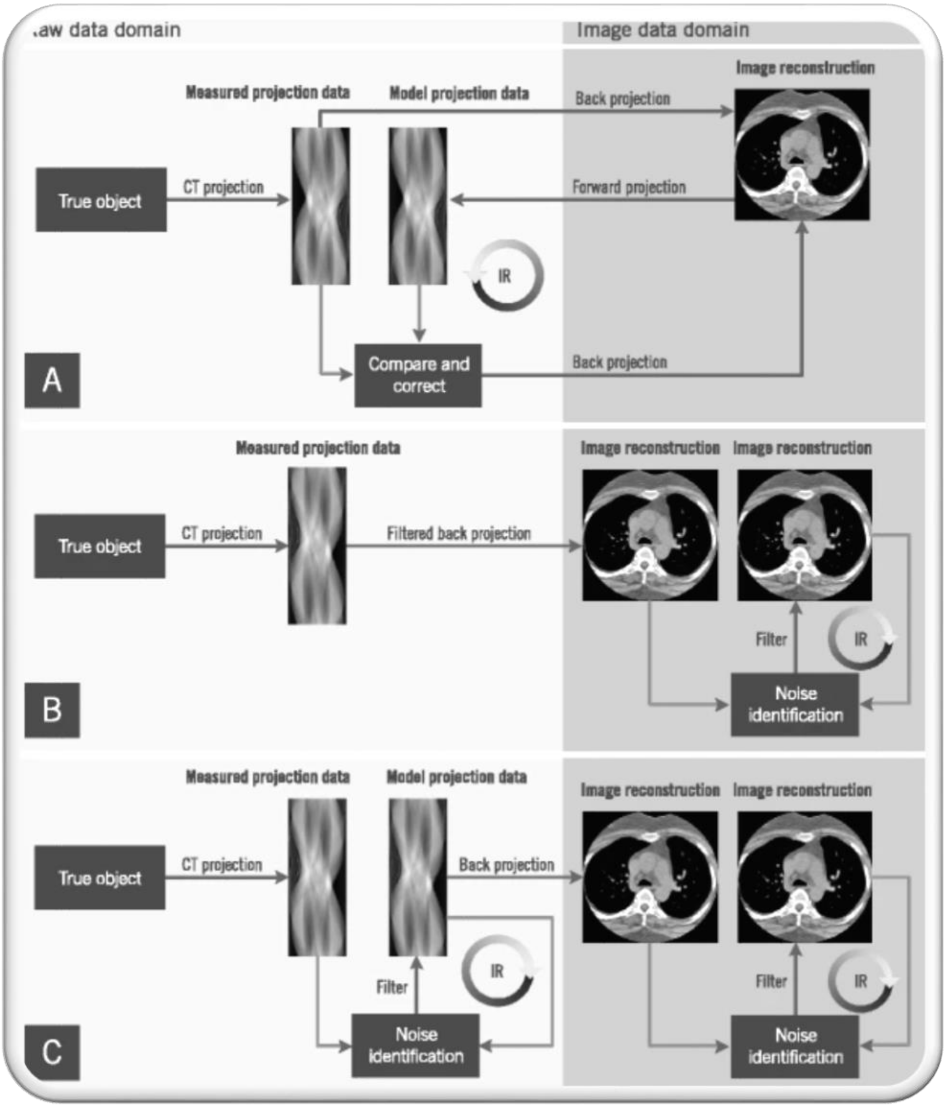
Chest CT = 1500/-500 (air Radiodensity)

- **Ww** Range = -1250 to +250 HU **wl** centred at -500 HU
- Gradations: Each 1500/16 or 94 HU displays a different shade of grey on the screen

Bone CT = 2000/250 (bone Radiodensity)

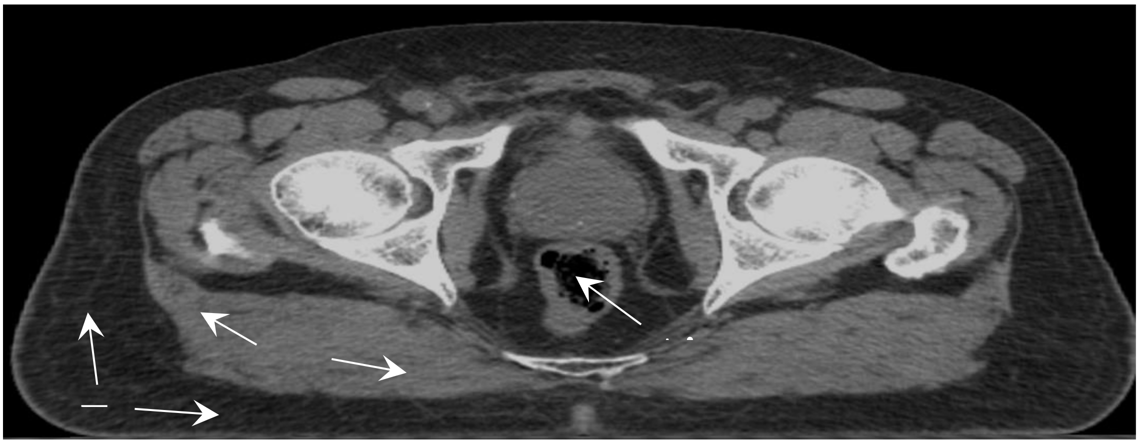
- **Ww** Range = -750 to +1250 HU **wl** centred at +250 HU
- Gradations: Each 2000/16 or 125 HU displays a different shade of grey on the screen

Scan Type	Window Width (WW)	Window Level (WL)	Why It's Important
👤 Brain	80–120	~40	Good for showing soft tissue detail in the brain (e.g., edema, hemorrhage).
🦴 Bone	1500–2000	250–500	Needed to show very dense structures clearly.
🫁 Chest/Lung	1500	-500	Wide window to show both air and soft tissue contrast.
🫁 Soft tissue (Abdomen)	350–400	~50	For distinguishing between liver, kidney, muscle, etc.
🩺 Mediastinum (Thorax)	350	40	Similar to abdomen — often used in trauma or cancer staging.

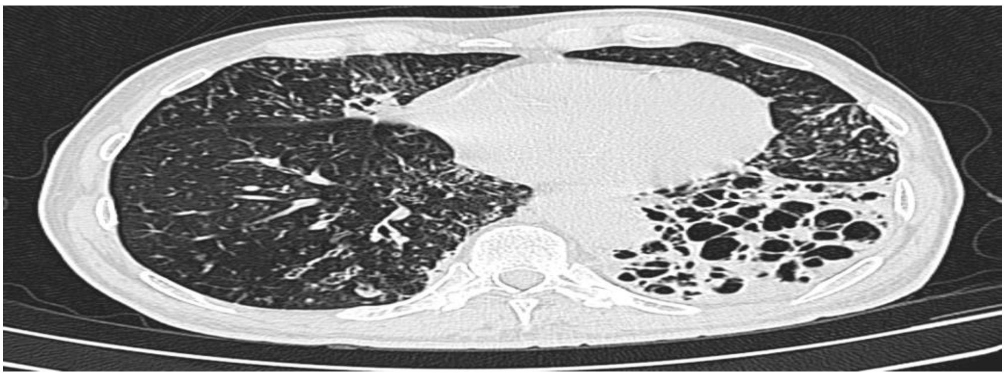


Viewing CT Images

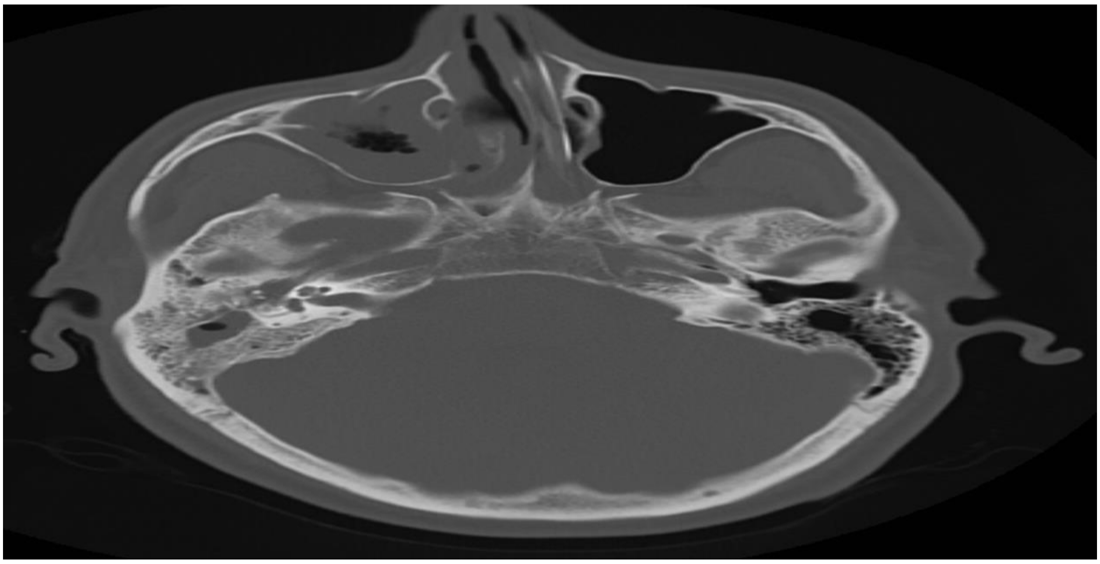
Soft tissue Window



Lung window



Bone Window

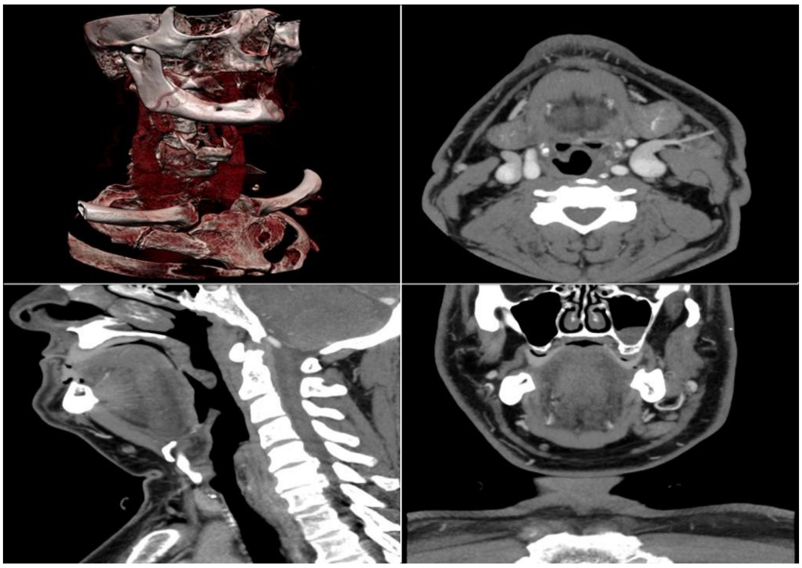


Brain window

- Cystic meningioma

Multiplanar reconstruction

- Images are required in the axial plane only



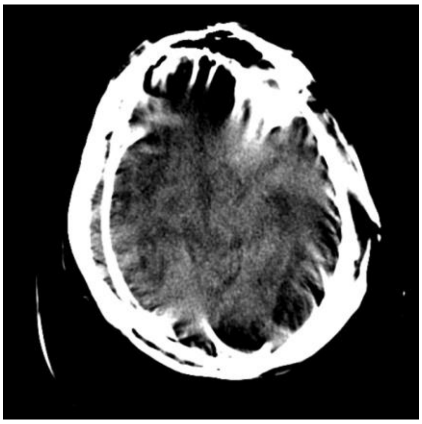
CT Artefacts and revision

- Scout uses a little dose, more important to get the correct exposure factors before carried out the scan
- Contrast we will need a higher Kv – iodine has a high atomic number

Definition of an artefact

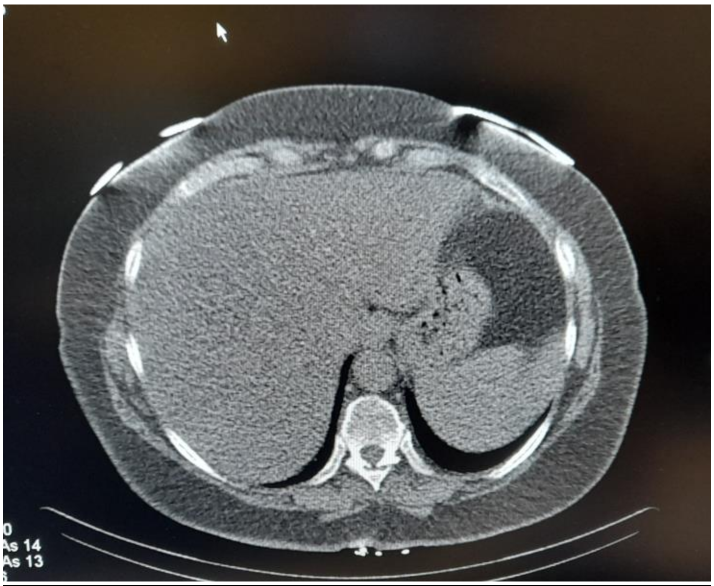
An image artefact is anything appearing on a image which is not present on the object being scanned'.

Categorise artefacts into three different groups;
- Patient
- Physics
- Scanner

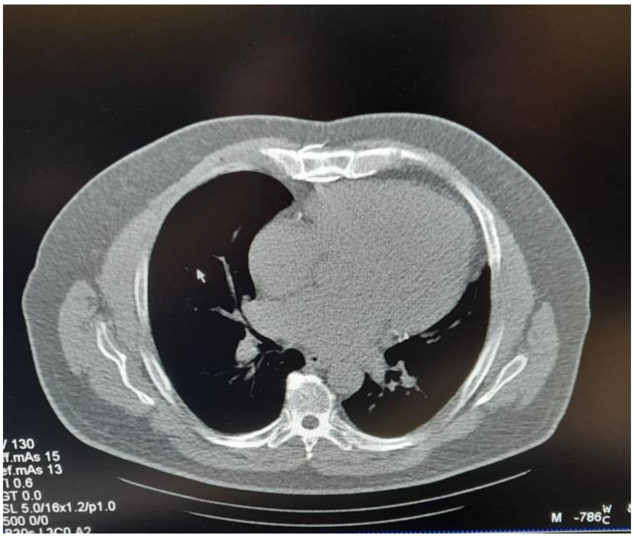


- Motion artefact
- Double edges

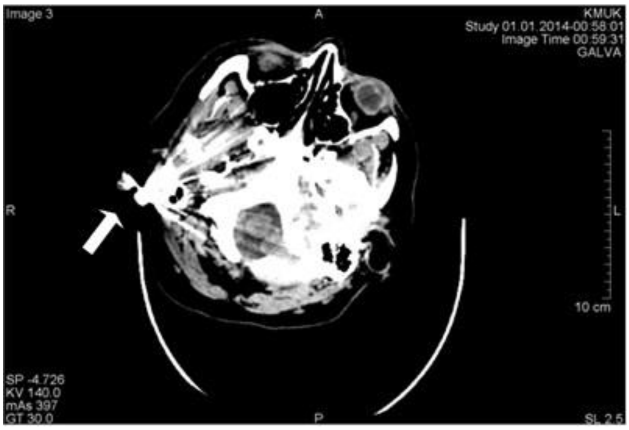
Solutions to motion artefacts?
- Immobilisations
- Carer or supporter
- Sedation, post feed.
- Step and shoot
- Faster scans
- Time of day



- Bra straps

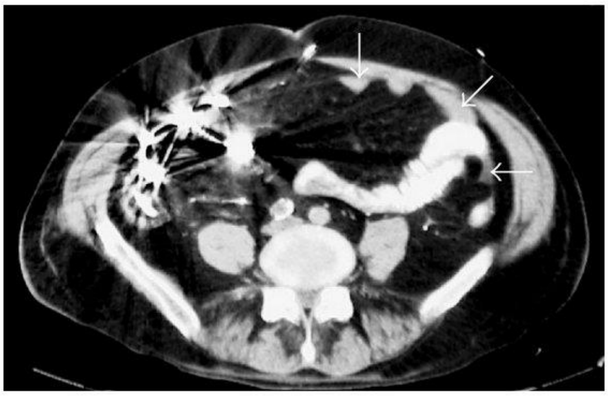


- Metal on sternum after open heart surgery



- Pulse oximeter on ear
- Streak artefacts – lost signal

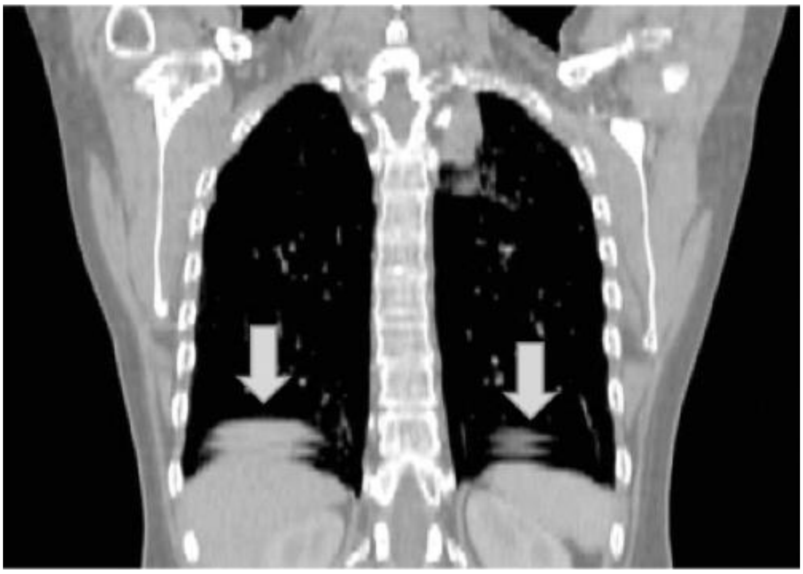
- Belly button piercing – streaks – loss of signal

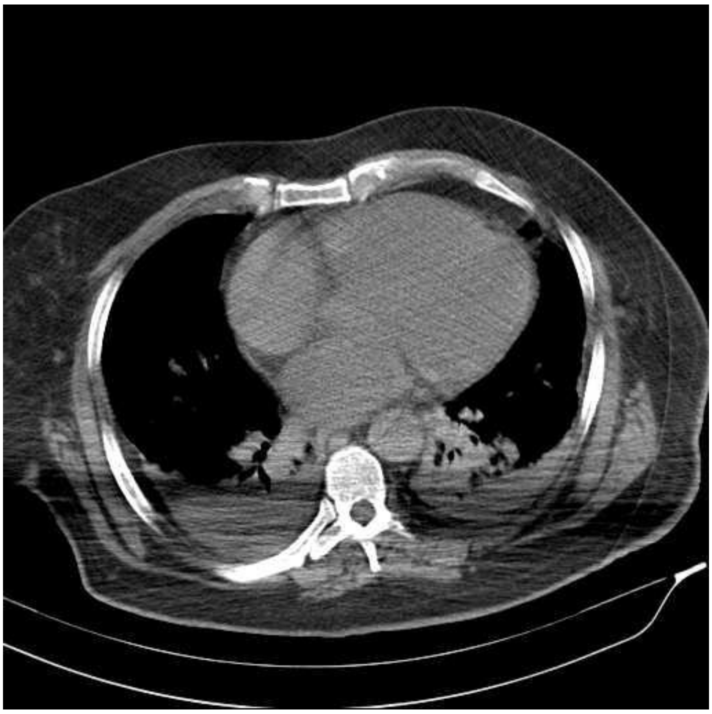


- Contrast in small bowel
- Barium sulfate another procedure prior to the CT scan

<u>Solution</u>

- Shouldn't be CT patient 10 days post barium swallows
- Plain abdomen x rays
- Use of laxatives
- Diverticular disease – barium can get stuck in the pouches
- Scout view





- Patient has had scan with arm by there sides called photon starvation

Solution to Beam Hardening Artifact

- Remove all radio opaque objects from the field of view where possible
- Arms up
- Remove belts, underwired bras, jewellery, piercings
- MPR can support Radiologists
- Using thicker reconstruction slices decrease the noise
- Make sure kV, noise index and mAs appropriate. ?High kV through base of brain

Metal Artifact Reduction Software

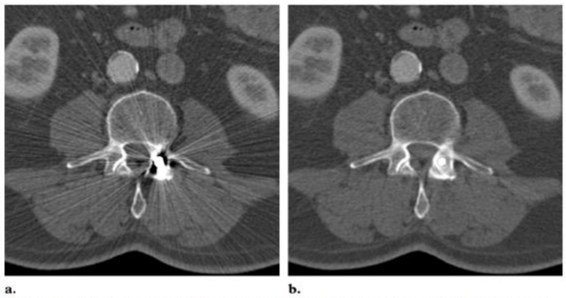
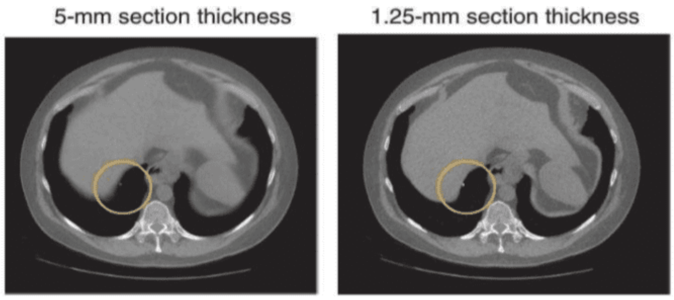


Figure 15. CT images of a patient with metal spine implants, reconstructed without any correction **(a)** and with metal artifact reduction **(b)**. (Courtesy of Siemens, Forchheim, Germany.)

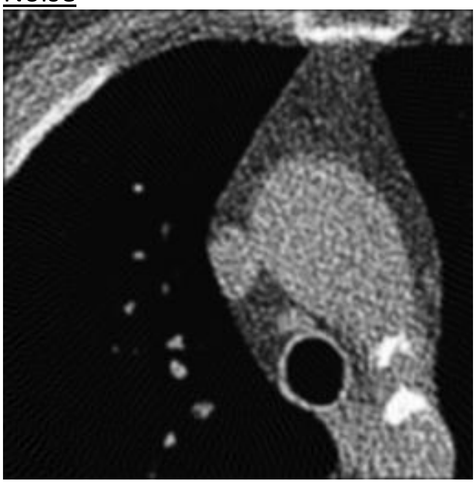
Partial voluming



Solution

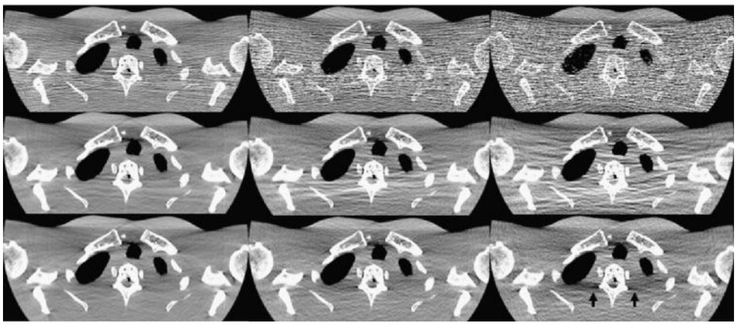
- Use thinner slices in the reporting images
- Use MPRs to clarify confusing appearances

Noise



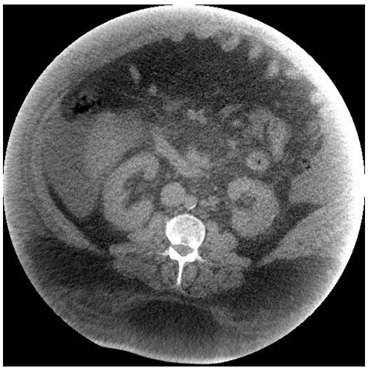
- Increase number of photons at the detector i.e. Increase mAs.
- Pitch
- Remove FBs
- Review thicker slices
- Select appropriate recon algorithm

Photon starvation



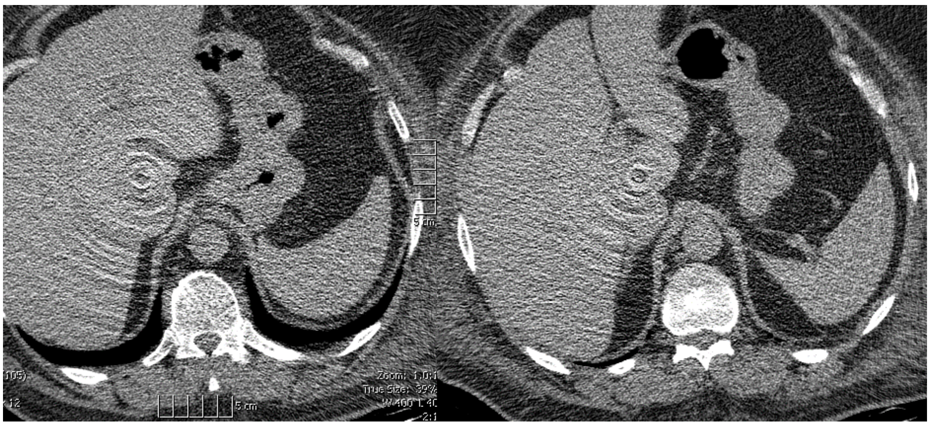
- Increase kV
- Arms up

<u>Truncation Artefact</u>

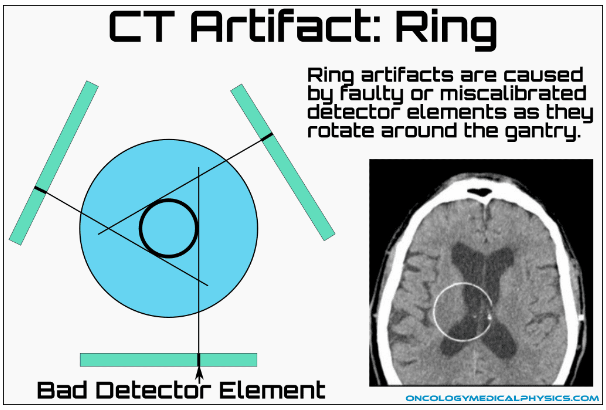


- Not in the scan field of view
- Use extended FOV if possible / available
- Peripheral HU units may not be accurate
- Difficult in interventional cases

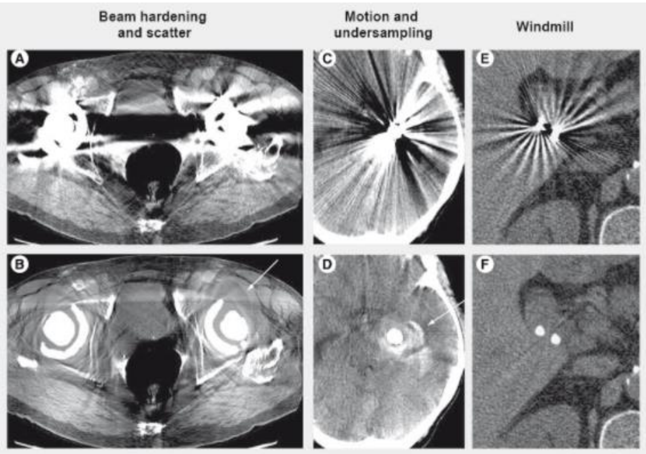
<u>Ring artefact</u>



- The scanner



- Call field engineer and do not use until rectified
- Sometimes visible on scout/ topograms as line in the z axis. If seen, stop before axials or helicals are performed.



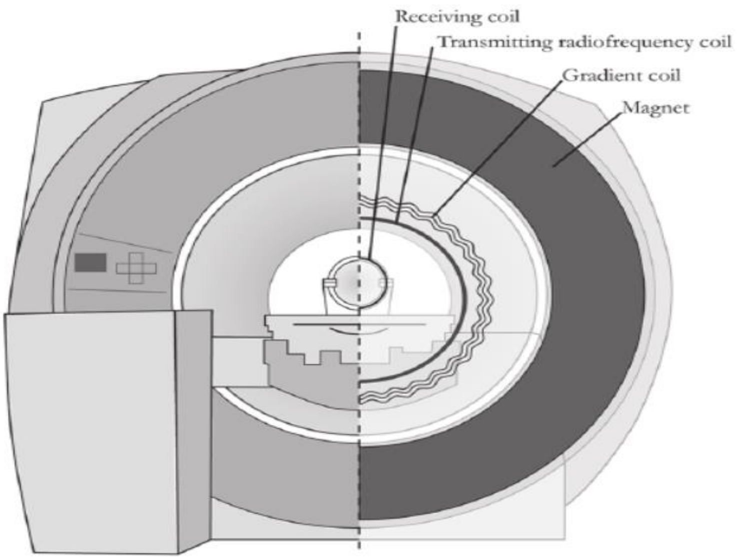
Introduction to MRI

What is MRI?

- Magnetic Resonance Imaging
- 3D imaging using magnetic fields 10,000-60,000 times stronger than the Earth's magnetic field.
- Utilises the properties of hydrogen protons within the body and their interactions with magnetic fields and radio waves to produce signal, which is collected and used to produce an image.
- Constantly developing, area of advanced practice.

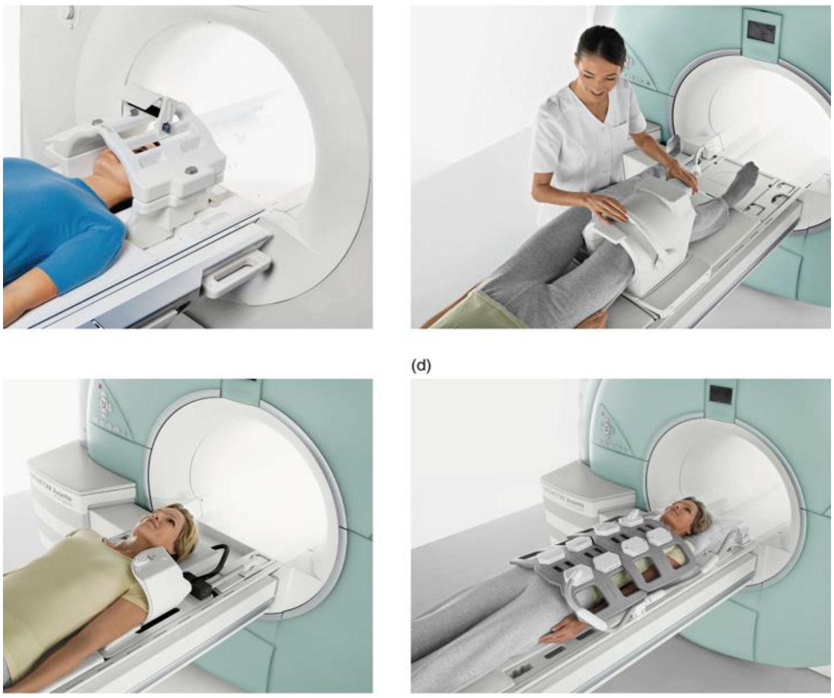
MRI Equipment

A 3T clinical MR system (Runge, Nitz, & Heverhagen, 2018)



Components of an MR System (Runge, Nitz, & Heverhagen, 2018)

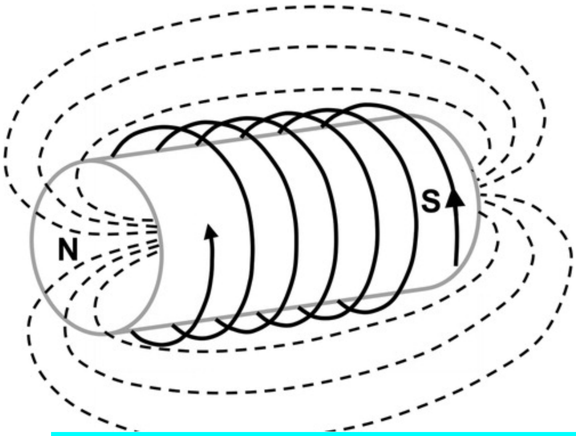
<u>MRI equipment Coils</u>



- Different types of coils, to be placed around the area being imaged. These will detect the MR signal (McRobbie et al, 2017)
- These collect our signal, but the signals produced by MRI are very small, and so we need our receiver coils to be as close as possible to be able to detect it.

The Magnetic Field (B_0)

- Loops of wire within the MRI machine have a current passed along them, this produces a magnetic field.
- Most MRI machines contain superconducting magnets. This means that there is no resistance along the wires. To achieve this, the wires must be kept very cold (-269˚C) which requires liquid helium for cooling.
- Magnetic field strength measured in Tesla (T). 1.5T and 3T MRI machines are most common clinically.



- Loops of wire are shown by the solid black line
- Dotted lines are the magnetic field.

Hydrogen atoms

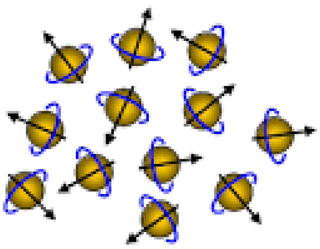


Figure 1

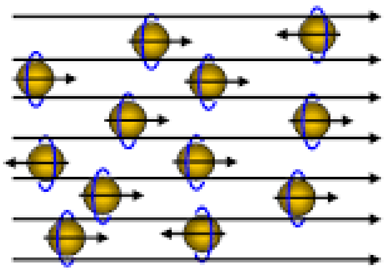


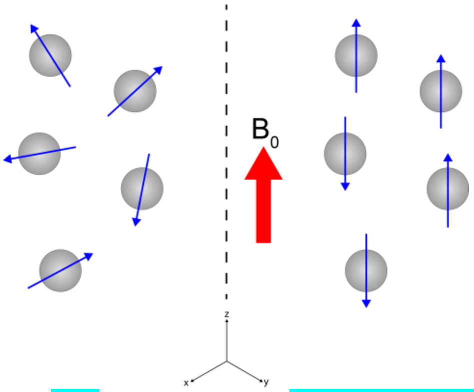
Figure 2

- Hydrogen atoms are used in MR imaging because they are the most common atoms within the body and contains a single proton within the nucleus.
- This spinning charges particle produces a small magnetic field, known as a "magnetic moment".
- These protons are orientated randomly.
- we use hydrogen atoms within MRI imaging. This is because they are the most common atoms within the body.
- They contain a single proton within the nucleus. They produce their own small magnetic field.

- Normally, our protons are orientated randomly, like the atoms demonstrated on the left hand side of the image.
- As well as pointing in all directions, these protons will spin on an axis and the same speed but not uniformly/in phase. They will also precess in a circular motion.

Precession

- Precession refers to the wobbling or circular motion of a spinning object for example the magnetic moments of hydrogen atoms when placed in a magnetic field. This precession occurs at a frequency known as Lamor



- Normally our protons "precess" (wobble) at different rates and point in all directions.
- When we apply a magnetic field, all of these protons line up (parallel or anti-parallel) longitudinally in our body.
- Their "wobbles" are still random.
- The magnetic field does affect precession, in that it increases the "wobbles". This higher the magnetic field strength, the higher the frequency of procession.

- These atoms will be doing this at slightly different rates. When we put a patient into an MRI scanner, their protons will align with the magnetic field.
- Protons with low energy will line up parallel, whilst higher energy protons will line up anti-parallel.
- They all remain within the same longitudinal plane, but some are upside down.
- There are far more protons lined up in the parallel direction, and so the net magnetisation is still stronger in this direction.

Lamor frequency

- The frequency of precession (w) is the number of wobbles over a period of time.
- This is also known as the Lamor frequency.
- $w = B_0\gamma$
- γ is the gyrometric ratio, which is our constant of proportionality.

Nucleus or Particle	Gyromagnetic Ratio (γ) in MHz/Tesla
^{1}H	42.58
^{3}He	-32.43
^{13}C	10.71
^{19}F	40.05
^{23}Na	11.26
^{31}P	17.24
electron	-27,204

- The lamor frequency is the frequency of procession, so how fast these protons are moving in that circular motion.
- We can calculate this with the lamor frequency, shown on the slide.
- Essentially, the frequency of precession, indicated by the lower case omega, is equal to the strength of the magnetic field multiplied by the gyrometric ratio.
- The gyrometric ratio is a constant and is different for different elements. We are only looking at hydrogen, and so looking at the table we can see that the constant is 42.58.

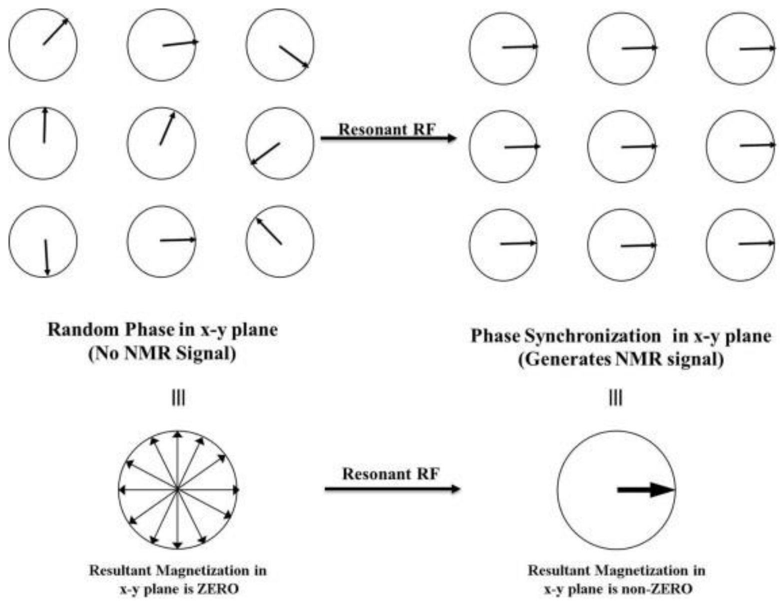
Resonance

We tune Radiofrequency waves (RF) to the processional frequency of the hydrogen atoms. This matching of the RF and processional frequency is called resonance

	Type of radiation	Wavelength (m)	Frequency (Hz)
	Radio	10^{3}	10^{4}
	Microwave	10^{-2}	10^{8}
	Infrared	10^{-5}	10^{12}
	Visible	0.5×10^{-6}	10^{15}
	Ultraviolet	10^{-8}	10^{16}
	X-ray	10^{-10}	10^{18}
	Gamma ray	10^{-12}	10^{20}

- We have now covered what happens when we stick someone into the bore of an MRI scanner.
- Now, we need to create signal.
- We do this through firing radio waves into our patient.
- These radio waves are tuned to the same processional frequency as our hydrogen atoms, using the previously discussed lamor equation.
- This tuning of the radiowaves (or RF waves) is called resonance.

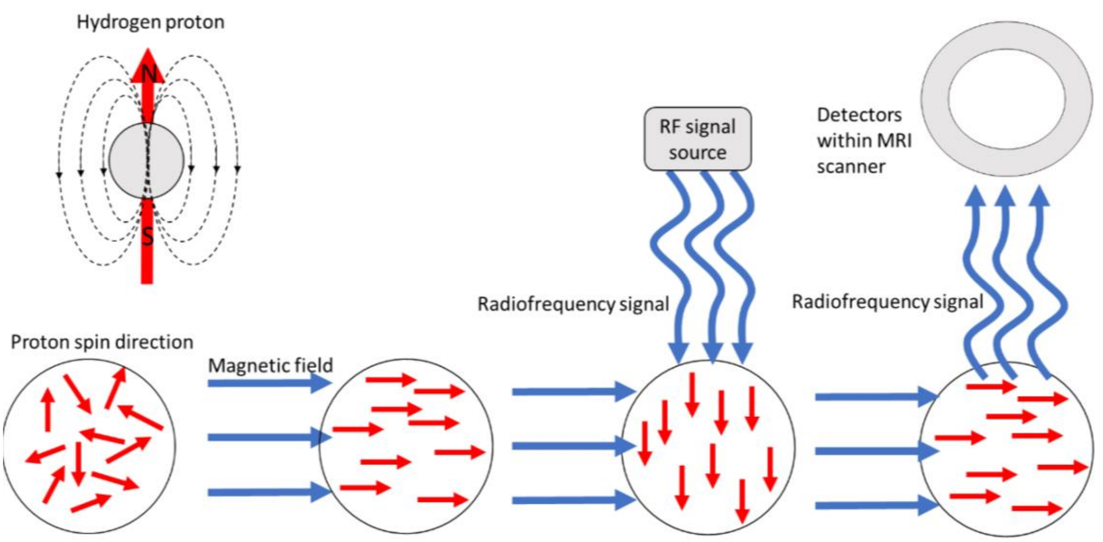
Radiofrequency



- We fire an RF pulse at the area we are imaging.
- When the frequencies match, the nuclei of the cells absorbs this energy and the proton is flipped through a 90 degree angle
- This transfers the proton from the longitudinal axis to the transverse axis
- This also makes the protons precess at the same time or 'in phase'

Relaxation

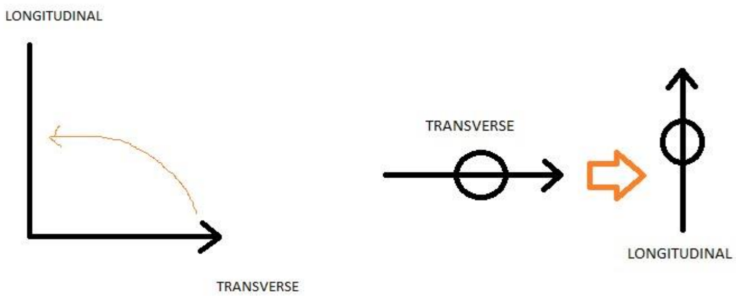
- After the RF pulse is turned off, the protons are once again affected by the magnetic field and will gradually realign with it. This process is known as relaxation. When the protons become out of phase again and go back into the longitudinal plane, they will lose energy, this energy is our signal.
- Relaxation: "The gradual increase in magnetisation in the longitudinal plane after the radiofrequency pulse."
- There are two processes occurring during relaxation – T1 recovery and T2 recovery



- Our protons initially line up randomly, we stick someone in the bore of the magnet, and the protons line up in the longitudinal plane.
- We fire an RF pulse, and these protons are knocked 90 degrees into the transverse plane, and when we turn this off, the protons realign with the magnetic field
- As our protons realign, they give out the energy they absorbed from the RF pulse. It is this energy that we collect as a signal, and this is done by the coil we have placed around out area of interest.

T1 Recovery

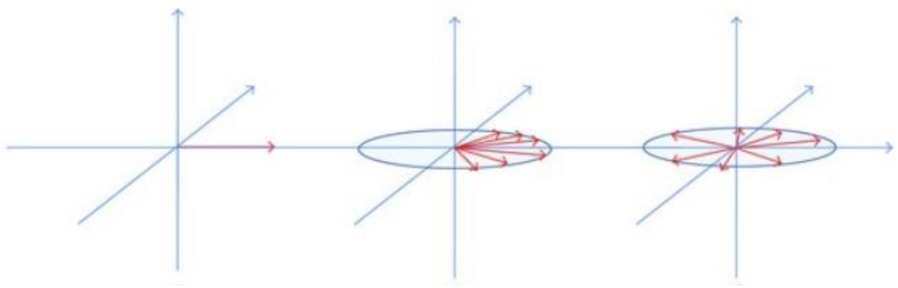
- Also known as "spin-lattice relaxation"
- "The time taken for the recovery of 63.2% of the net magnetisation to the longitudinal axis"
- This is where the proton moves from the transverse axis back to the longitudinal axis.



T2 Recovery

- Also known as "spin-spin" relaxation
- "The time taken for the net transverse magnetisation to decay to 36.8% of its original value".

- This is loss of phase coherence, where the spins or “wobbles” will become different for each proton again, and they will begin to misalign.



- T2 recovery is also known as spin spin relaxation. This is because it is to do with the precession of the protons. We know that the spins are different with the protons normally, they remain different or “out of phase” when we put the person in a magnet, the only thing that changes is they all point in the same direction, but when we shoot an RF pulse at them they all spin at exactly the same time, they become in phase. When this RF pulse is switched off, they become out of phase again, and this also releases energy. This is the T2 recovery. The definition of this is “”.

the time taken for the net transverse magnetisation to decay to 36.8% of its original value

Image formation

- When these protons begin to relax back, they give out the energy absorbed by the RF pulse.
- This energy is detected by the coils, and read as a signal.
- These RF pulses will be switched on and off multiple times throughout the examination.

Parameters - TR and TE (image quality)

- TR – “Repetition time” – the time between sequential applications of the RF pulse.
- TE – “Echo time” – the time interval between the application of the RF pulse and the moment when signal is detected in the receiving coil.
- These times can be changed to give different weighting in images (e.g., your T1 and T2 weighted images).

How we create our “weighted” images, is through changing our parameters such as the TR and TE.

Identifying different tissue types

- Different tissue types will have different numbers of hydrogen protons
- Different tissues will also have different structures, whereby the hydrogen atoms are more tightly or loosely bound.

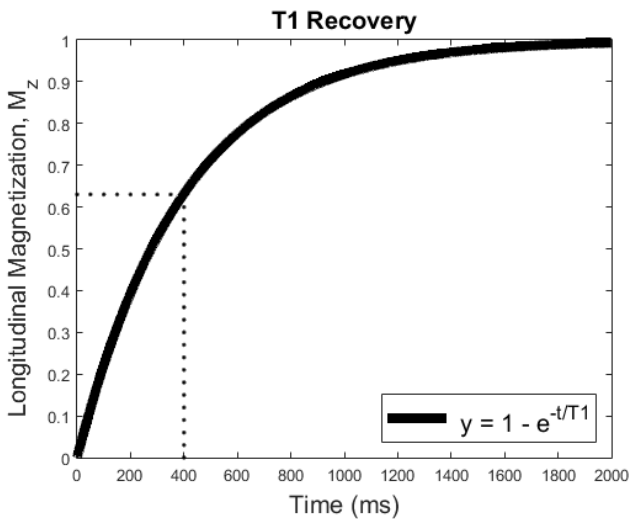
- This will change the amount of signal received in both the quantity (more atoms, more energy absorbed by the RF pulse, more energy released during relaxation).
- This will also change the speed of which this energy is released. If atoms are close together, they will become out of phase quicker as they will interact with each other's magnetic fields, or bump into each other to lose coherence. This is more related to T2 relaxation.
- if the hydrogen atom is tightly bound to other atoms, it may mean it is really hard for the atom to move from the transverse plane back to the longitudinal plane.

Image weighting

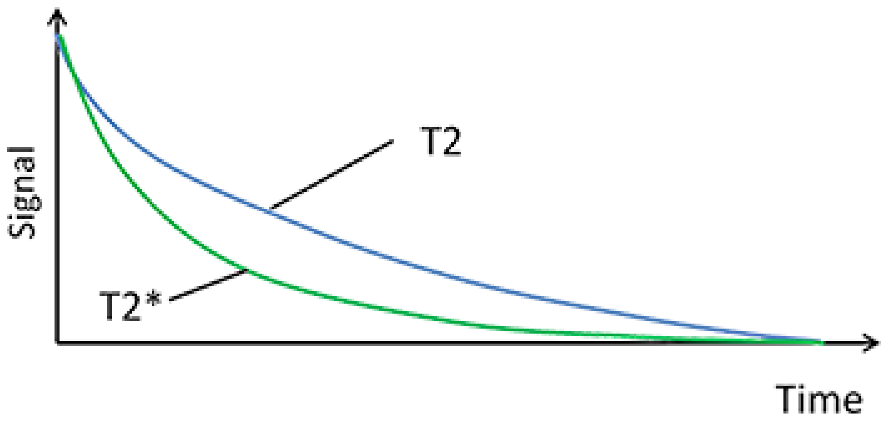
- We can therefore alter TR and TE to change the amount of signal a specific tissue type will give us.
- Brightness on an image shows greater signal, and is called hyperintensity.
- Darkness on an image shows reduced signal, and is called hypointensity.

T1 Weighting

- Requires a short TE and TR
- Water has a slow longitudinal magnetization realignment after an RF pulse.
- With a quick TR and TE, not a lot of protons would have realigned with the longitudinal axis and released energy.
- Thus, water has low signal and appears dark (hypotintense).

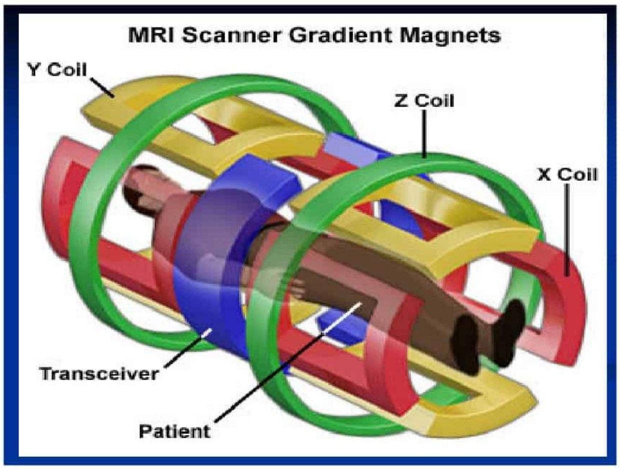


T2 Weighting



- Requires Long TE and long TR
- The interaction between water spins is weak, which means that the T2 is relatively long. We essentially need to wait longer to ensure that there has been decay, for signal to be detected from fluid and appear bright.

Magnetic Field Gradients



This is another part of our MR scanner.

- There are 3, one in the x direction, one in the y direction, and one in the z direction, which are essentially like our axial, sagittal and coronal planes.
- These turn on and off during a scan, and are what cause the loud booming noise.
- Essentially, these create slight variations in the magnetic field, slightly changing the precessional frequency of the atoms, which allows us to identify exactly where the signal is coming from. This gives us the spatial data.
- The data acquired from these gradients is combined with the data acquired from our release of signal, to be mapped on a grid to produce our image.

Advantages and Disadvantages of MRI

Advantages
Superior soft tissue imaging
Non-ionising
Fantastic alternative for patients not suitable for other imaging e.g. CT.

Disadvantages
Safety considerations
Long scan times – claustrophobia, pain etc.
Lots of patients with contraindications
Expensive
Long wait times for scans currently

Proton Weighted Density

- Proton density (PD) is the most basic MRI measure, representing the apparent concentration of water protons (mobile hydrogen atoms) in each voxel.
- Useful for high contrast areas such as joints
- Using long TR times (>1000ms) to allow full T1 recovery and very short TE times (< T2) to minimize T2 contrast.
- Used regularly in the assessments of joints

Other common sequences

- FLAIR – Fluid Attenuated Inversion Recovery - Sequence that produces strong T2 weighting, suppresses the CSF signal, and minimises contrast between gray matter and white matter. Enhances the visibility of lesions.
- STIR – Short Tau Inversion Recovery – Highly water sensitive with suppressed signal from fatty tissues. Essentially a T1 with fat suppression.

Contrast in MRI

- All contrast in MRI is created on the basis of the T1 relaxation values, T2 relaxation values, and number of protons within tissues.
- We alter the speed in which we send in RF pulses (TR), and how quickly we read these signals (TE), to show the different relaxation times of different tissues.

Viewing our images

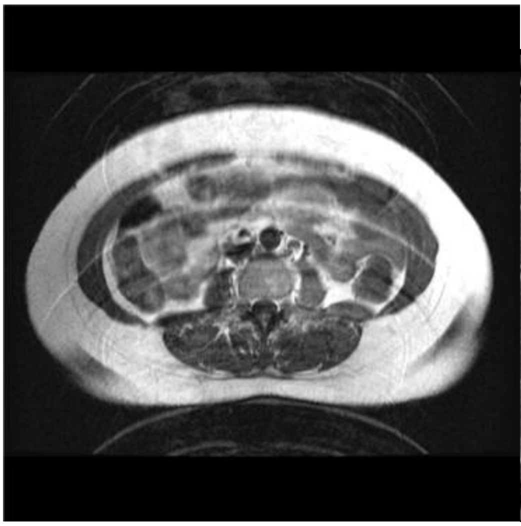
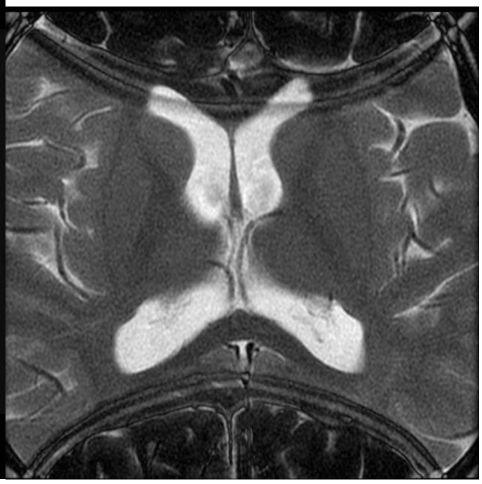
- The signal information from the receiver coils, and the spatial information from the gradients will be combined within k-space.
- This is used to map out which signal intensities are coming from where in the body onto a matrix.

Contrast Agents

- Most commonly used contrast media is gadolinium.
- Provided intravenously
- Causes shortening of T1, T2 and T2* relaxation times.
- Injection-site discomfort, nausea, itching, rash, headaches, and dizziness are the most prevalent adverse effects.
- Patients with significant renal issues are more likely to experience serious, but uncommon side effects, including gadolinium poisoning and nephrogenic systemic fibrosis

Imaging Artefacts

- Movement artifact (MOST COMMON)
- Wrap (aliasing artifact) - occurs when the field of view (FOV) is smaller than the body part being imaged.
- The part of the body that lies beyond the edge of the FOV is projected onto the other side of the image
- There are many more but these are the most common.

- The first is motion artifact, this one is from someone breathing.
- The second is Aliasing or wrap around is caused by setting a field of view that is too small. We then have anatomy overlying other anatomy, and it is caused when there is a mismatch between the spatial and signal information being put together due to the fov being too small.

MRI Safety Lecture

Safety risks can be split into four areas of interest

- Static magnetic field
- Radiofrequency
- Gradients
- Miscellaneous

Static Magnetic field – projectiles

- Any ferrous metals, meaning anything that contains iron, will be pulled towards the magnet, turning it to a projectile.
- The strength of the magnet increases exponentially the closer you get to the magnet.
- This is potentially fatal consideration within MRI.

Static Magnetic Field – Metal Implants

- Some may be affected by torque – this is where the magnetic field forces metallic items to align with the magnetic field, which can produce a twisting motion. aneurysm clip within the brain, this could cause a bleed.
- cardiac pacemakers, stents, aneurysm clips, prosthetics etc.

Radiofrequency burns

- Burns
- These are the number 1 adverse safety event reported due to MRI scans.
- These can appear immediately, or take days to develop.
- These can be caused by the creation of "loops", essentially creating a circuit. This can be with parts of the body, such as feet or hands touching, from the patient touching the bore of the magnet etc. It can also be from skin touching metallic components, such as metal fibres within clothing (lululemon) or within tattoos/ permanent makeup etc.

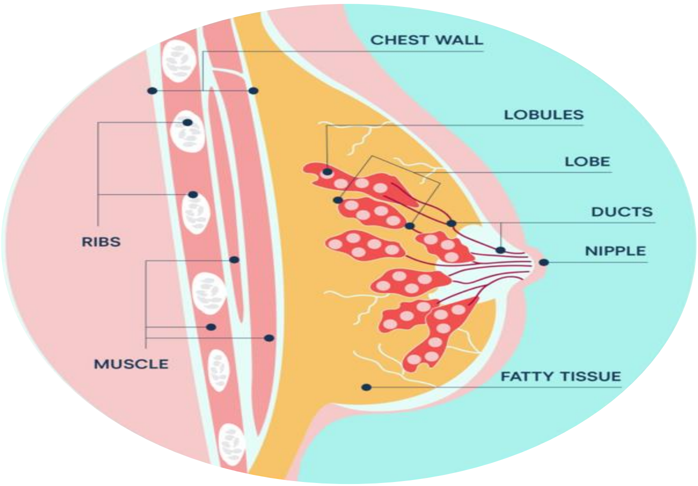
Gradients

- PNS – peripheral nerve stimulation
- - Rapidly changing magnetic fields of gradient coils can induce electric fields in human tissue causing stimulation of peripheral nerves which can feel like pins and needles within the limbs. This is not fatal but it is an uncomfortable sensation.
- Acoustic noise – the booming sound that you can hear within the MRI department is the changing gradients, this acoustic noise can cause hearing damage.

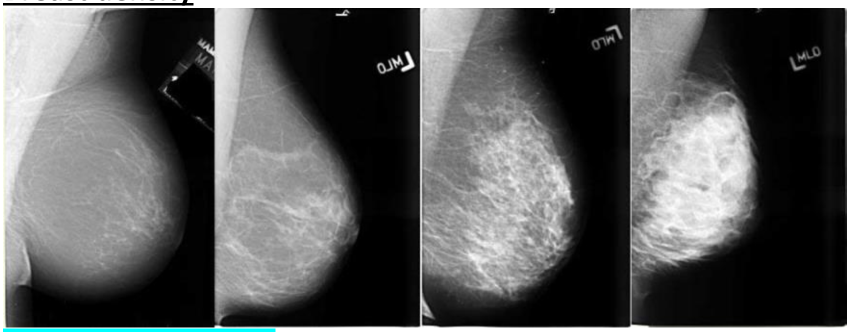
Breast Anatomy and Physiology

Female breasts comprise of:

• Lobules •Ducts • Fatty (adipose) tissue • Connective (fibrous) tissue



Breast density



Left – adipose breast
Right – glandular breast

What is Mammography?

A mammogram is x-ray imaging of the breast.

They can be used in 2 ways:

- To check for breast cancer in women who have no signs or symptoms of the disease. (SCREENING PATHWAY)
- To check for breast cancer after a lump or other sign or symptom of the disease has been found. (SYMPTOMATIC PATHWAY)

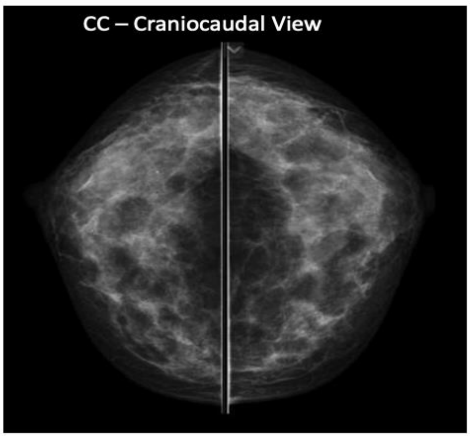
Modalities for Imaging breast tissue

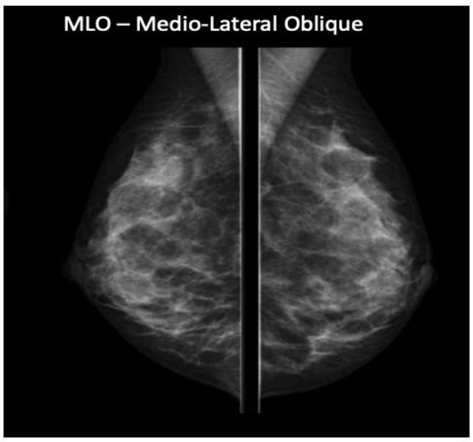
- Mammography;
- Digital Breast Tomosynthesis (DBT) (advanced form of mammography produces 3D images of the breast).
- Contrast Enhanced Spectral Mammography – highlights areas of increased blood vessel activity.
- Vacuum assisted Biopsy
- Ultrasound
- MRI

What are the main aims of mammography?

- To image the soft tissue of the breast to detect cancer.
- To be able to differentiate between adipose tissue, fibro glandular tissue, cancerous or non-cancerous masses and to visualise micro-calcifications.
- To keep doses ALARP

Standard Mammographic projections

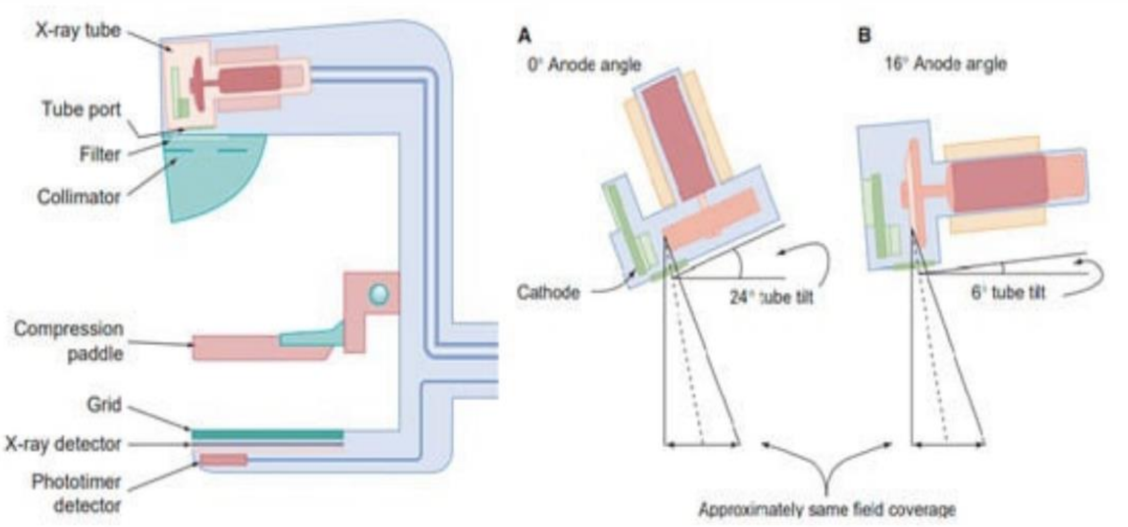




- Pectoral muscle should be shown down to the nipple to ensure all the posterior breast tissue and axillary region are fully included.

X-ray production in Mammography

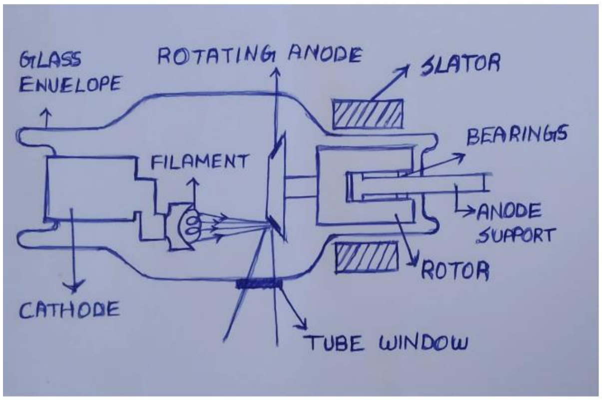
X-Ray Production in Mammography



- The tube port which tends to be made of Beryllium (Be) absorbs low energy photons that are unable to penetrate the breasts which will not contribute to the image quality, it will just create noise and increase radiation dose. Lets through those with higher energies.

Revision: X-ray Production

tps://www.youtube.com/watch?v=KEASC8UVAmM&t=218s



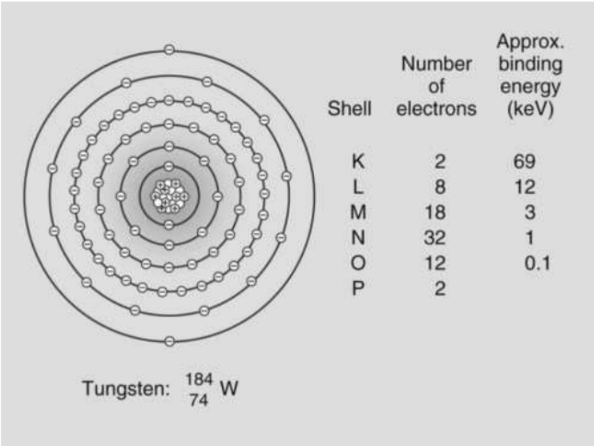
X-rays are produced when high energy electrons interact with atoms in the anode material.

Bremsstrahlung radiation

Characteristic radiation

They create diagnostic images based on the tissue attenuation differences.

Revision: X-ray Production



Using tungsten as an example:

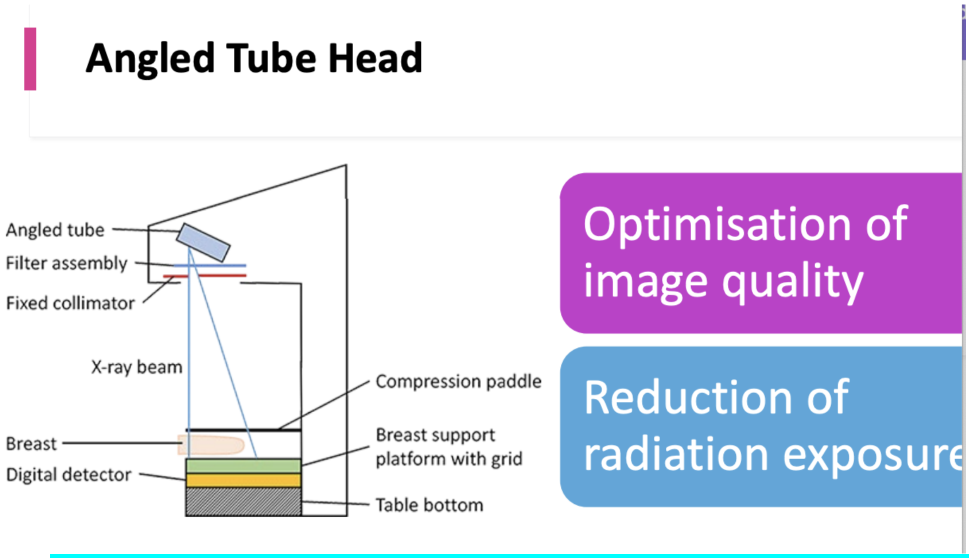
- K-shell energy = 69.5keV
- L-shell energy = 11.5keV
    - An electron moving from the L-shell to fill a K-shell vacancy in tungsten would produce a photon with energy approx. 58.0keV (69.5-11.5)

3 requirements for x ray production;

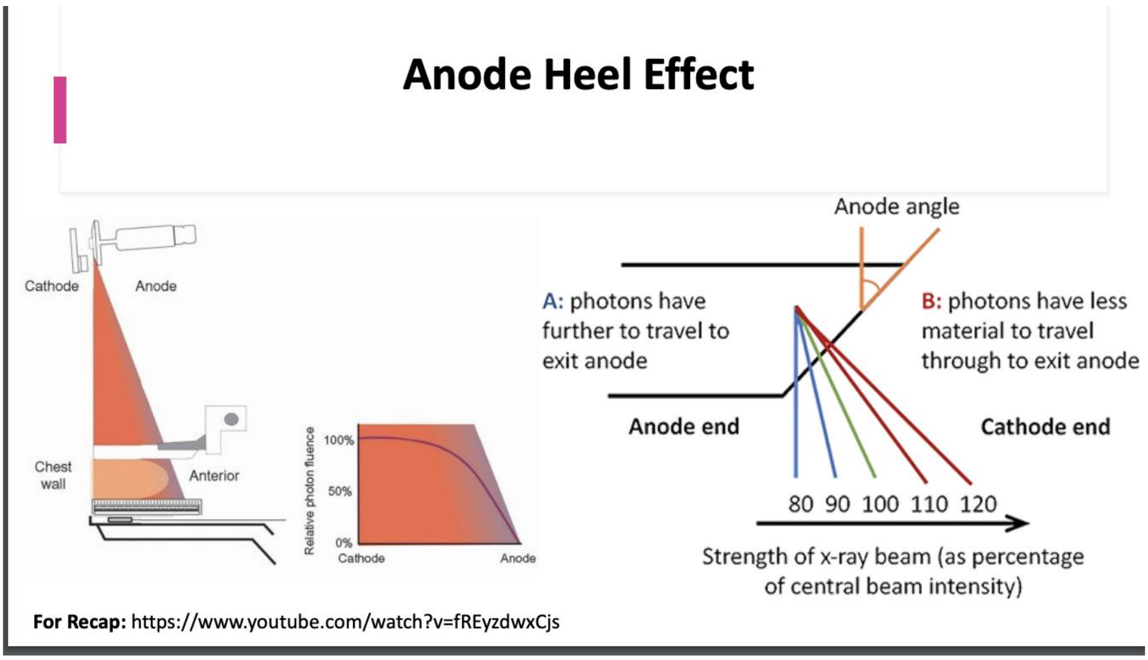
- source of electrons,
- acceleration of these electrons
- decelerating/deenergising these electrons.

<u>All three steps of x ray production happen inside the x ray tube;</u>

- Electrons are produced at the cathode filament, a process known as thermionic emission which is the release of electrons in the response to heat
- A current running through the filament causes it to become extremely hot, that electrons are dissociated from the metal and form an electron cloud around the filament
- A electrical voltage (kvp) is applied across the tube which causes the electrons to accelerate towards the positively charged anode.
- These highly energetic electrons slam into the anode of the x ray tube in the process of deceleration
- The number and energy of x rays are controlled by the operator by altering the exposure factors known as KVp and Mas.

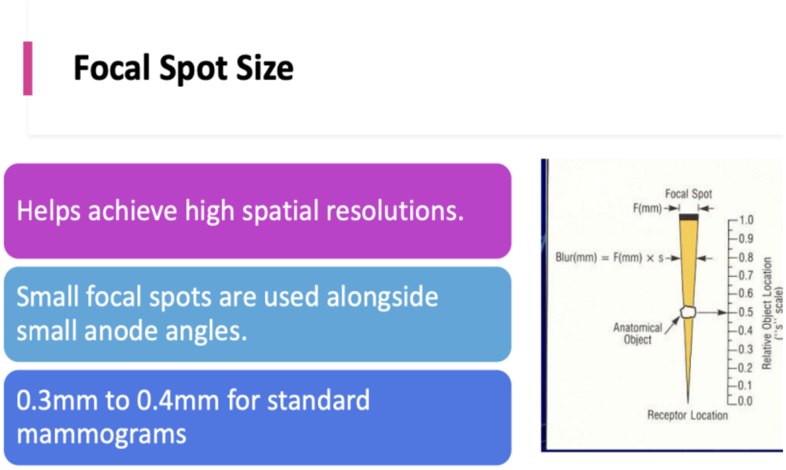


- In mammography angle tube head for image optimisation and reduction in dose due to anode heel effect

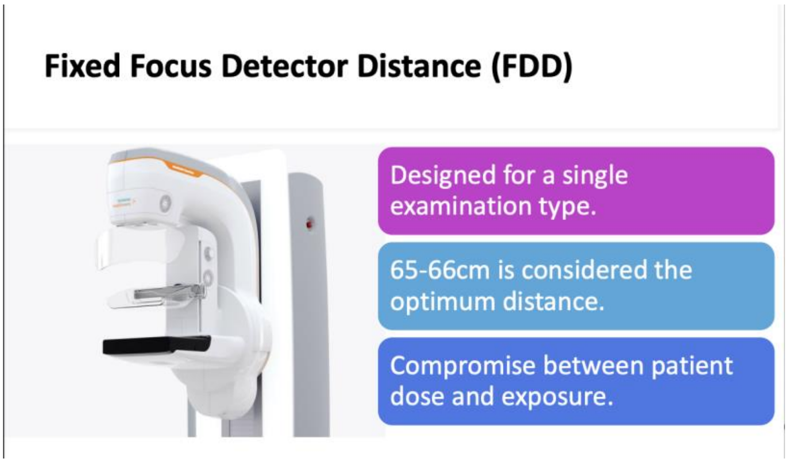


- The anode heals effect effects the intensity of the x ray beam
- The anode is usually angled between 6- 20 degrees
- The anode angle increases the surface area of the focal spot which increases the ability of the anode to absorb heat
- Decreases the effective focal spot size which increase spatial resolution
- The anode angle does have one negative as it causes a variation of the intensity of the x ray beam over the x ray field.

Focal spot size – the area of the anode struck by the electron beam.

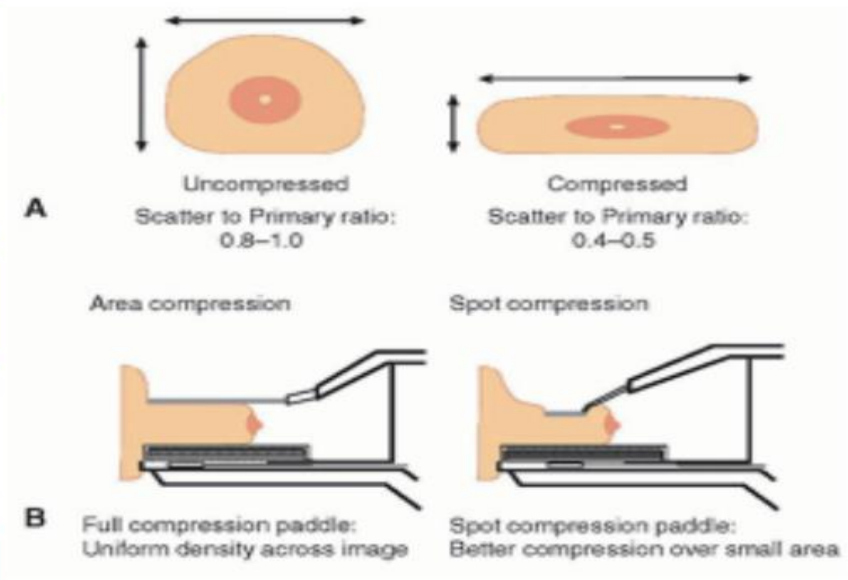


<u>C-Arm Design</u>



<u>Advantages of Compression paddle</u>

1. More uniform breast thickness.
2. Reduced blurring from patient motion.
3. Reduced scattered radiation and improved contrast sensitivity
4. Reduced radiation dose
5. Better visualisation of tissues near the chest wall.

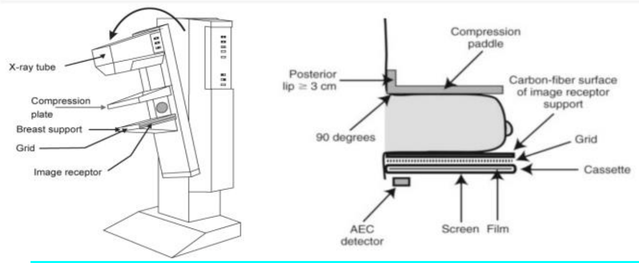


Fixed field Size

Fixed Field Size

- The field size is fixed to the paddle for example you would use different size paddles for different size breasts
- Collimation is then adjusted to the size of the compression paddle.

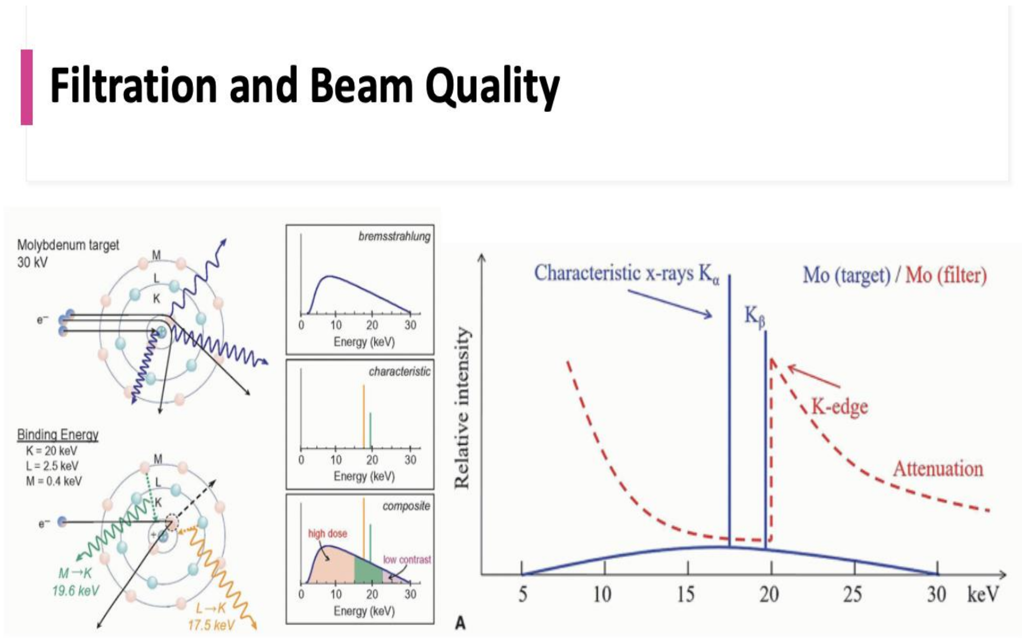
Grids



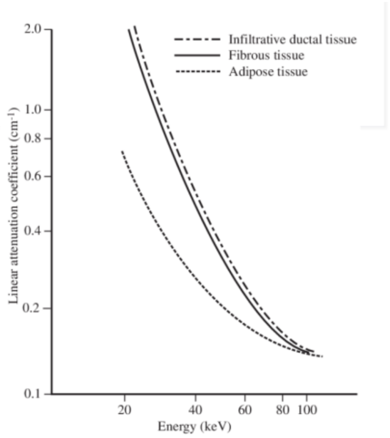
- Different sizes, the most common used grid is 5:1.

Filters and Beam quality

- In mammography we want our x rays beam to be unified because are going through one or two types of tissue
- We use molybdenum as our target, tungsten or rhodium
- They may be changed depending on thickness of the breast,
- molybdenum tend to be used for smaller breasts or rhodium for bigger breasts. More modern scanners use tungsten, it has a better life time.



Linear Attenuation Coefficient

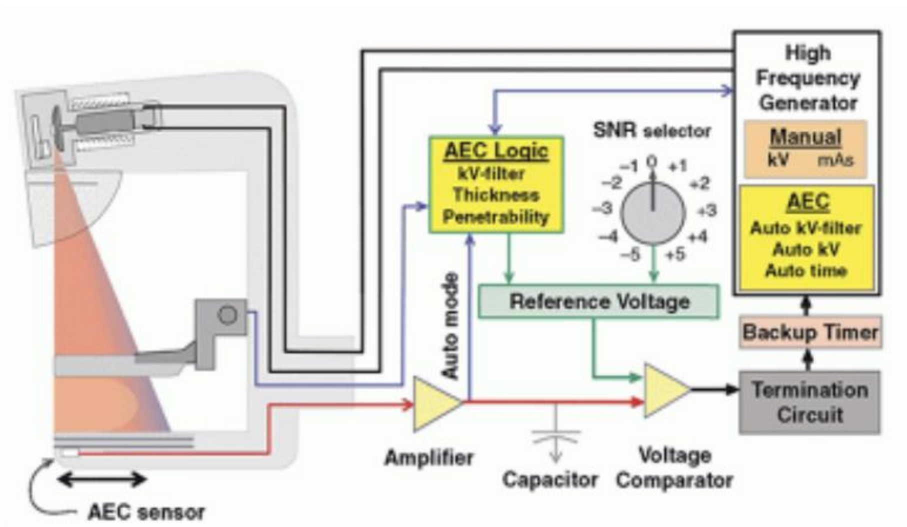


- Infiltrative tissue is our cancer tissue, we need use our lower keV, to differentiate between infiltrative ductal tissue and fibrous tissue

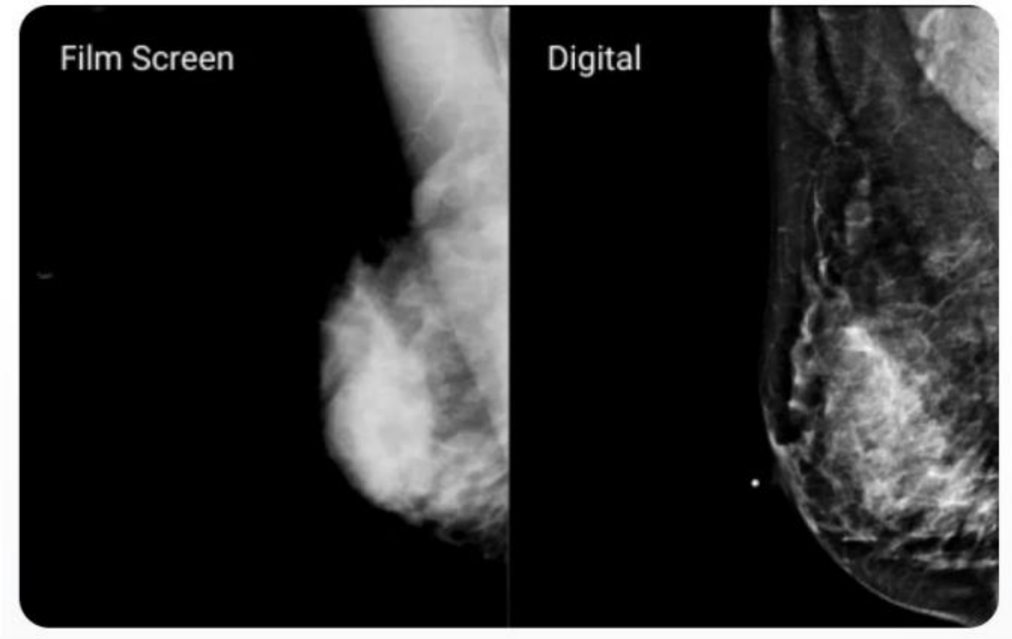
Automatic Exposure Control

3 Types of AEC options:

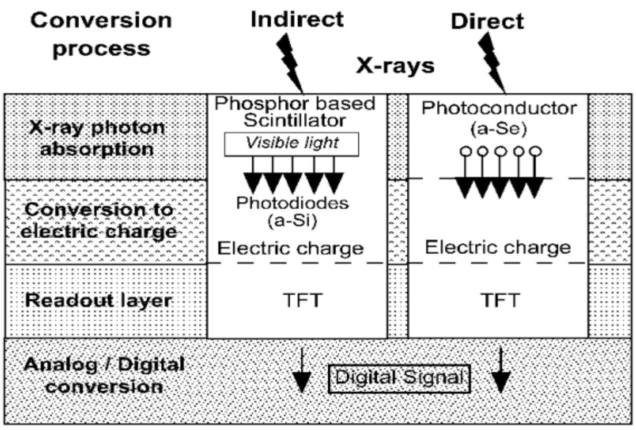
- Fully automatic AEC mode
- Automatic kV selection with a short test exposure
- Automatic time of exposure with manually set target, filter and kV values.



Full field Digital Mammography



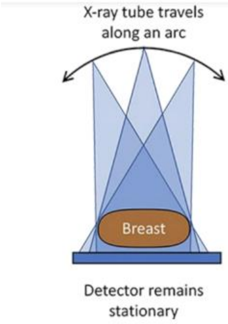
Detectors

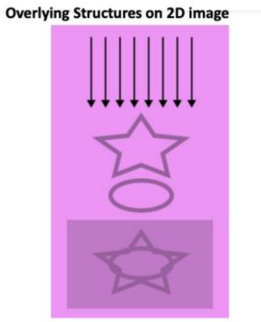


- Direct detectors use a photo-conductor to directly convert photons into electrical charges.

Digital breast tomosynthesis (DBT)

- Is an imaging technique that allows a volumetric reconstruction of the whole breast.
- Allows for the detection of a greater number of expansive lesion





Contrast Enhanced Spectral Mammography (CESM)

- CESM is based on dual-energy acquisition.
- The process is straight-forward - iodinated contrast is given (a typical dose is 100 mls of Omnipaque 300 at 3mls/second) via a cannula.
- Approximately 2 minutes later, the first images are acquired

Repeat Rates

MAMMOGRAPHIC IMAGE ASSESSMENT

Dates of Assessment: | Static/ Mobile

Assessor(s): | Clinic Code | Date Taken | Mammographer

Case No.	View	Correct patient ID & Markers		Appropriate exposure		Adequate compression to hold breast firmly - no movement		Image sharp		No artefacts obscuring image		No obscuring skin folds		Nipple in profile		MLO's: Pectoral muscle to nipple level		MLO's: Pectoral muscle at appropriate angle		MLO's: IMF shown clearly		CCs: Medial border demonstrated		CCs: Back of breast clearly shown with some medial central & lateral		CCs: Some axillary tail shown		Symmetrical Images	whole breast imaged	Comments
		R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L			
11	MLO																													
	CC																													
12	MLO																													
	CC																													
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Notes:No less than 20 exams should be reviewed, more if problems/trends are highlighted. No patient identifying numbers should be used. To view trends easily only place an X in boxes where criteria are NOT met

- Mammographers should minimise the number of repeats.

- This can include technical repeats (TPs) Or it can include technical recalls (TRs) Mammographers must undertake regular audit.
- Practice should be reviewed against unit, regional and national standards.

Common Artefacts in Mammography

- Patient related
- Detector related
- Equipment related
- Post-Acquisition related

Patient Artefacts

Blurring Skin Folds Jewellery/Medical Devices/ Clothing Antiperspirant or Skin creams

Detector Artefacts

- Ghosting
- Gouging
- Horizontal Line

Equipment Artefacts

- Dust or Dirt
- Collimator Misalignment
- Grid Lines
- Misplacement of the Grid
- Noise

Post-Acquisition Artefacts

- Breast within-the-breast
- Loss of edges
- Vertical processing bars
- High density

Quality Assurance

Consists of two parts;

- Quality Management (QM): to determine and implement quality policy.
- Quality Control (QC): operational activities necessary to fulfil the requirements for quality routine tests

Medical Physicists

Medical Physicists attend 6 monthly intervals

- To measure absolute values using calibrated equipment for comparison with national standards and commissioning values.

Radiographers

- Radiographers test daily, weekly, monthly
- To comparison with baseline to ensure consistency of performance

Quality Assurance

Ionising Radiation Regulations (Reg 32)

- Requires suitable QA programme to be in place for all x-ray equipment used for medical exposure
- Approved code of conduct special attention to be paid to equipment used in a health screening programme.

Ionising Radiation (medical Exposure) Regulation

- Radiation dose to patients from diagnostic x-ray equipment must be the minimum consistent with achieving adequate diagnostic accuracy
- Quality of each element of the imaging system needs to be assured

QA in Mammography

- Routine quality control is essential in mammography to ensure that equipment meets regulatory standards and is performing as expected.
- In the NHSBSP where we are screening asymptomatic clients, risk/benefit must be even more carefully considered – stronger duty towards optimization/safety
- We also have a greater responsibility to ensure our clients receive the right results – no false +ve/-ve
- overtreatment Symptomatic imaging benefits from high standards expected from the NHSBSP (same equipment)

Fundamentals of QA

Daily Tests	Weekly Tests	Monthly Tests
Signal to Noise Ratio	Uniformity/ Artefact Tests	AEC Thickness
Contrast to Noise Ratio	tor(MAM) phantom	Safety/Function Checks
Daily Monitor Checks	Stereo Target Accuracy	SMPTE/TG18-QC Monitor Test

Daily Monitor Checks

- Should be performed on acquisition and reporting monitors.
- To ensure the monitor is fit for purpose and free from any obvious defects
- The monitor is visually inspected for obvious faults such as dirt, scratches, flicker, distortion or artefacts.
- An additional optional test is to display a test pattern or standard clinical mammogram to check appearance.
- A record of all checks must be kept. If any issues are found, take action as appropriate.

Weekly monitor checks

- This is a TOR(MAM) and is considered an optional monthly check.
- It is designed to mimic mammographic images and associated abnormalities
- Send a TOR(MAM) image to all workstations which are used in reporting clinical imaging. Score the image on all monitors at each workstation.
- These images should be stored for future review if necessary.

Mean glandular dose

Mean Glandular Dose (MGD) is the average dose of radiation delivered to the glandular tissues of the breast, which are the most sensitive to radiation and most at risk for developing cancer.

Factors that affect the mean glandular dose;
Breast Composition
Breast Thickness

X-ray Beam Quality
Imaging Technique

Mean glandular dose calculation

- Not measured directly but estimated
- Estimated by the mammographic equipment ensure higher degree of accuracy and consistency in comparison to manual calculation which has the risk of human error and saves time.

Mean Glandular Dose – UK requirements

In the UK NHSBSP the MGD for the average patient is assumed to be equal to 3mGy for a two-view examination.
This is based on average doses of 1.5mGy per view for digital mammography systems in the between 2010 and 2012

Weekly Uniformity and Artefact tests

- Uniformity should be visually checked on a weekly basis.
- This test checks that the x-ray set is performing uniformly across the entire field
- All uniformity images should be visually inspected for artefacts, faulty pixels or areas of unusually low noise, adjusting the window through all widths/levels.

Monthly AEC thickness

Automatic Exposure Control in mammography is designed to adjust & optimise exposure factors individually depending on the many combinations of size and breast density of patients imaged.

We should expect patients with similar breast thickness and density to receive similar dosed with similar image quality.

Monthly Safety/function tests

- Patient safety is a top priority, so it’s important that all safety features and operator functionalities of our equipment are working as expected.
- Every month the practical working of each x-ray set is checked following a list of set functionalities.
- Any issues should be escalated and resolved

Radionuclide Imaging

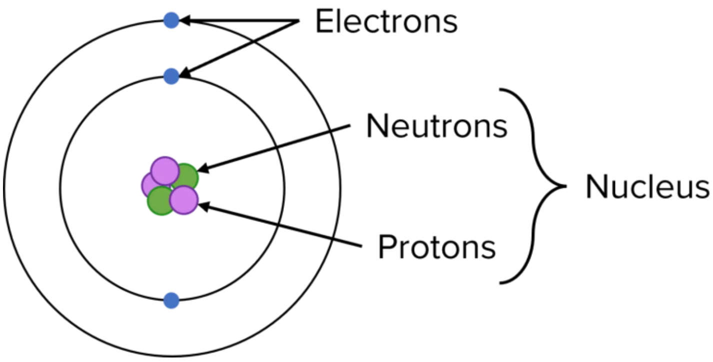
What is radionuclide imaging?

- Also known as nuclear medicine
- Use of small amounts of radioactive material for the diagnosis of illness, injury and disease
- Physiological (functional) imaging
- Increased quantities of longer-lived radionuclides for the treatment of disease (benign or malignant)

<u>Review of radioactivity</u>

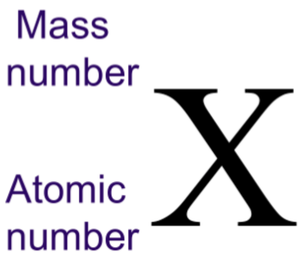
<u>Atomic structure</u>

- Electrons
- Protons and neutrons



<u>Atomic structure</u>

- Mass number of an element is the number of protons and neutrons in the nucleus
- Atomic number (symbol Z) of an element is the number of protons in the nucleus
- Number of protons dictate what the element is



<u>Radioactivity and radioactive decay</u>

- **An isotope of an element has the same number of protons (Z) but different number of neutrons**
- **Radioisotope is a radioactive isotope with an unstable nucleus**
- **Radioactive is the term used to describe nuclei which are unstable**
- **Atoms which are unstable emit excess particles and energy in the form of radiation this is radioactive decay**
- **Radioactive decay is a spontaneous process by which a unstable parent nucleus emits a particle (alpha or beta) or electromagnetic radiation (gamma) and transforms into a more stable daughter nucleus that may or may not be stable**

<u>Emissions</u>

Two types of emission from the an atom:

Atomic – electrons e.g. X-ray photons
Nuclear – from the nucleus – **gamma photons – alpha and beta particles**

- **RNI = nuclear emissions**
  - **Gamma photons for imaging**
  - **Beta and alpha particles for radionuclide imaging/therapies/treatment**

<u>Clinical Uses of Bets and Alpha</u>

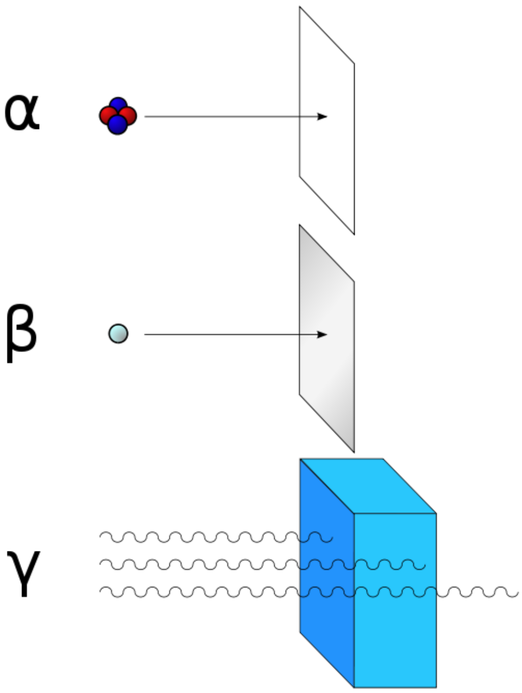
Radionuclide	**Beta or alpha?**	**Chemical form**	**Indication (treatment of)**	**Route of admin**
Iodine-131	Beta	Iodide	Thyroid cancer	IV or oral
Iodine-131	Beta	Iodide	Benign thyroid disease (e.g., hyperthyroidism)	IV or oral
Lutetium-177	Beta	DOTATATE/ DOTATOC/ DOTANOC	Neuroendocrine malignancy	IV
Yttrium-90	Beta	Microspheres	Hepatic malignancy	Intra-arterial
Radium-223	Alpha	Dichloride	Bone metastases in castration resistant prostate cancer	IV

<u>**Linear Energy Transfer (LET) – is the average energy deposited (KeV) per unit path length along the track of an ionising particle.**</u>

- Alpha and beta particles give up their energy quickly = High LET
- Alpha and beta particles do not travel far = would not exit the body
  Therefore not detected by the equipment
- High radiation dose to the patient – therapeutic uses

- Gamma photons of sufficient energy pass through tissue and therefore can be detected by the gamma camera – these are useful for diagnostic imaging
- In imaging gamma emitting radioisotopes are used

Nuclear emissions

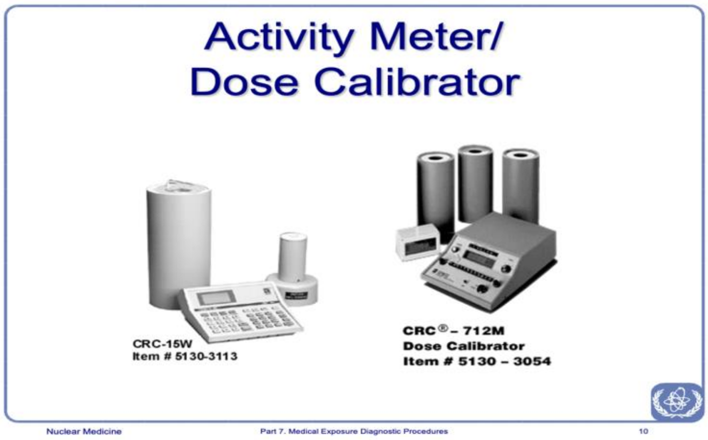


<u>Some terms used in RNI</u>

- **The activity of a quantity of a radionuclide is the number of nucleus transformations which occur in that quantity per unit of time**
- **The physical half life of a radionuclide is the time taken for the activity of a sample of that radionuclide to decrease by one half e.g. technetium is 6 hours**
- **The biological half life of a radio pharmaceutical is the time taken after its introduction for the amount left in the body to reduce to half its original value.**

<u>Measurement of radioactivity</u>

- Radioactivity is measured in becquerels after Henri becqueral
- 1Bq – 1 disintegration per second
- In RNI we use megabecquerels



Radioisotopes used in RNI

Radionuclide	Principle photon emission (keV)	Half life
Technetium-99m	140	6 hours
Indium-111	173, 247	2.8 days
Iodine-123	159	13 hours
Iodine-131	360	8 days

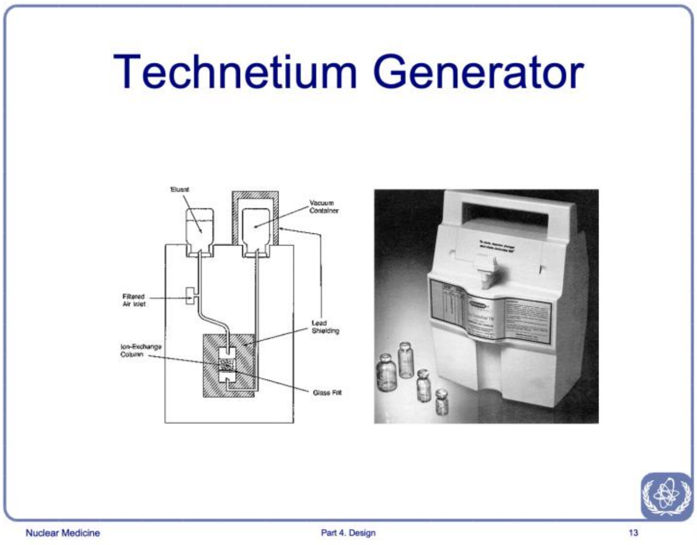
<u>The ideal radioisotope</u>

- **Technetium – 99m**
- **Emits gamma photons of 140keV** – Ideal for NaI(TI) (sodium iodide and thalium) scintillation crystal (in gamma camera) but not too penetrating that it goes straight through.
- **Short physical half-life (T1/2) = 6 hours**
- **Long enough for imaging but short enough to ensure ionising radiation dose is low**
- Produced from a generator on site – readily available at the hospital
- **Molybdenum-99 (99Mo) decays to technetium-99m**

Technetium Generator

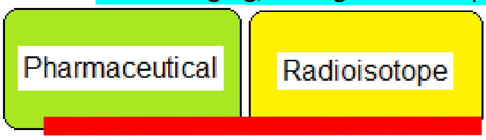
Nuclear Medicine Part 4. Design 14

- **Shielding – lead casing**
- **Polystering is for distance whoever is lifting it**

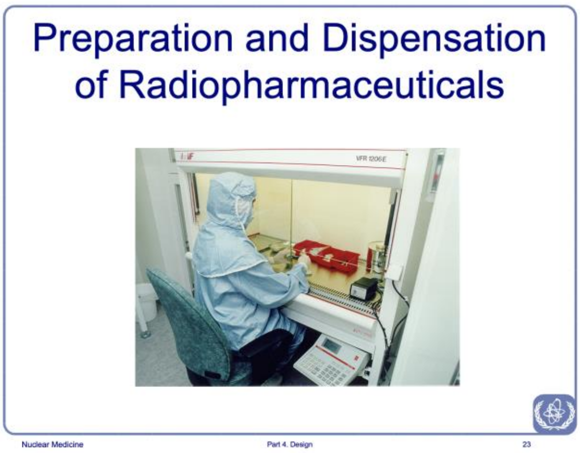


Radiopharmaceuticals

A **pharmaceutical** designed to accumulate in the cells, organs or body system of interest e.g. bone imaging, a drug similar to phosphate is attached to a radioisoptope – technetium



- A **radioisotope** that emits gamma rays which are detected by the gamma camera
- Distribution of the radiopharmaceutical provides physiological (functional) information



- Operator is protected from the radiation

- Equipment – shielded bench/cabinet, lead glass
- Clothing – cloak, hat and gloves
- Training
- Testing/QA

Technetium – 99m based RPs

Form the mainstay of RNI
Must be

- Sterile and pyrogen free
- Readily available with a long shelf life (prior to reconstitution)
- Easy to prepare and chemically stable
- Economic Cost per patient
- Available
- Suitable routes of administration

Administration of radioactive substances advisory committee

- Updated February 2025
- Good practice in nuclear medicine in the Uk
- Guidance notes including activity for administration
- ARSAC certificate holder normally a radiologist

Transmission Vs Emission Imaging

- Emission imaging – internally emitted radiation from radioactive tracers to produce imaging
- Transmission – externally generated radiation

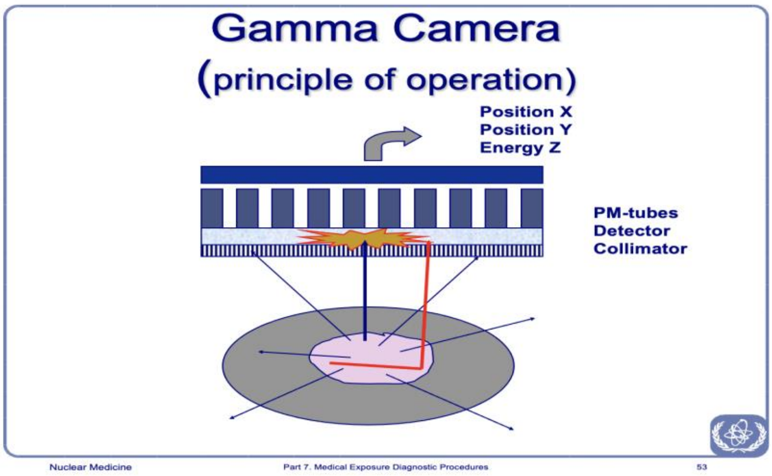
TOPIC 2 Introduction to radionuclide Imaging – Instrumentation

Dual Head Gamma Camera

Collimator

- Lead or titanium septa, series of holes
  (usually parallel to the scintillation crystal)
- To improve image resolution - attenuates (absorbs) emitted photons that are not perpendicular to the collimator
- Important to have the collimator as close as possible to the organ of interest
- Resultant image is accurate representation of radiopharmaceutical distribution in in-vivo.

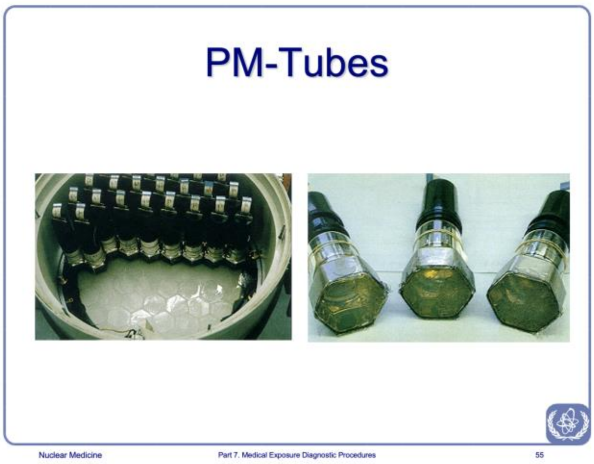
Gamma Camera



Scintillation crystal

- Sodium iodide crystal, activated with Thallium – NaI(TI)
- One crystal covers entire gamma camera
- Gamma photons interact with the crystal – crystal emitted light (scintillates)
- Light emitted is proportional to the energy of the gamma photons interacting with the crystals
- Scintillation crystal are hygroscopic (absorbs water) – easily damaged and expensive to replace
- Light guide – transmit scintillations to photomultiplier tubes (PMT)

PM – Tubes

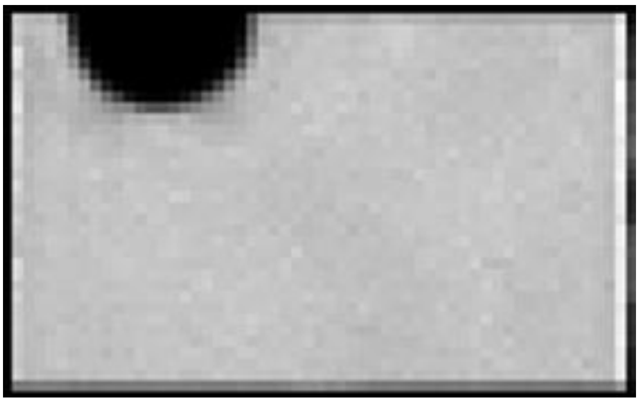


Photomultiplier tubes (PMT)

- Converts light into electrical current – electrical current is proportional to light produced by gamma photons
- Carefully calibrated and tuned at installation and servicing to ensure uniform response
- Electrical signals are amplified (preamplifiers) and undergo analogue to digital conversion (ADC)
- Information is fed into a pulse height analyser (PHA) to determine the energy of the incident gamma photons – PHA rejects any low energy gamma photons which represent Compton scatter
- Location of signal plotted in an image matrix to produce the image

QA - Photomultiplier tubes (PMT)
- Daily QA – the 'flood'

- Circular defect produced when a round PMT fails

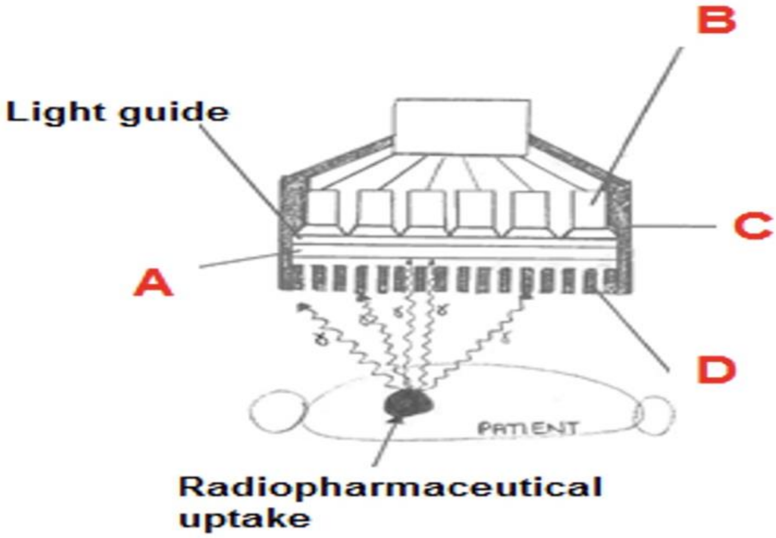


Shielding the Gamma camera
- Casing (lead, tungsten or other high atomic material)
- Covers the outside of the gamma camera
- Prevents background radiation from striking the crystal and giving false scintillations
- Sources of background radiation

Summary of the Gamma Camera

- Collimator only allows perpendicular gamma photons to reach the crystal
- Gamma photon interacts with scintillation crystal and emits visible light
- Photomultiplier tubes convert the light into electrical currents

- Electrical currents are plotted in a matrix to produce a digital image representative of the radiopharmaceutical in the body
- Casing prevents background radiation contributing to the image



Single Photon Emission Computed Tomography (SPECT)

- Gamma cameras rotate in 'steps' around the region of interest
- Multiple 2D planar images acquired over 360 degrees (or 180 degrees for myocardial perfusion imaging)

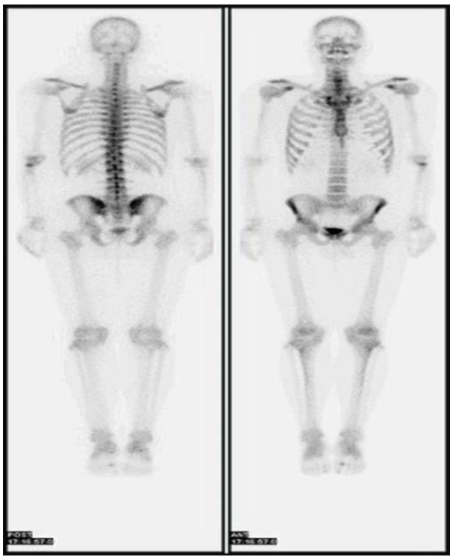
- 2D planar images reconstructed (using FBP or OSEM) to form multiplanar images
- Combined with CT (thus, SPECT-CT) when attenuation correction and/or anatomical localization is required

TOPIC 3 – Introduction to radionuclide Imaging – Imaging Examinations – not really needed for exam

NM Bone scans or Bone Scintigraphy

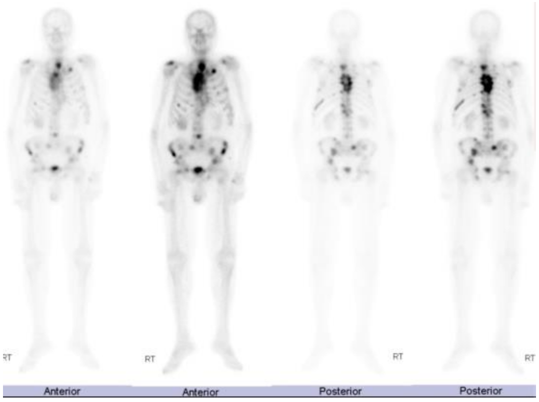
- ^{99m}Tc-HDP or MDP (phosphate analogue) - uptake in bone healing (osteoblastic activity)
- Very sensitive test...but not specific, thus accurate patient history required
- 600MBq (2.9mSv) or 800MBq (3.9mSv) SPECT (ARSAC, 2025, p.39),
- Scan 2-4 hours later
- Approx 50% of activity will concentrate in the skeleton
- Remainder excreted via urinary system (50% by 4 hrs) – how might we reduce patient radiation dose?
- Most common clinical indication: ?bone metastases

Whole body scan – Adult normal



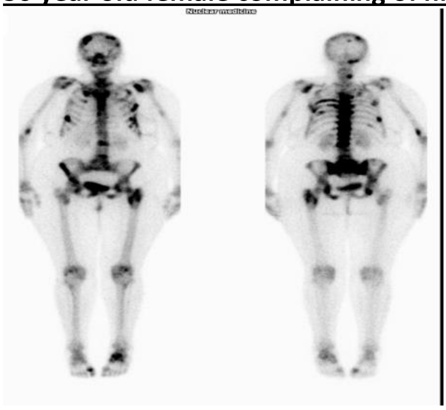
- Increased uptake in the left elbow – maybe where the injection was given (note where the injection is given)
- Uptake in big toe could be a bunion.

75 year old male with prostate cancer



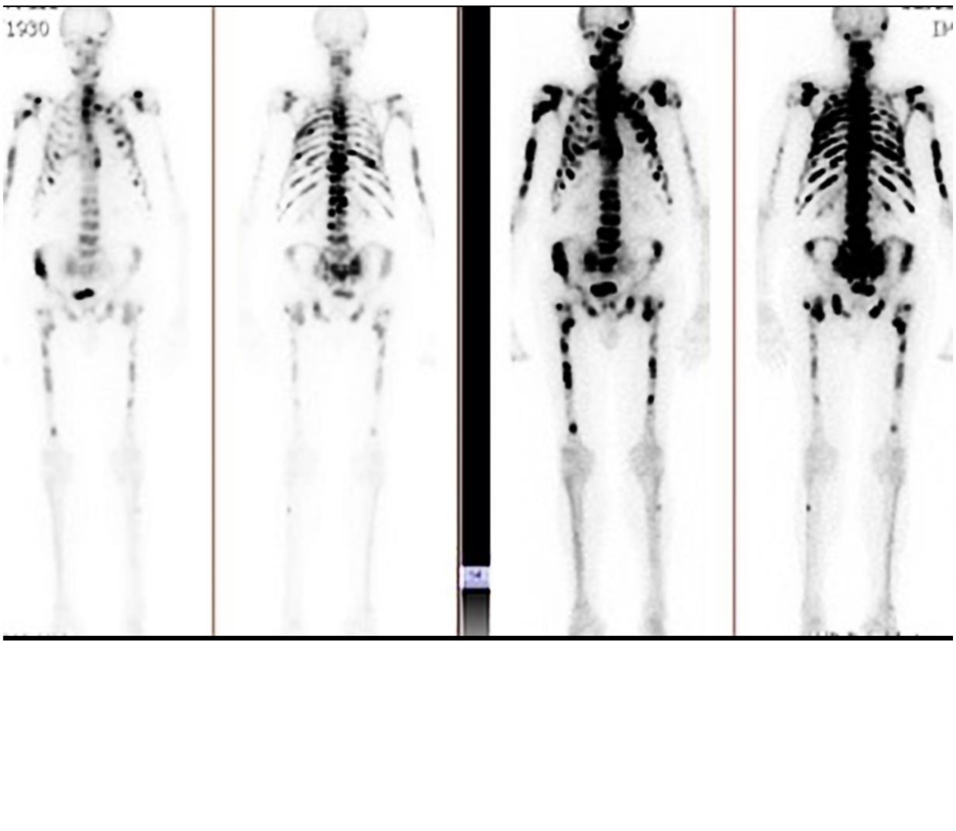
- Hotspots within the sternum and pelvis

<u>50 year old female complaining of hip pain and breast cancer</u>



- Multiple areas of increased uptake – lots in spine, pelvis and hip.

<u>70y M, prostate cancer, elevated PSA (blood test) - "Superscan"</u>



Rib fractures

- NOT a clinical indication, but can be seen
- When assessing bone scans, it is important to take account of the clinical history and pattern of radiopharmaceutical uptake

Rib fractures

- History of trauma
- Focal areas of increased uptake
- Linear pattern

Bone metastases

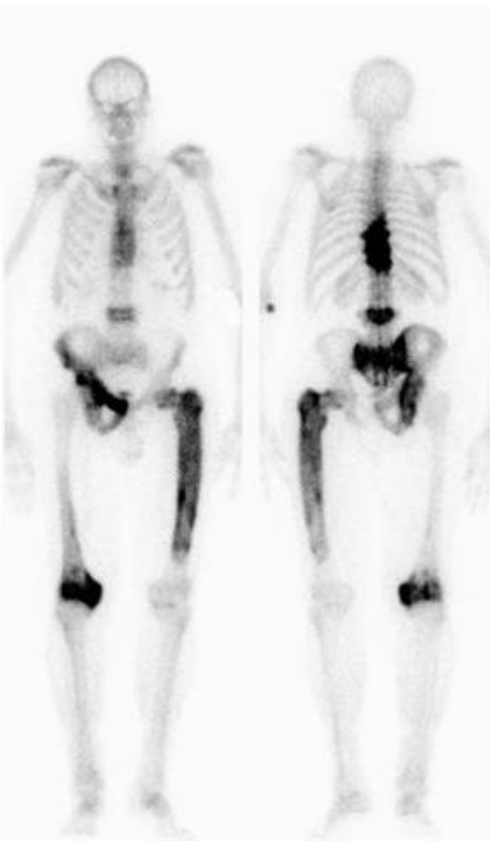
- +/- history of cancer, particularly lung, breast or prostate
- Irregular pattern
- Focal or extend along rib

19 year old female, army recruit, aches and pains

- Shin splints
- Stress fractures

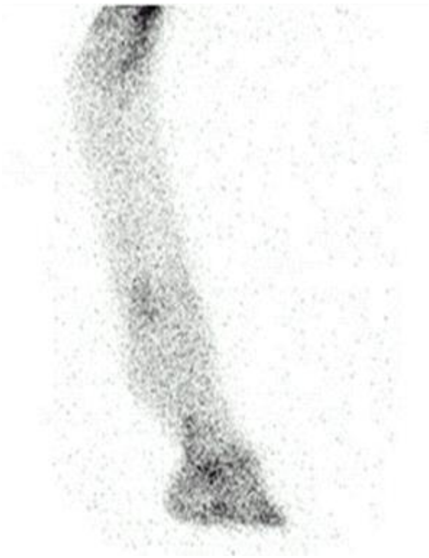
Abnormal bone scan

- Intense radiopharmaceutical uptake:
- Lower thoracic vertebrae
- 4th lumbar vertebra
- Right hemi pelvis & sacrum
- Left proximal femur
- Right distal femur (knee)
- Pathology?



- Pagets disease

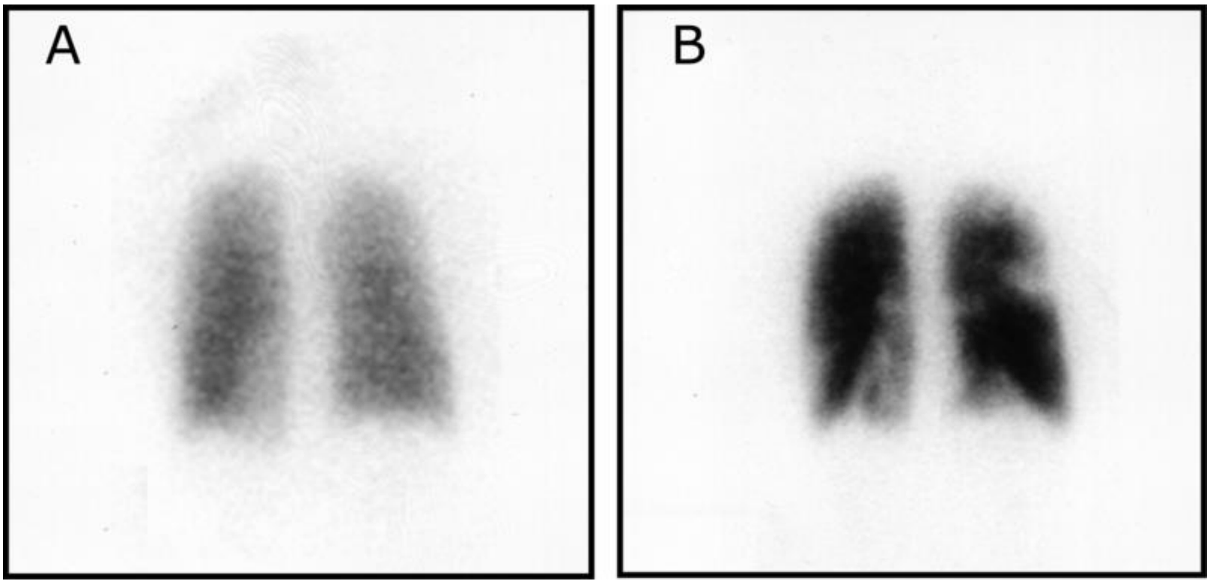
NM Bone scan – veterinary uses



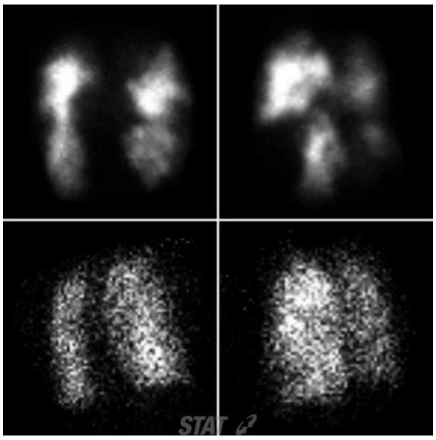
<u>Ventilation/Perfusion (V/Q)</u>

- A pulmonary embolism (PE) is an embolus within the pulmonary artery – usually thrombus (clot), but may be amniotic fluid, fat or air
- V/Q scan or CT Pulmonary Angiography (CTPA) for diagnosis
- V/Q scan – functional imaging to compare blood supply (perfusion) with air supply (ventilation)
- Ventilation: Technetium-99m or krypton-81m inhaled
- If PE present, perfusion is abnormal, but ventilation is normal

- Perfusion
- ^{99m}Tc-MAA (macroaggregated albumin or microspheres)
- 100MBq injected IV, image immediately
- 200MBq SPECT (ARSAC, 2025, p.41)
- Particles, 10-40 µm in diameter are trapped in lung capillaries (7 µm), thus, distribution is proportional to blood supply
- Particles are eventually broken down and removed from circulation by liver and spleen



- On image B – where the white patches are within the lung shows the perfusion

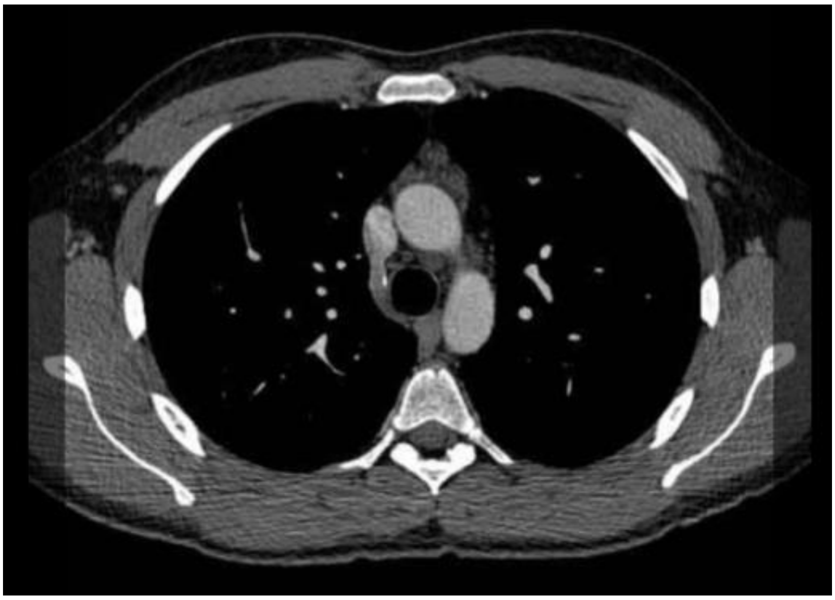


- Top row – perfusion
- Bottom Row – ventilation

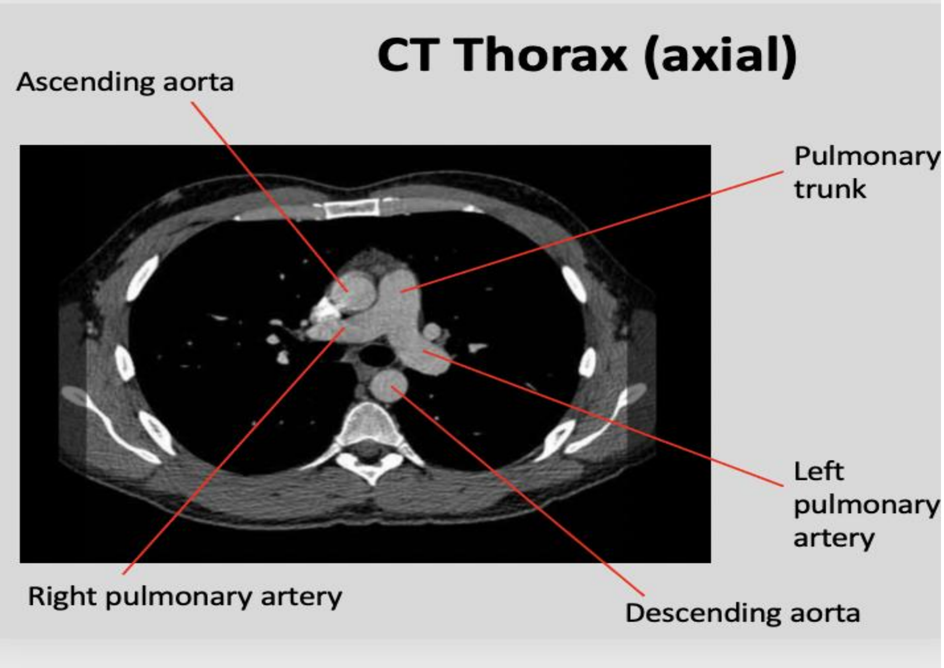
<u>CT Thorax (axial)</u>

- Arch of aorta and trachea are visible within the image

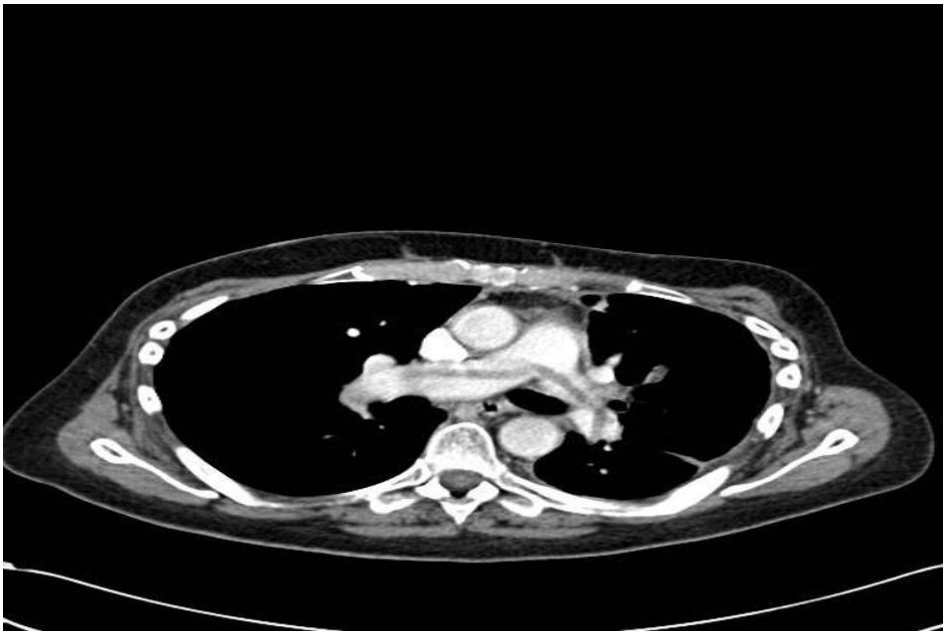
CT Thoracic (axial)



- Ascending and descending aorta visible



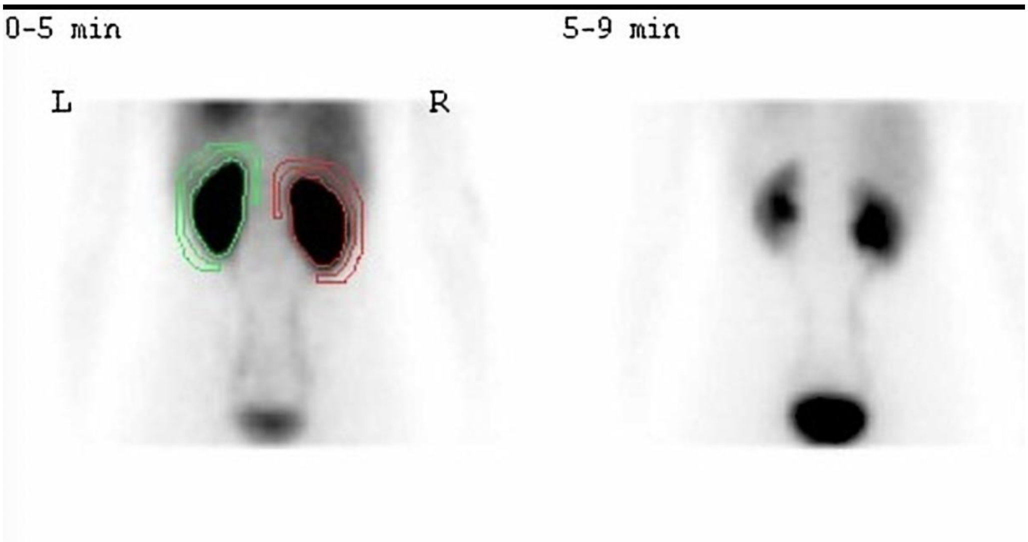
<u>Pulmonary embolism (PE) on CTPA</u>



<u>MAG3 Renography</u>

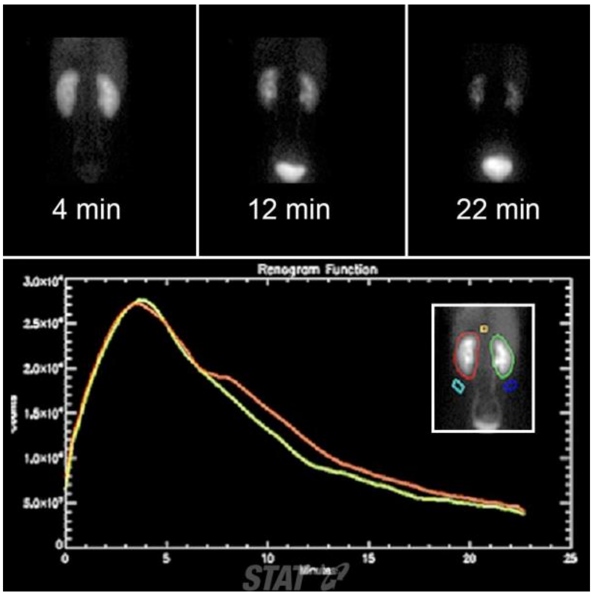
- ^{99m}Tc-MAG3 for renal imaging
- mercaptoacetyltriglycine
- 100MBq ^{99m}Tc-MAG3 IV (ARSAC, 2025 p.38)
- Effective dose: 0.7mSv (ARSAC, 2025, p.38)
- Not metabolised, undergoes renal excretion
- Visualise uptake and excretion
- Clinical indications include the assessment of PUJ obstruction, renal transplant evaluation

Normal MAG3 renogram



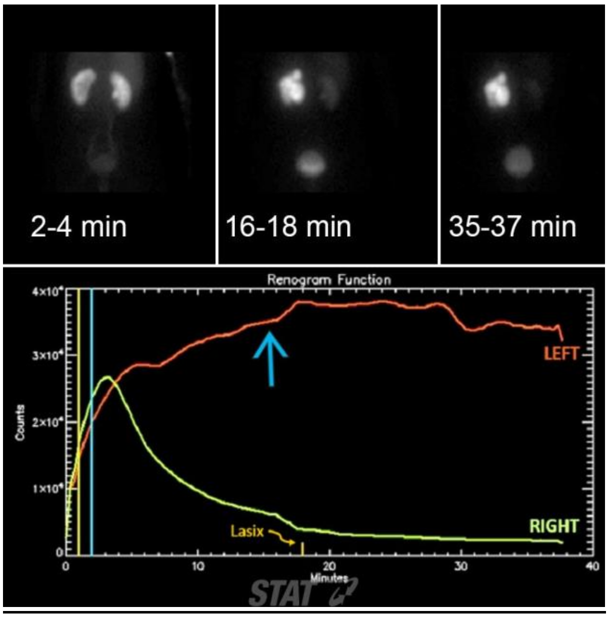
- 44y F, ultrasound suggested left PUJ obstruction

Normal renal time curve



1. Vascular/extraction – arrival of radiopharmaceutical in vascalature
2. Perfusion – uptake and transit through the nephrons
3. Excretion – from the kidneys into the bladder

Obstructed left renal time curve



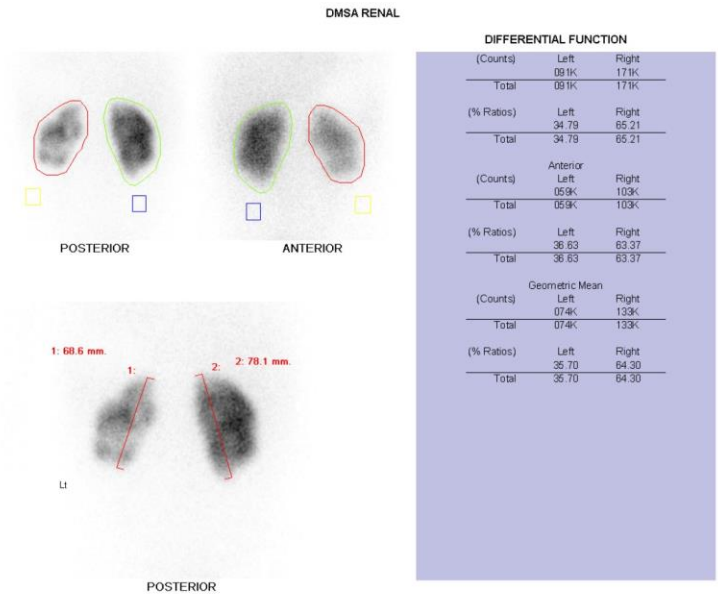
MAG3 vs CT Urogram

- CT Urogram provides high detail, anatomical information, including structure and location of kidneys
- MAG3 renogram provides physiological information, including location of functioning renal tissue

Static renal imaging

- ^{99m}Tc-DMSA - dimercaptosuccinic acid
- 80MBq IV, 0.7mSv (ARSAC, 2025, p.40)
- To identify cortical scarring (e.g., following pyelonephritis), differential renal function
- Urinary tract infection in under 16s: diagnosis and management (NICE, 2022) https://www.nice.org.uk/guidance/ng224
- Use DMSA 4-6/12 after acute infection to detect renal parenchymal defects in babies and children with recurrent UTI

1 Year old child, recurrent urinary tract infections

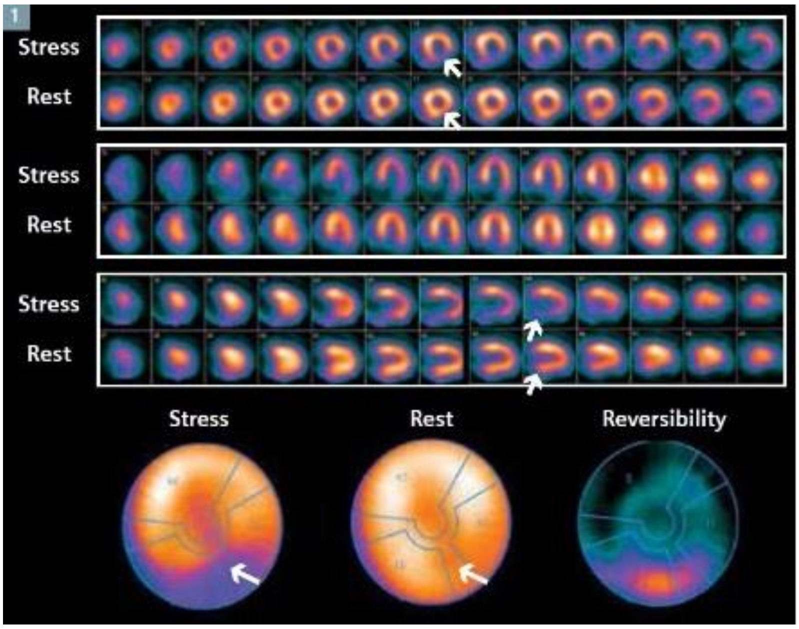


- Heterogeneous uptake, irregular outline and defects in keeping with renal cortical scarring

<u>Myocardial Perfusion Imaging (MPI)</u>

- To detect coronary artery disease (CAD)
- To assess myocardial viability in known CAD
- To assess functional significance of angiographic stenoses
- To stratify cardiovascular risk pre-operatively e.g., pre-general anaesthetic, pre-renal transplant

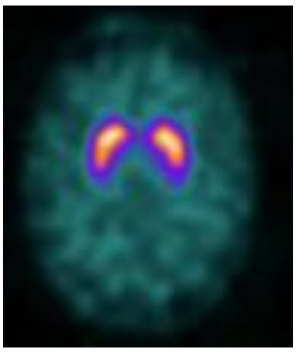
80y F c/o exertional dyspnoea, PMHx mild CAD



- Reversible perfusion defect in the inferolateral wall (proximal RCA territory)
- Coronary Angiography – 95% proximal RCA occlusion (corresponding to defect at MPI)

Dopamine Transporter Imaging

- ^{123}I-Ioflupane (DaTSCAN^{TM}) – iodine 123
- 185MBq, 4.6mSv (ARSAC, 2025, p.37)
- Imaging only in patients where it is not possible differentiate essential tremor from Parkinson's disease
- Parkinson's disease in adults (NICE, 2017)
- https://www.nice.org.uk/guidance/ng71
- 80y with tremor
- Assess uptake in caudate and putamen
- Normal uptake = symmetry, comma



Radiation protection for patients EXAM CONTENT

- Justification
- ALARP
- Legislation – IRMER – protection of patients and staff are protected by IRR 2017
- Time, distance and shielding

Aftercare for radiation protection:

- Most technetium-based radiopharmaceuticals are excreted via the urinary system
- Patients advised to ↑ fluid intake and ↑ frequency of micturition
- Patients advised to avoid prolonged contact (↑ 30 minutes) with pregnant women and children under 12 years for 24 hours

Shielding materials

- Alpha particles

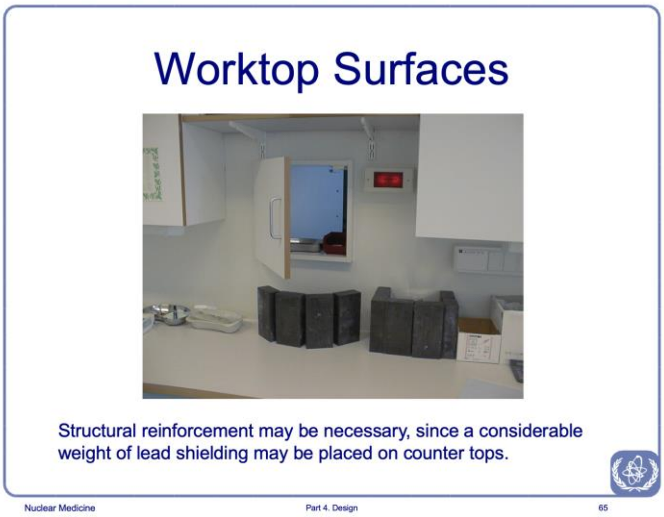
Stopped by a sheet of paper

- Beta particles

Stopped by aluminium sheet or Perspex

- Gamma photons
    - More penetrating
    - Absorbed by dense material e.g. Lead

- When the radiographer draw up the activity into a syringe
- Bench top shields
- Syringe shields
- Structural shielding



- Distance by using – forceps and tongs (inverse square law)

- Spread the workload fairly – drawing up the pharmaceuticals

<u>Ultrasound Imaging</u>

<u>SONAR</u>

- Sound navigation and ranging
- For locating objects by distance and direction of their echoes
- A pulse of ultrasound is sent out into the sea

- If it hits a solid object, it is reflected back and picked up by an underwater microphone called hydrophone
- The position of the object is indicated by a blob of light on the display screen
- So knowing the speed of sound in water (1510m/s) and the time it takes for the echo to return the distance/range of the object can be calculated
  ♣ S=D/T therefore D=ST (remember to divide by 2 as the sound made a return journey)
  ♣ Medical ultrasound in essence is a scaled down version of the SONAR...with some differences of course

Early Ultrasound

- Karl Dussick – 1930s
- Dr Ian Donald, University of Glasgow, 1950s
  Used A-mode and B-mode equipment, detected an ovarian cyst in a woman patient, after RAF experience with sonar

What is US?

High pitched sound beyond/above the range of human hearing
♣ Usually above 20kHz frequency
♣ Sound below the lower human hearing threshold is called infrasound (less than approximately 20Hz)
♣ Some animals use ultrasound to locate objects
♣ Bats-25khz
♣ Dolphins-125kHz
♣ Children can hear sounds of frequency 25kHz- and this ability reduces with increasing age.
♣ Anti- ASBO
♣ Medical u/s 2-15MHz: These days it we even have 20MHz

Sound frequency ranges

- Humans can hear from about 20Hz to 20kHz
- Dogs and bats can hear sounds at ultrasound frequencies (above 20kHz)
- Blue whales can emit and hear sounds at subsonic frequencies (below 20Hz)
- Lower frequency sounds travel further and a whale can hear another thousands of miles away.

Main differences between US and X-rays

Wave type - longitudinal – mechanical waves (compression waves)

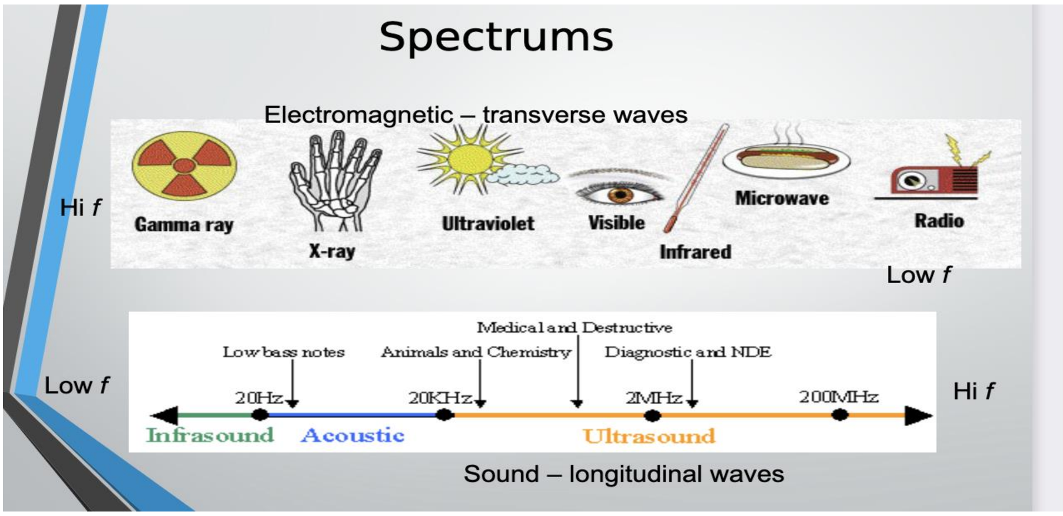
Transverse – electromagnetic waves

Transmission requirements – elastic medium and no medium needed

Generation – stressing the medium (vibrations) and electrons losing energy

Velocity – depends on the medium through which it propagates and relatively constant
Similar waves – seismic waves and light/microwaves

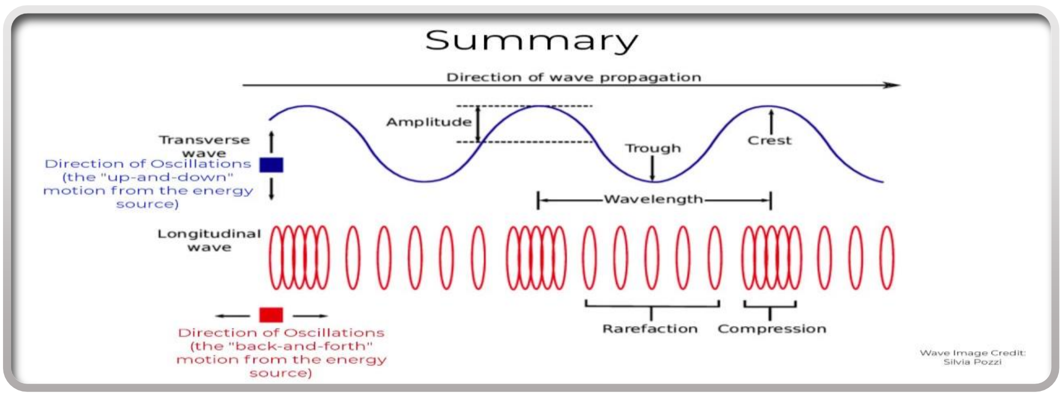
Spectrums



Frequency, penetration and resolution

- In medical ultrasound, lower frequency waves (2MHz) penetrate deeper but have less resolution
- Higher frequency waves penetrate less deep but have better resolution
- We try to use the highest frequency possible

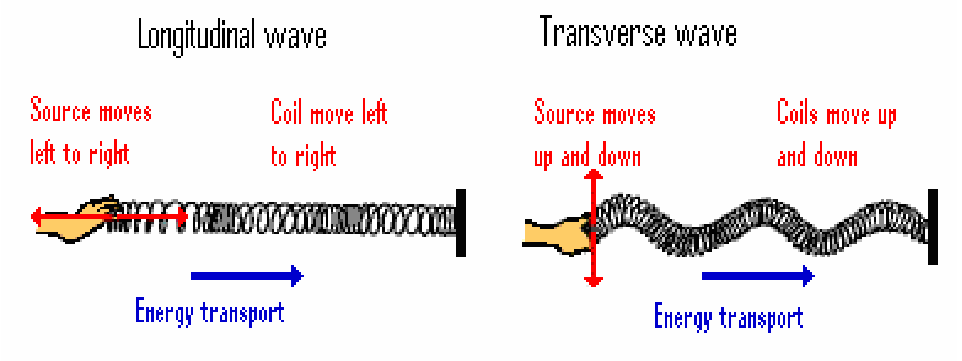
Waves



- Waves transfer energy from one place to another
  • Transverse – electromagnetic
  • Oscillates at 90 degrees to the direction of travel

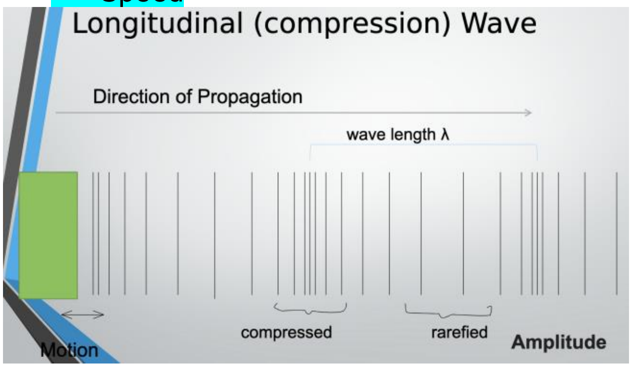
- Longitudinal – Compression - sound
  • Oscillation is aligned to the direction of travel
  • Propagation through a medium
  • Compression and rarefaction

• These waves correspond to regions in the medium where pressure is alternately higher than and lower than the resting or ambient pressure.



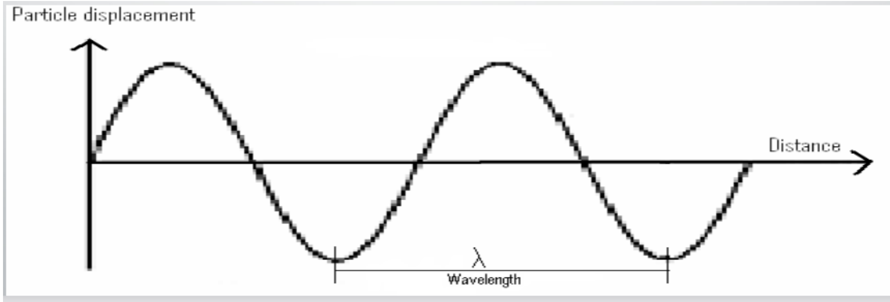
Characteristics of sound

- Amplitude
- Wavelength
- Frequency
- Speed



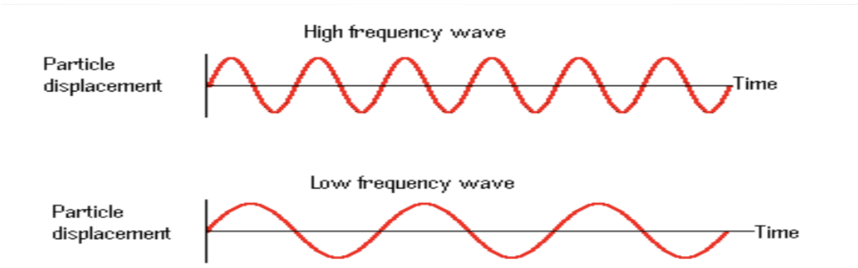
Wavelength

- The ultrasound wavelength (λ) is defined as the length in the medium of a single wave cycle
- It is the distance between a point on one wave and the same point on the next wave
- Wavelength – λ(lambda) – units are metres
- Inverse relationship between f and λ (f=s/ λ)



Frequency

- The frequency of a wave is the number of waves produced by a source each second
- Frequency f units are Hertz (Hz)
- 1 Hz = 1 cycle per second
- f is determined by the source of the sound wave



Speed of response

C = f λ

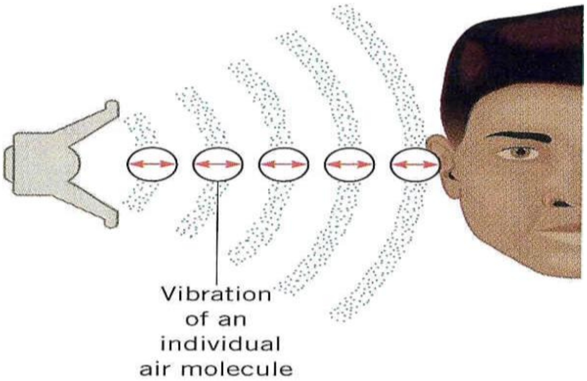
Material C (m/s)
Bone 3190
Liver 1578
Kidney 1560
Average tissue 1540
Amniotic fluid 1534
Fat 1430
Water 1480
Air 333

Creating and detecting sound

- Sound waves are created by the vibration of some object and are detected when they cause a detector to vibrate (ear drum for example)

- In medical ultrasound, A piece of piezo electric material is used to generate an ultrasound pulse and receive echoes

The material is made of ceramic material call Lead zirconate titanate (PZT).



The Piezoelectric effect

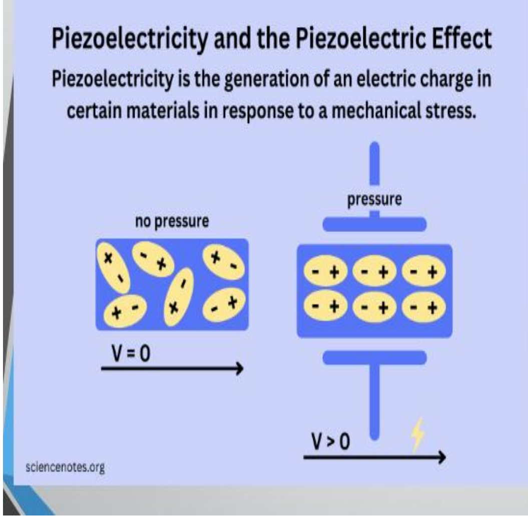
When an electrical current is applied across the crystal, it resonates sending out a sound wave – transmitter
• When a force is applied perpendicular to the crystal an electrical charge is produced receiver - So it is a transceiver

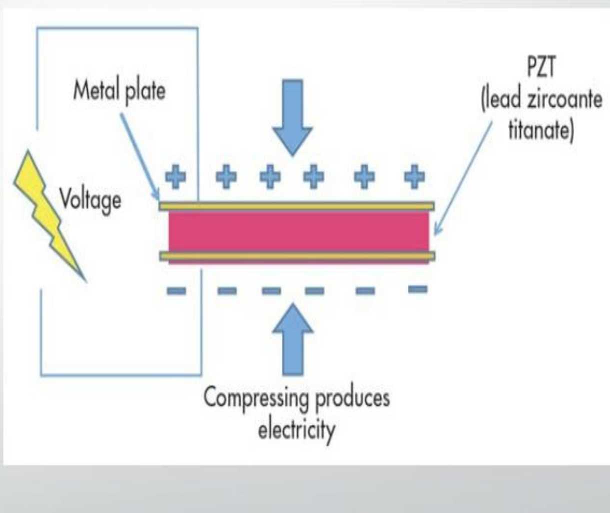
The Piezoelectric effect

- The piezoelectric effect is a phenomenon where certain materials, such as crystals or ceramics, can generate an electrical charge in response to mechanical stress or pressure. E.g. sound
- Conversely, these same materials can also deform or vibrate in response to an electrical charge.
- A voltage is applied to the conducting plates causing the molecules to twist in the direction of the electric field and this causes the crystal to become thicker. If this voltage is reversed the molecules will twist back in the opposite direction making the crystal thinner. Applying an alternating voltage to the crystal will cause it to expand and contract (oscillate) at the same frequency as the voltage, producing a continuous sound wave of that frequency.

Electricity resulting from pressure

- Piezoelectricity is the generation of electric charge in certain materials in response to a mechanical stress.





The process

1. Alternating electrical current applied to PZT crystal

↓

2. Crystal vibrates/rings at a frequency

↓

3. Inaudible sound and mechanical wave emitted

↓

4. Wave interacts with tissue and some are reflected back

↓

5. US machine receives echo (reflected wave) and converts it to electrical current

↓

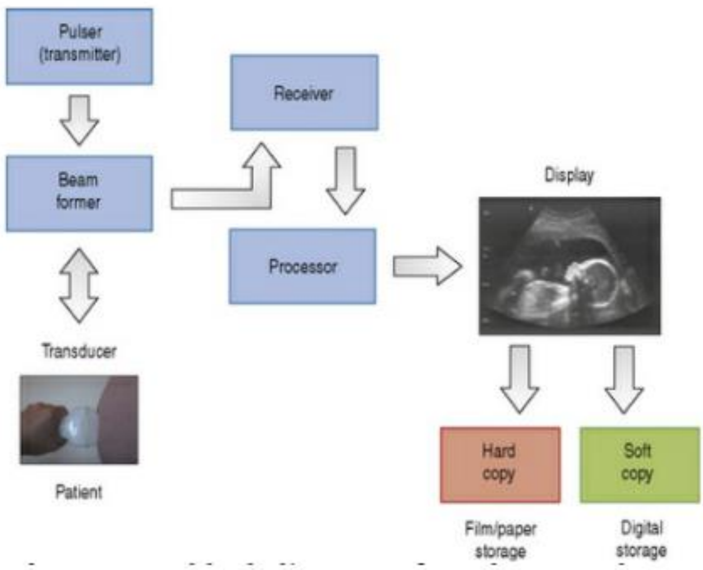
6. Assigns a grey level according to frequency & amplitude (volume) of echo

- These signals are then amplified, converted into a digital format and stored as digital numbers in a computer memory known as a scan converter.
- Each digital number will be assigned to an individual pixel according to how large the returning echo is, and the digital number for each pixel determines the shade of gray used to represent it on the display.

Components

Transducer
• Pulser
• Beam former
• Receiver
• Processor

• Display
• Digital storage
• Hard copy printer devices



Transducers

- Wider probes are usually lower frequency
- Act as both transmitter and receiver – transceiver
- Each probe has several frequency settings
- The frequency of the transducer depends on the thickness of the crystals

Transducers

- Transducer works best when the crystals operate at their natural frequency
- Natural frequency occurs when crystal thickness is half its wavelength (λ/2).
- Thinner piezoelectric materials produce higher frequencies
- 2MHz transducer=1mm crystal thickness
- 7.5MHz transducer= 3.75mm crystal thickness

<u>How is the image formed?</u>

- By knowing the distance and direction of the returning echo, an image can be built
- The piezoelectric materials are excited in a certain sequence in order to obtain reflections
  - Electronic Beam Scanning
- E.g. In ultrasound the materials are excited in a certain pattern such that the wave fronts arrive simultaneously at a specific point (Beam focussing)
  - That is a phase delay is applied to achieve this

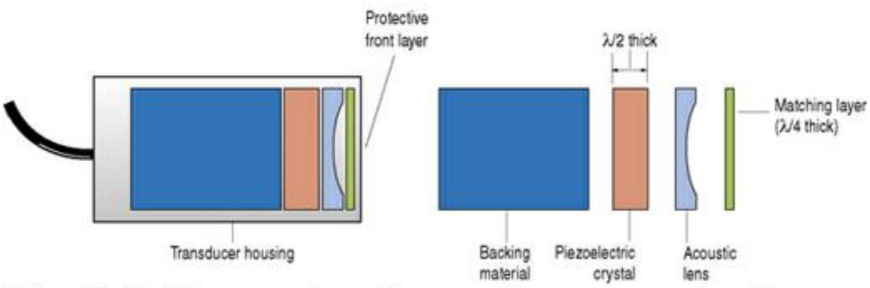


Fig. 6.2 The construction and components of a simple single element circular transducer

1. Most modern US imagers automatically scan the ultrasound beam using transducers consisting of arrays of many narrow piezoelectric elements. The array may consist of as many as 128–196 elements
2. Housing: The housing is the outer casing of the transducer and provides protection for the internal components.
3. Cable: The cable connects the transducer to the ultrasound machine and carries the electrical signals between them.
4. Acoustic lens: The acoustic lens is a curved piece of material that focuses the ultrasound beam and improves the image quality. It reduces the width of the beam and thus improve lateral resolution.
5. Piezoelectric crystals: The piezoelectric crystals are the key components of the transducer that convert electrical signals into ultrasound waves and vice versa. The crystals are typically made of ceramic materials such as lead zirconate titanate (PZT) and are arranged in an array or linear configuration.
6. Matching layer: The matching layer is a thin layer of material that is placed between the piezoelectric crystals and the body. It helps to match the acoustic impedance of the crystals to that of the body, improving the efficiency of the ultrasound transmission and reception.

7. Backing material: The backing material is a layer of material placed behind the piezoelectric crystals that helps to absorb and reduce the unwanted vibrations and echoes in the ultrasound signal, improving the image quality.
8. Wear plate: The wear plate is a protective layer that is placed on the surface of the transducer to prevent damage to the acoustic lens and crystals during use.
9. Fine guage micro coaxial cables to reduce equipment weight and size and support cable flexibility.

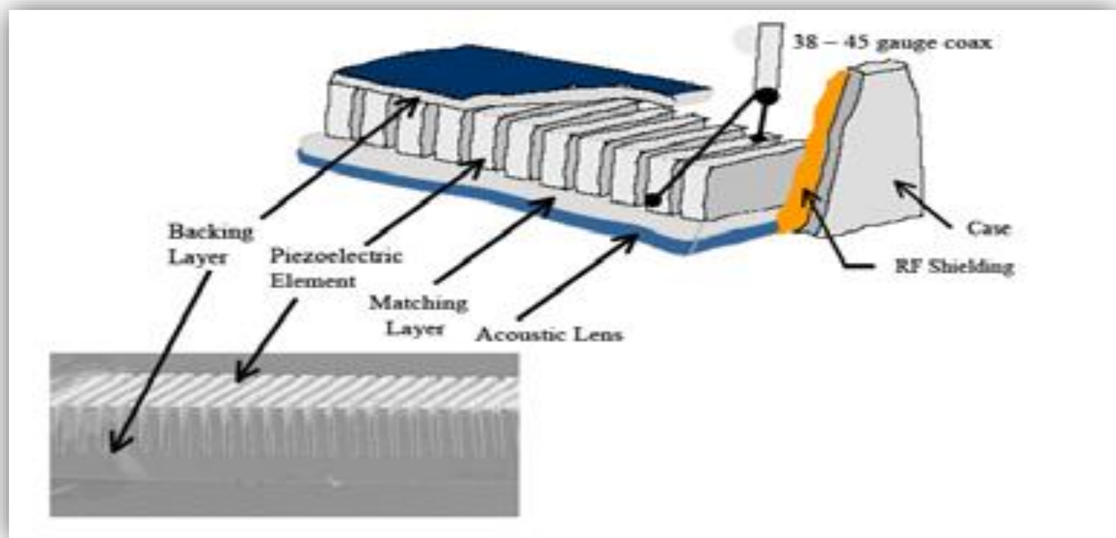
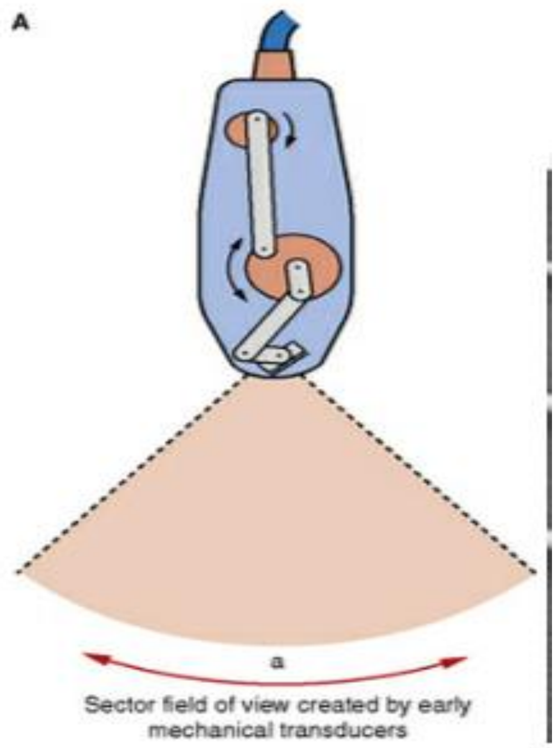
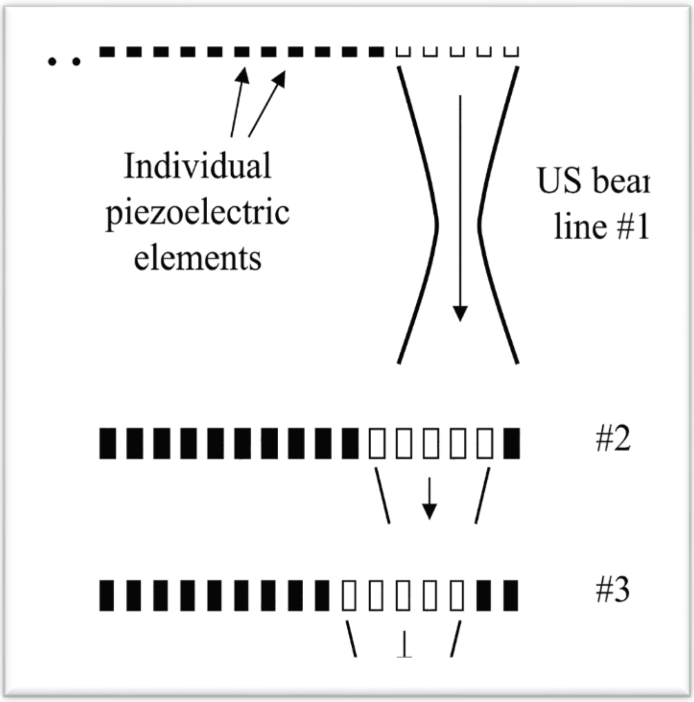


Diagram shows the method of electronic beam scanning for a linear-array transducer





- Electronic transducers form an image by sequentially activating small groups of elements (typically 5–10)
- Ultrasound beam scanning is performed electronically by sequentially activating small groups of elements.
- Only portion of the probe is activated at the time when we are scanning.

- Transducer connector
- Each element is individually connected via the port and has its only electrical supply.

<u>Types of transducers</u>

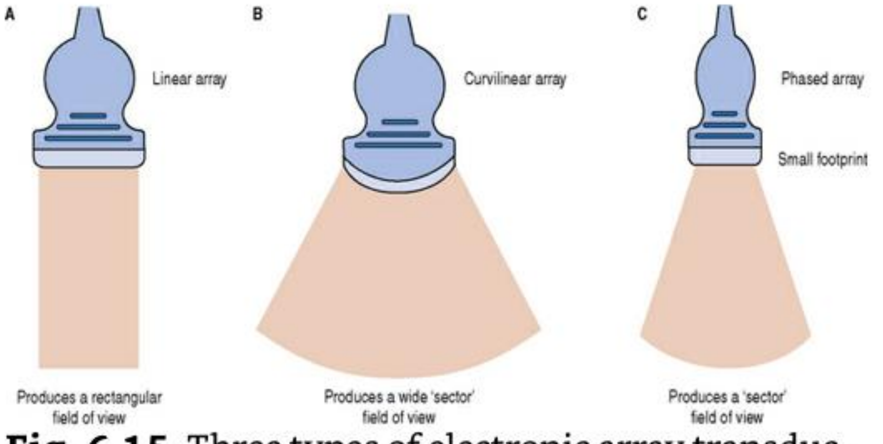
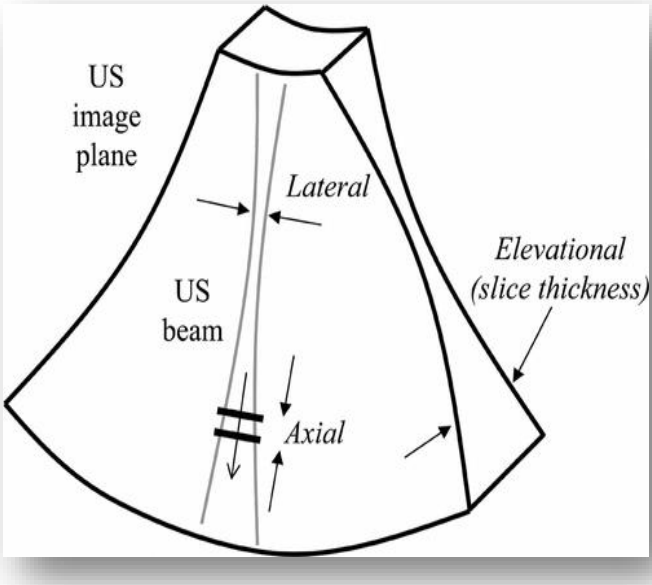


Fig. 6.15 Three types of electronic array transducers. a) Linear array; b) curvilinear array; c) phased array

-

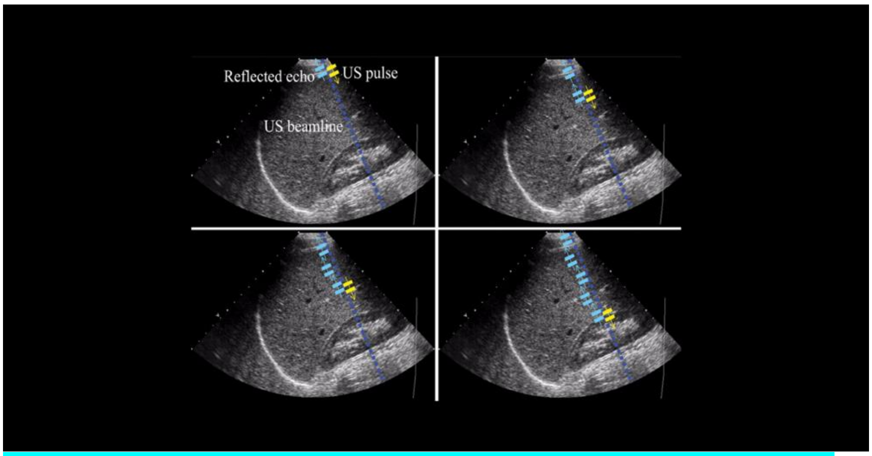
A – superficial structures – vascular and MSK – 4MHz
B – deeper structures – abdominal and obstetrics – 3.5 MHz
C – electronically steered – deeper and difficult to reach structures e.g. cardiac -



- Geometry of the US image plane
- Three spatial resolutions
- Resolution: The ability of an ultrasound system to distinguish two closely spaced reflectors as separate structures is known as resolution.
- The resolution in the direction of the beam is called axial resolution
- Lateral resolution
- Slice thickness – elevational resolution
- DO NOT NEED TO KNOW THIS FOR THE EXAM

Types of US images

- A Mode – Amplitude modulated. Produces a graphical peak whose height shows the strength of the reflection.
- B Mode – Brightness modulated. Produces a greyscale based on the strength of reflected sound
- Doppler – change in sound frequency indicates speed of tissue motion
- M Mode – Shows motion of objects over time (e.g. heart valves) https://www.youtube.com/watch?app=desktop&v=phxWbTxxv-M



The path that is followed by the beam is called a beam line
The direction of the US pulse propagation along the beam line is called the axial direction.; the direction in the imaging plane perpendicular to this is called the lateral plane

B mode

- As the pulse travel deeper into the body, it would usually encounter a train of echoes on their way back
- The different reflectivity of various structures in the body means that there would be a variation in the echo strength
- The detected echo signals are processed and translated into luminance
- This results in the brightness or B-mode display
- More reflective structures appear brighter

- A complete image is obtained by repeating the pulse echo cycle for many coplanar beam lines
- The pulses for successive beam lines are transmitted after all the echoes from previous beam lines have been detected by the transducer
- Echoes from all of the beam lines are detected and processed (in the processor)
- The signals are mapped to the proper locations in the image pixel matrix (localised), and the complete B-mode image is displayed
- The whole process is repeated to obtain the next frame rate of 20-40 frames per second)
  - time it takes for an ultrasound system to produce a new image= frame rate

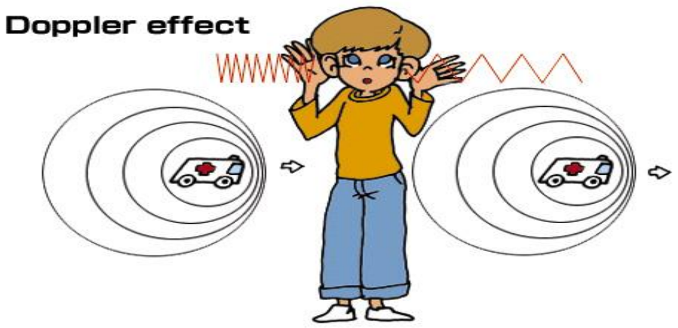
- To display the target in the correct place, the machine must know:
  1. The distance from the source to the target
  2. The direction from the source.
- Pulse echo principle

The doppler effect

- If something is travelling towards us and emits waves, the wave frequency is increased - the wavefronts become "bunched up"
- Thus a speeding train heading towards us sounds high pitched
- A speeding train heading away sounds low pitched as the wave frequency is reduced – the wavefronts get "stretched out"
- That's the Doppler effect

Doppler shift

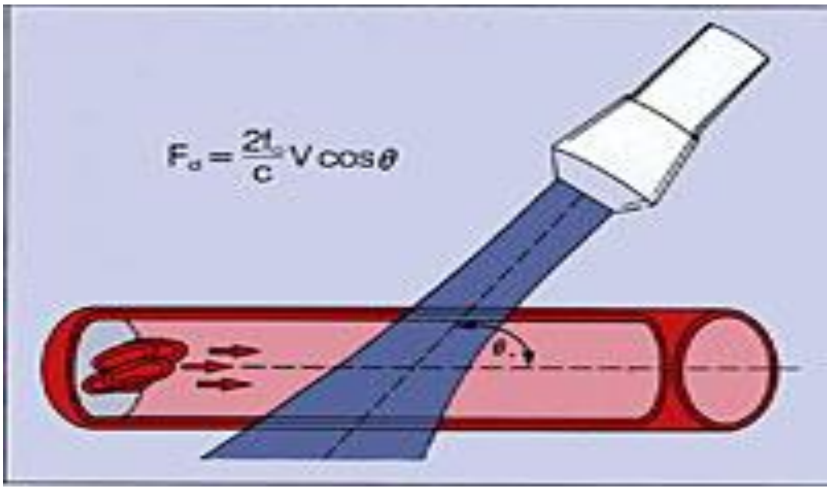
- The ultrasound machine knows what frequency it is transmitting at
- It receives the returning echo and determines its frequency
- It can then calculate the difference between the two (the Doppler shift)
- From that work out the speed (of blood flow for example)
- A positive Doppler shift means that the received frequency exceeds the transmitted frequency and that red blood cells are approaching the transducer. A negative Doppler shift means that the received frequency is less than the transmitted frequency and that the red blood cells are moving away from the transducer.



The Doppler equation:
$f_d = f_r - f_t = 2f_t\, v \cos\vartheta / c$

f_d = doppler f
f_r = received f
f_t = transmitted f
V = blood flow speed
θ = doppler angle
c = speed of sound

Doppler angle



Doppler angle

- Doppler Angle
- Smallest angle is best, 0 degrees is not possible as its parallel.
    - 0º is best but not practical
    - Over 60º the margin of error is too great to be accurate
    - 45º - 60º practical
    - 90º no signal since perpendicular to the flow
    - Doppler can:
    - Detect the presence of flow
    - Assess the direction of flow
    - Calculate the velocity of flow

Conditions – clinical indications

- heart valve defects and congenital heart disease
- a blocked artery (arterial occlusion)
- narrowing (stenosis) of an artery
- blood clots (deep vein thrombosis)
- varicose veins (venous insufficiency)
- arteriovenous malformations
- movement of the cardiac wall.

What happens when it enters the body?

Targets

- Ultrasound echoes are generated from the junctions between tissues of different acoustic impedances
- Whenever an ultrasound beam gets to an interface between two materials of different densities/stiffness, some of the beam will be reflected, and the remainder transmitted

Acoustic impedance (*z*)

- The stiffness of a medium
- Determined by the density of the material
    - The denser the material, the higher its acoustic impedance
- Soft tissue / air interface – large *z* difference = large reflection
- Soft tissue / bone interface – large *z* difference = large reflection
- Recall that material density also affects the speed at which sound travels through it
- Gel improves sound transmission at the skin (prevents an air / tissue interface)
- *Product of tissue density and speed of sound*

Typical acoustic impedance (Z) values – DO NOT NEED TO MEMORISE THIS

Tissue	Impedance
Air	0.004×10^6
Fat	1.34×10^6
Water	1.48×10^6
Liver	1.65×10^6
Blood	1.65×10^6
Muscle	1.71×10^6
Bone	7.8×10^6

Speed of sound – DO NOT NEED THIS

- $C = f\lambda$
- **Material C (m/s)**
- Bone 3190
- Liver 1578
- Kidney 1560
- Average tissue 1540
- Amniotic fluid 1534
- Fat 1430
- Water 1480

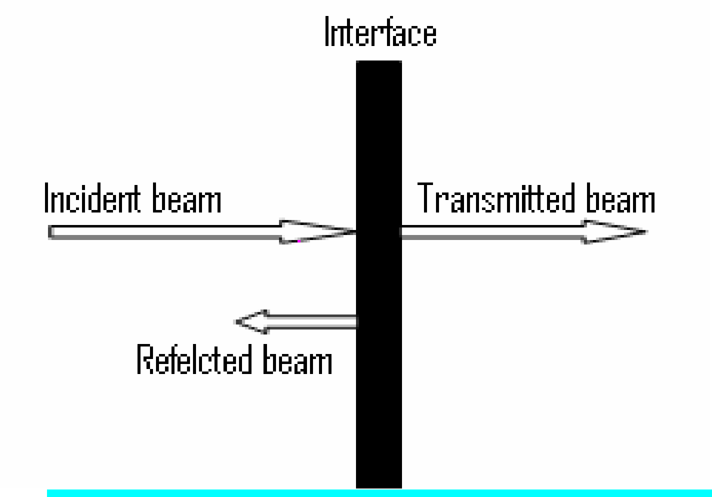
- Air   333

Attenuation

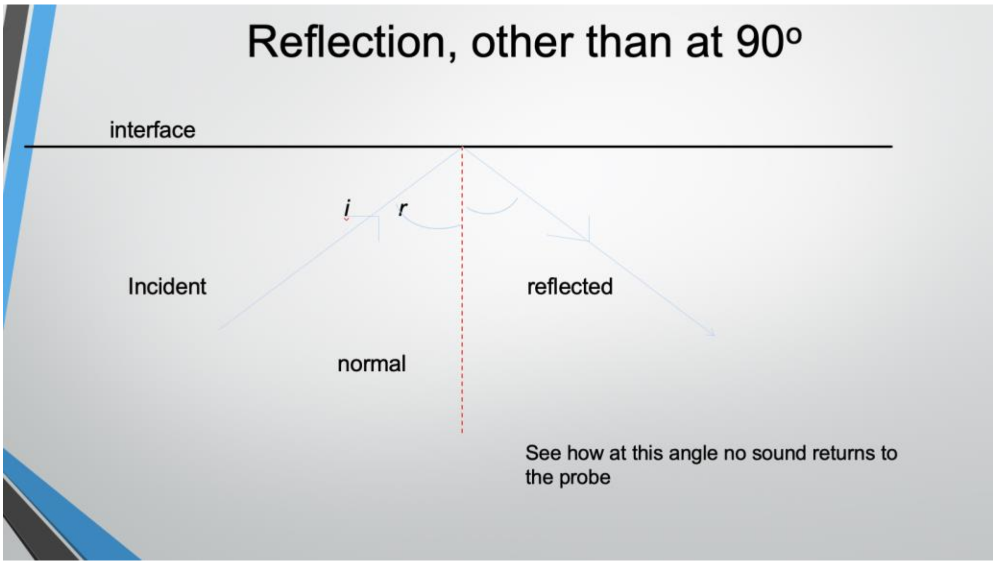
- Attenuation is the reduction in intensity of the u/s beam with distance from the source.
- Attenuation of the ultrasound beam is due to:
    - Reflection
    - Refraction
    - Absorption

- Attenuation is the reduction in intensity of the u/s beam with distance from the source.
- $A = A_0 e^{-\alpha x}$ - DO NOT NEED TO KNOW THIS
- A= Amplitude or pressure of the sound wave
- A_0 = initial amplitude of the sound wave
- α= amplitude attenuation coefficient
- x=distance travelled by the sound

Reflection at 90 degrees



- Sound at 90 degrees gives the best echoes – operators try to keep the probe at this angle



<u>Amount of reflection at different surfaces</u>

Tissue boundary	Reflection
Muscle - liver	2%
Fat - muscle	10%
Muscle – bone	64%
Muscle - air	99%

- Some of the remaining sound is transmitted

<u>Refraction</u>

- Where the angle of incidence is not 90º
- C (speed) changes between the mediums
- Then the direction of propagation changes

Refraction of **waves** involves a change in the direction of **waves** as they pass from one medium to another. **Refraction**, or bending of the path of the **waves**, is accompanied by a change in speed and wavelength of the **waves**.

For non-perpendicular incidence on an interface between two media with different speeds of sound, the transmitted wave will not continue along the straight-line path of the incident pulse but rather will be deflected by some angle.

<u>Absorption</u>

- Conversion of the ultrasound wave's mechanical energy to heat energy
- Safety issue

- Low absorption in water
- High in bone

Detection and display

- Echoes are processed by the US scanner in a number of steps
- Amplification in the ***receiver*** occurs at several stages
- The echo signals are all **uniformly pre-amplified** immediately after detection by the transducer, and a uniform user-controllable gain can also be applied.
- To overcome the effects of attenuation, **a depth-dependent gain is applied** to the echoes, with echoes originating deeper in the patient (which are attenuated to a larger degree) having larger gain factors than those originating closer to the transducer.
  - The effect of this process is to cause equally reflective structures to be displayed in the B-mode image with the same brightness, regardless of their depth
  - Called swept gain, depth-gain compensation (DGC), and time-gain compensation (TGC depending on manufacturer

- Compression of the dynamic range of the echo signal
  - Dynamic range refers to the ratio of the largest and smallest signal levels at any particular processing stage.
  - detected echo signals can exceed 150 dB in dynamic range. Even after depth-dependent amplification may still be 50–60 dB or greater.
- This signal range is too large to be properly presented on an 8-bit/pixel electronic display, so the dynamic range must be further reduced

The process – HOW DOES US WORK OR HOW DO WE GENARATE A US IMAGE?

1. Alternating electrical current applied to PZT crystal (lead, zinctate
↓
2. Crystal vibrates/rings at a frequency
↓
3. Inaudible sound and mechanical wave emitted
↓
4. Wave interacts with tissue (reflection depending on the acoustic impedance difference at the interface)
↓
5. US machine receives echo (reflected wave) and converts it to electrical current
Then Amplification and also dynamic range compression takes place
↓
6. Assigns a grey level according to frequency & amplitude (volume) of echo

ULTRASOUND SAFETY ISSUES

Who governs sonographers?

- HCPC?
- BMUS-British medical ultrasound society
- UKAS- United Kingdom association of Sonographers
- EFSUMB- European federation of societies for ultrasound in medicine and biology
- WFUMB- World federation for ultrasound in medicine and biology

Is ultrasound safe?

- Diagnostic ultrasound has been in clinical use for at least 30 years. Millions of examinations have been performed but there has been no independently confirmed report that the technique causes harm to patients
- It is perceived safety has encouraged its widespread application in medicine

- The biological effects of ultrasound are still not fully understood and care is required for certain applications
- Acoustic output from medical diagnostic systems has risen steadily over the years
- Therefore the potential to cause a biological effect has increased
- Caution advised in pregnancy with endovaginal scans and high powered doppler scans

Intensity

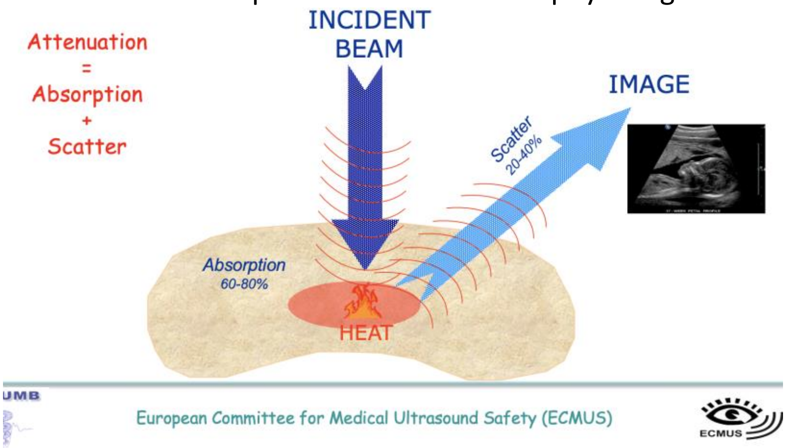
- Acoustic intensity is defined as the power per unit cross-sectional area of the ultrasound pulse.
- Ultrasound that is tightly concentrated or focused has a higher intensity than ultrasound emitted with the same power but spread over a broader area.
- Intensity is correlated with the likelihood of bio effects resulting from exposure to ultrasound.

Safety

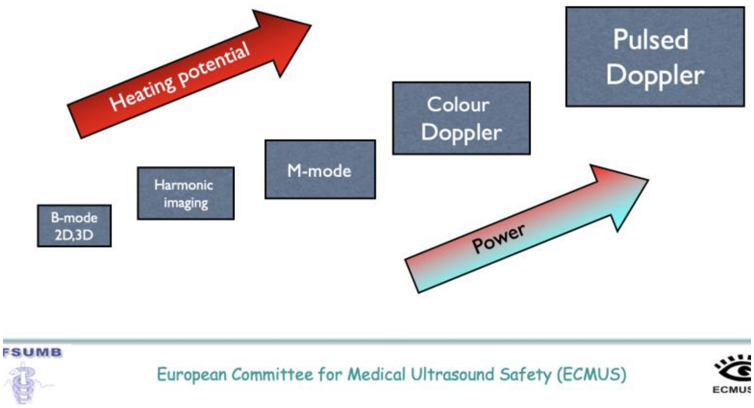
- Biological effects of ultrasound
  - **Thermal and Mechanical Indices**
- Legislation regarding who can scan and which organisation govern them
- Safe practice - ALARA
- Other bioeffects? (any evidence?)

Biological effects

- 1. Cavitation
    - Growth, oscillation and decay of gas bubbles
    - Cavitation- failure of liquid at very low pressures causing water vapour bubbles which collapse explosively
        - *the bubble fills with vapour and grows rapidly in size (almost three orders of magnitude)and then collapse violently, giving rise to high pressures and temperature*
    - Gas filled organs – lung, bowel
- 2. Heating
    - Absorption of u/s wave
    - Increases with frequency
    - Dependent on factors such as beam intensity, focusing, depth, type of tissue, time and blood supply
    - Temps 1.5°C above normal physiological levels not harmful (WFUMB)



Increases with: frequency,
exposure duration,
pulse repetition frequency



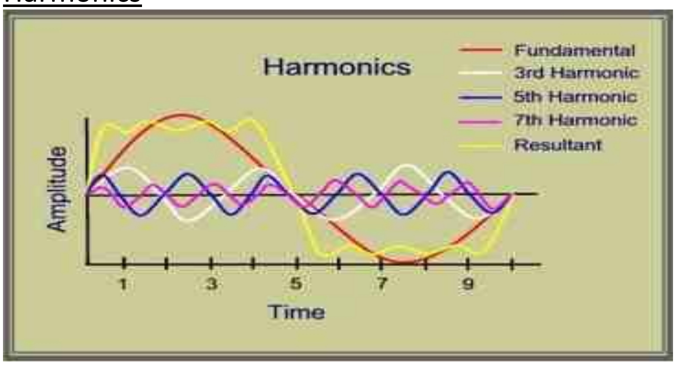
Contrast – enhanced US - microbubbles

- Ultrasound (US) contrast agents consist of a sphere of gas microbubbles enclosed by a stabilizing biodegradable shell of protein, lipid or polymer
- Diameter of between 1-10μm
- microbubbles are able to pass through the lungs unfiltered but remain wholly intravascular
- Similar to red blood cells and consequently called blood pool agents (remains in blood for 10 mins)
- any signal that is obtained from the microbubbles can be assumed to emanate from the blood
- Thus, microbubbles are used mainly for intravascular imaging

Contrast enhanced Ultrasound – How does it work?

- The intensity of the echo returning to the transducer is proportional to the difference in acoustic impedance(density) between the blood and gas in the microbubble
- Due to the big difference of acoustic impedance at the boundary between blood and gas all the incident sound is reflected(backscatter) back to the transducer
- This backscatter is greater than it would have been without the contrast agent.

Harmonics



Harmonics are a multiple of a fundamental frequency – a 2nd harmonic is twice the frequency of the fundamental and so on – in US, tissue reflections can produce harmonics. A transducer can transmit at f and receive at 2f etc

Why are harmonics useful?

- Sound produced contains higher frequency components (harmonics) which are a multiple of the fundamental frequency (like in a guitar)
- Second harmonic is separated from the fundamental frequency using filters

- Harmonics are formed most in centre of beam
- The higher f values gives improved SNR and resolution, useful in large and hard to examine patients, lesion depiction

<u>Your role</u>

- Mostly observing
- Make yourself useful by assisting with tasks
- Ask the Sonographer what you can help with
- Do not be hurt if a patient refuses for you to be present during the scan
- Psychologically prepare- patients might be receiving bad news

<u>Fluoroscopy equipment</u>

- Imaging moving structures in 'real-time'
- Using x-rays
- Diagnostic or guiding treatment
- Fluorescence

- "Materials called **phosphors** absorb **high-energy photons**, such as X-rays, and emit short bursts of **visible light photons**"

Why do we use fluoroscopy?

- Barium Studies
    - e.g. barium swallows
- Urology theatre
    - e.g. Nephrostomy insertion
- Orthopaedic theatre
    - e.g. Fracture reduction

    - Contrast studies e.g. HSG (Hysterosalpingogram)

    - Orthopaedic theatre
    - e.g. Fracture reduction

    - X-ray guided procedures
    - e.g. Lumbar punctures

    - Cardiology
    - E.g. pacemaker insertion

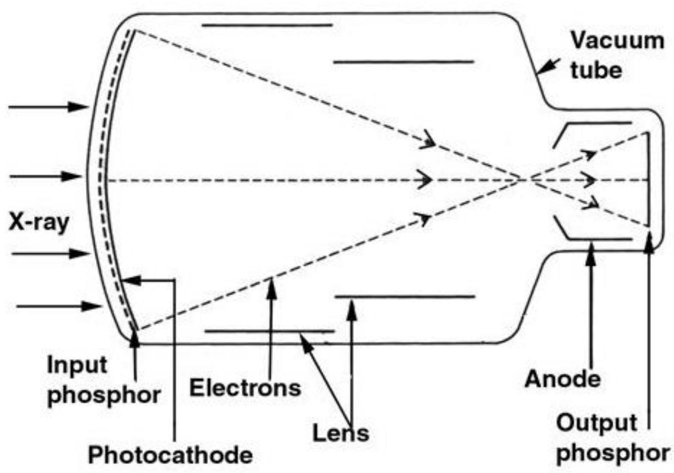
    - Endoscopy
    - E.g. ERCP (Endoscopic Retrograde Cholangiocreatography

- Angiography
- E.g. Stent insertion

Basics of a fluoroscopy unit

- Invented in the 1950s
- Converts x-rays into visible light
- Increases the brightness of the image

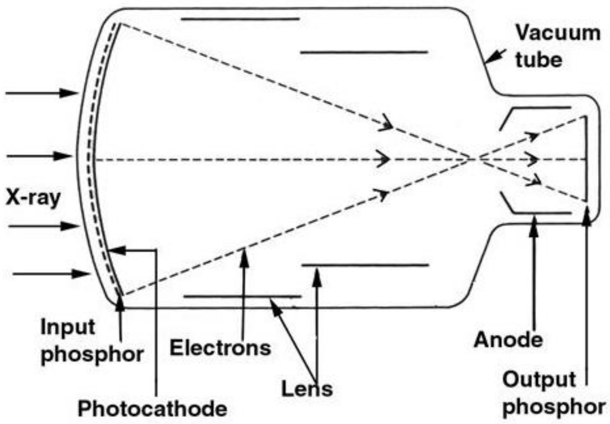
Components of a image intensitifer



Input Phosphor

- Needle-like Csl crystals
- Packed end-on
- Light channels along ‘light pipes’
- Excellent spatial resolution

Spatial resolution = the ability to distinguish between objects or structures that differ in density



Photocathode

- The photocathode releases electrons, dependant on how intense this light is
- Alloy of antinomy and caesium (SbCs3)
- Input phosphor and photocathode close contact

Output phosphor
- Converts the energy from electrons into light photons
- Silver activated Zinc Cadmium Sulphide (ZnCd:Ag)

How does this make the image brighter?

Minification gain

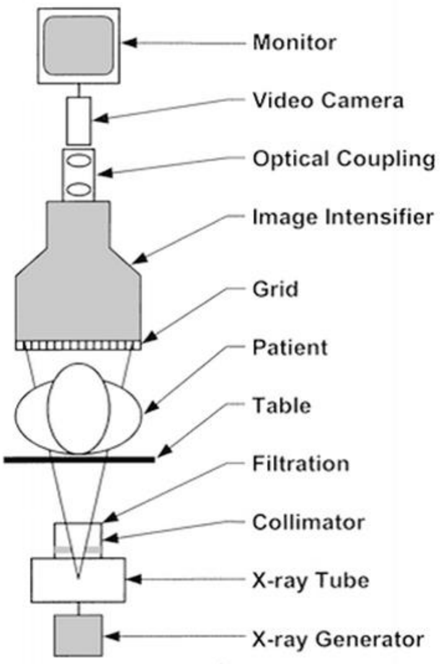
- Output phosphor is smaller than the input phosphor
- Set number of light photons emitted from smaller area means increased image brightness

Flux gain

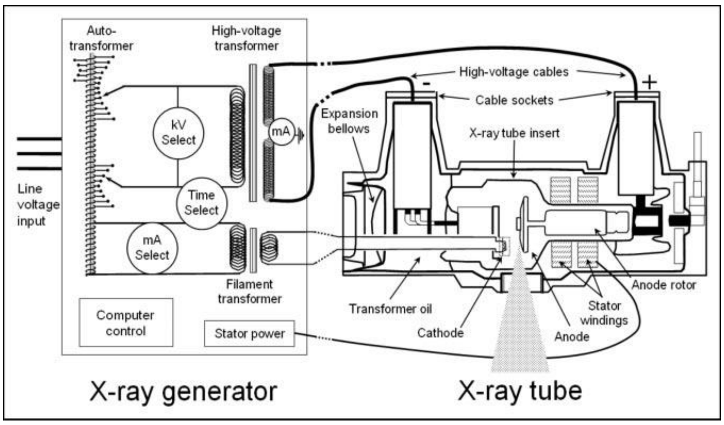
- High voltage of electrons from photocathode to output phosphor
- Gain kinetic energy from the electric field

Total Brightness Gain = Minification gain x Flux gain

Components of fluoroscopic equipment



X ray generator



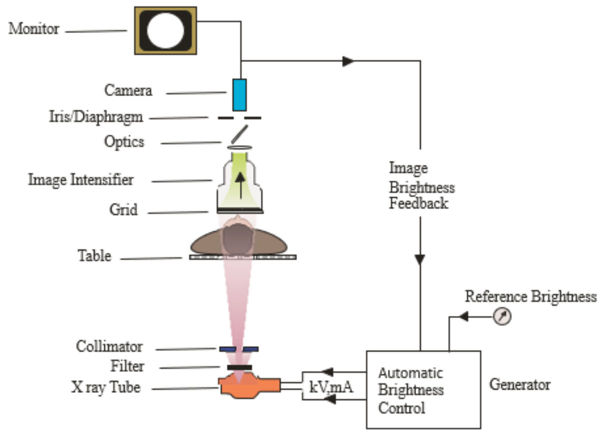
Continuous fluoroscopy

- Provides steady tube current
- 30 images per second, 33msec per image

Pulsed fluoroscopy

- Exposure in short bursts
- 30 images per second, 3-10msec per image
- Use lowest pulse rate - can reduce patient dose

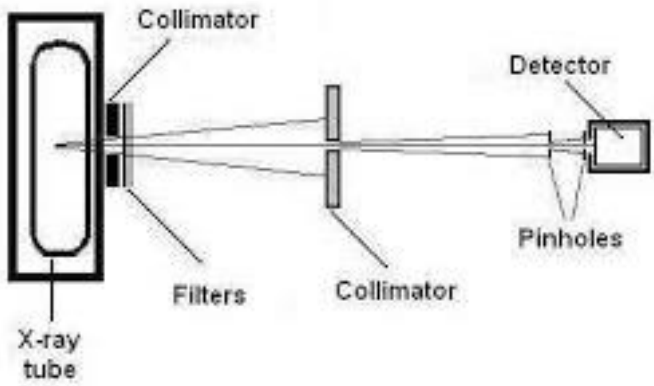
Automatic brightness control (ABC)



- Ensure constant brightness
- Compensates for differences in tissue thickness and attenuation
- Automatically adjusts kV and mA to achieve predefined image brightness

<u>Automatic Brightness Control (modes)</u>

<u>Components of fluoroscopic equipment</u>
<u>Filters & Collimators</u>



<u>Filters</u>

- Aluminium
- Attenuate low energy X-rays
- Reduce patient dose

<u>Collimators</u>

- Collimate to area of interest
- Reduces direct exposure
- Reduces scatter

<u>Components of fluoroscopic equipment</u>
<u>Grid & Optical Coupling</u>

Grid

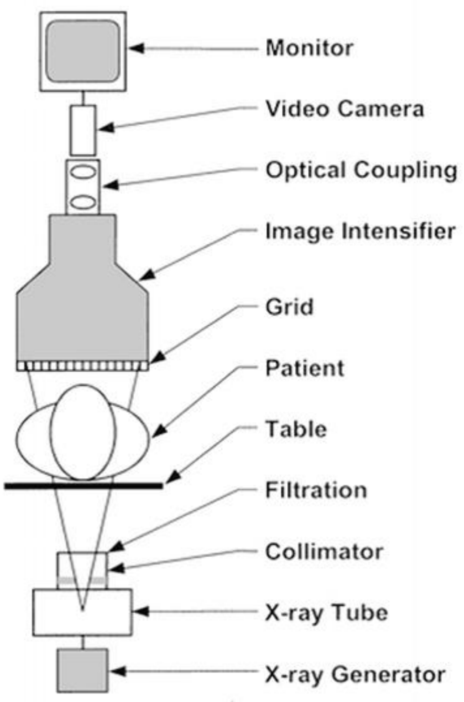
- reduces scattered radiation reaching the input phosphor
- Improves image contrast
- Can be removed for small patients/paediatrics & extremities (in theatre)

Optics/optical coupling

- the connection between the output phosphor and the camera

Camera & Monitor

- Camera
  - Cathode ray tube - Vidicon (Plumbicon = cardiac)
  - Undesirable **image lag** – blurring from movement
  - Superceded by **charge-coupled device (CCD) cameras**
  - Solid state, photodiode array
  - Converts light into proportional electrical signal
  - ↓↓image lag – good for fast procedures e.g. cardiac
- Monitor

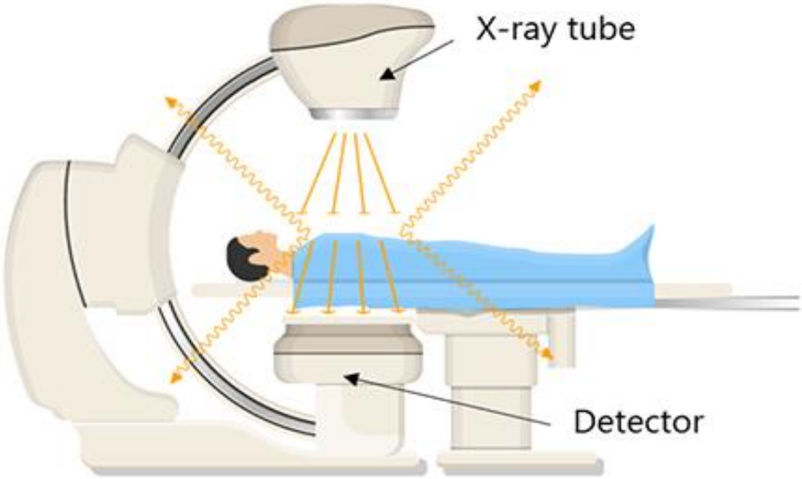


Monitor – displays the images acquired
Camera – captures the visible light to display on the monitor
Optical coupling – connects the output phosphor to the camera
Image intensifier – converts x-rays into visible light and increases the brightness of the light image
Grid – reduces scattered radiation & improves image quality
Table – where the patient lays
Filters – reduce patient dose through attenuating low energy x-rays
Collimators – define the shape of the x-ray beam

X-ray tube & Generator – produces the x-rays

Types of fluoroscopy units

Overcouch



Under couch

Flat panel detectors

Indirect conversion

- X-ray photons to light photons
- Scintillation crystals (caesium iodide)

- Light to electrical charge
- Photodiode (amorphous silicon)
- Charge read and sent to image processor

Direct conversion

- X-ray photons to electrical charge
- Photoconductive material (amorphous selenium)
- Charge stored in a capacitor to be read

Dose measurement

- DAP = Dose Area Product
- DAP meter is an ionisation chamber between the collimators and the patient
- Good estimation of total radiation delivered to patient
- DAP = absorbed radiation dose (to air) X area of the x-ray field
- Measured in $mGycm^2$
- Always record fluoroscopy time and DAP