

## Principles of operation of DXA systems

Dr Wil Evans  
Head of Medical Physics  
University Hospital of Wales, Cardiff

## What does DXA mean and why is it important?

- DXA stands for Dual energy X-ray Absorptiometry - the measurement of absorption of x-rays at two different energies
- Sometimes the longer abbreviation DEXA is used
- Widely accepted method of bone densitometry - measuring bone mineral density (BMD)
- Bone densitometry is important for assessing fracture risk, diagnosing osteoporosis, making decisions about patient management and monitoring change of BMD

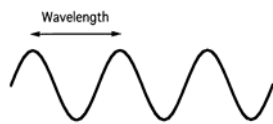
## How can we measure bone mineral density?

- What agents can we use?
  - Radiation (x and gamma)
  - Ultrasound
- What properties can we measure?
  - Velocity
  - Attenuation (reduction of intensity)

## What is radiation?

- X and gamma rays are types of electromagnetic radiation
- Similar in nature to ordinary visible light
- Light (and other types of electromagnetic radiation) exist in two forms

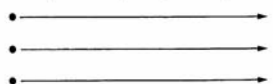
Is light made of waves....



Wavelength = 0.4 (blue light) to 0.6 (red light) micrometres

1 micrometre = 1 millionth of a metre

....or particles (called photons)?

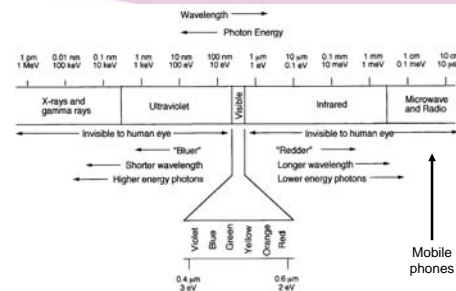


Photon energy = 2 (red light) to 3 (blue light) electronvolts

1 eV =  $1.6 \times 10^{-19}$  joules

- For phenomena such as interference and polarisation, we need the wave picture of radiation
- To describe the interaction of radiation with matter, we need the photon picture

## What kinds of electromagnetic radiation are there?



- X and gamma – very short wavelength ( $1 \text{ nm} = 10^{-9} \text{ m}$ ) and very high photon energy ( $1 \text{ keV} = 10^3 \text{ eV}$ )

## X and gamma rays

Wavelength is 50,000 times smaller than light  
Photon energy is 50,000 times larger than light

## Radio waves (mobile phones)

Wavelength is 500,000 times longer than light  
Photon energy is 500,000 times smaller than light

## What are the radiation methods for bone densitometry?

- Photon absorptiometry
- X-ray absorptiometry
- Quantitative computed tomography

## What about photon absorptiometry?

- Used radioactive source of x or gamma radiation
- Single photon absorptiometry (SPA) for peripheral skeletal sites
- Dual photon absorptiometry (DPA) for axial skeletal sites
- Superseded by x-ray absorptiometry

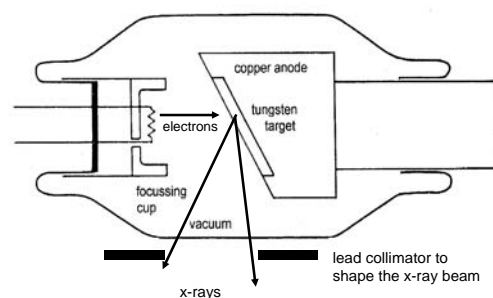
## What are the radiation methods for bone densitometry?

- Photon absorptiometry
- X-ray absorptiometry
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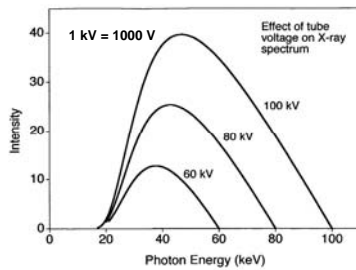
## Where do x-rays come from?

- X-rays are produced in an x-ray tube
- Tiny negatively charged particles called electrons are released from a wire filament when it is heated
- Electrons are accelerated by a high voltage towards metal target made of tungsten
- In the target some of the electron kinetic energy is converted to x-ray energy (i.e. x-ray photons) – the remainder appears as heat

## What does an x-ray tube look like?



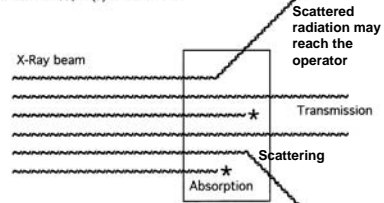
## What is the energy of the x-rays?



- X-ray photons have a wide range of energies with a maximum energy determined by the voltage applied across the x-ray tube
- As the voltage increases the average x-ray photon energy increases and the total x-ray intensity increases

## What happens when x-rays pass through the body?

When X-ray photons pass through the body they are either: (1) transmitted totally unaffected; (2) are absorbed, or (3) are scattered

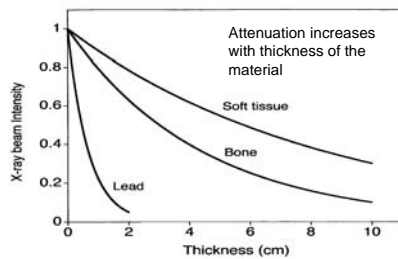


Absorption and scattering deposit some of the x-ray energy in the patient - this is the radiation dose

Attenuation = Absorption + Scattering

- Attenuation is the reduction in intensity of the x-ray beam
- Radiation detector used to measure transmitted intensity so that attenuation can be calculated

## Does attenuation depend on the material?



- For a given thickness the attenuation increases with the density of the material
- This is the basis of x-ray bone densitometry methods

## How would you do x-ray absorptiometry?

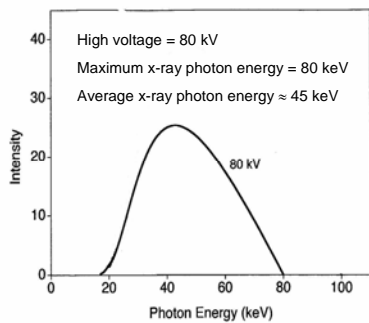
- Pass an x-ray beam through a part of the body containing bone
- Measure the attenuation and solve an equation to convert this to a thickness of bone mineral expressed as an area density in g per cm<sup>2</sup> (proportional to thickness)
- BUT some of the attenuation is due to soft tissue surrounding bone
- We have two unknown quantities (the thickness of bone mineral and the thickness of soft tissue) and only one equation - PROBLEM

How do we get over the problem that a measured x-ray attenuation is due to an unknown amount of bone mineral and an unknown amount of soft tissue?

## What types of x-ray absorptiometry are there?

- Single energy x-ray absorptiometry SXA
- Dual energy x-ray absorptiometry DXA

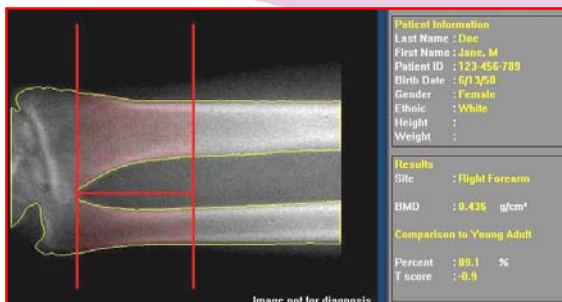
## What is the x-ray spectrum for SXA?



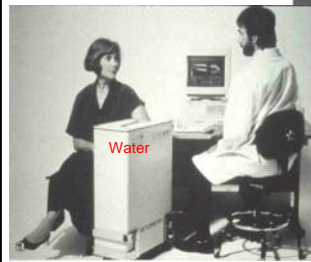
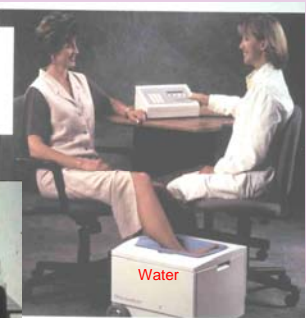
## How does single energy x-ray absorptiometry work?

- Surround body part with water to keep total thickness constant
- Restrict to peripheral sites e.g. heel or forearm
- Scan beam over the bone and measure extra attenuation through bone at many points
- Calculate area density of bone mineral at each point
- Sum over bone area to give bone mineral content (BMC) in g
- Divide BMC by bone area to give average bone mineral density (BMD) in g per  $\text{cm}^2$

## What is the output from a SXA scan?



## SXA of the heel

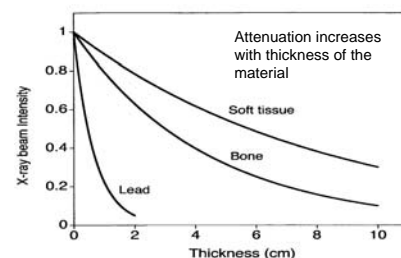


## SXA of the forearm

## What types of x-ray absorptiometry are there?

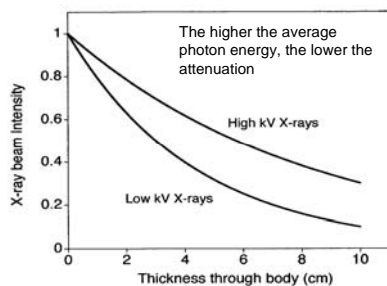
- Single energy x-ray absorptiometry    SXA
- Dual energy x-ray absorptiometry    DXA

## Does attenuation depend on the material?



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## Does attenuation depend on x-ray photon energy?

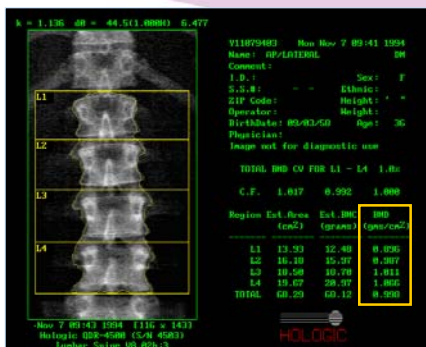


- The dependence of attenuation on both the material and the average x-ray photon energy is the basis of DXA
- Allows us to measure the amounts of both bone mineral and soft tissue

## How does dual energy x-ray absorptiometry work?

- Use x-ray beam which has two different average x-ray energies
- Measure attenuation at high and low energies
- Calculate area density at each point by solving two simultaneous equations
- Calculate BMC, bone area and average BMD
- No need to keep total thickness constant
- Can measure at axial sites e.g. spine and hip as well as peripheral sites (pDXA)

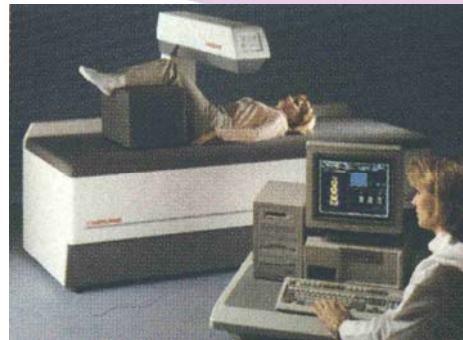
## What is the output from an axial DXA scan?



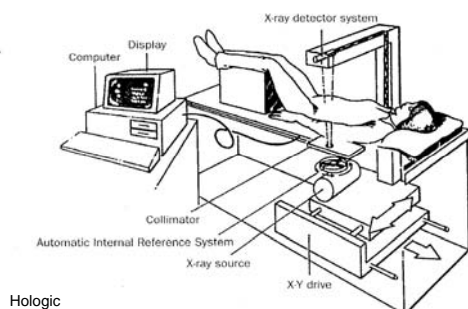
BMD (Bone Mineral Density) – area density in g per cm<sup>2</sup>

## What does a DXA scanner look like from the outside?

Patient in position for a lumbar spine scan



## What is inside a DXA scanner?

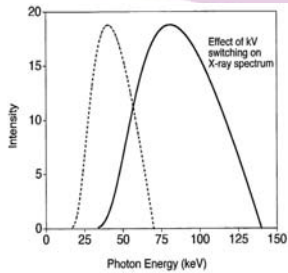


Hologic

## How do we generate two different average x-ray energies?

- Either continuously switch high voltage between high and low values
- Or use carefully chosen metal filter (thin sheet of a special metal) to create two separate energy peaks in x-ray spectrum

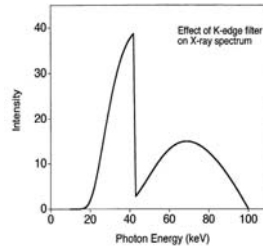
### What is the x-ray spectrum for DXA with voltage switching?



Dual energy x-ray beam produced by continuously switching the tube voltage between high and low values e.g. Hologic

- Average energies of about 90 keV (at 140 kV) and 40 keV (at 70 kV)
- At any instant only one spectrum is present

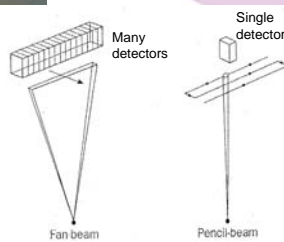
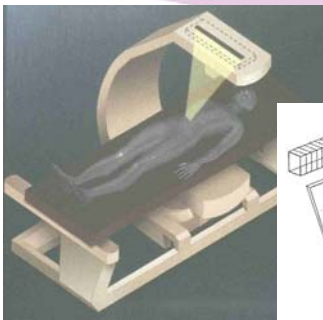
### What is the x-ray spectrum for DXA with filtration?



Dual energy X-ray beam produced by placing a metal filter in the beam to split the spectrum into high and low energy parts e.g. GE/Lunar and Norland

- Energy peaks at about 70 keV and 35 keV
- Spectrum looks like this all the time

### What does the x-ray beam look like?



### What are the differences between pencil-beam and fan-beam DXA systems?

#### Pencil-beam DXA

- Older technology
- Scan time 5-10 min
- Good image quality
- Low patient dose (~1  $\mu$ Sv)

#### Fan-beam DXA

- Latest technology
- Scan time 30-60 sec
- Better image quality
- Low patient dose (~10  $\mu$ Sv)

### What do pDXA scanners look like?



pDXA of the forearm

pDXA of the heel



No water needed

### What are the differences between axial DXA and peripheral DXA?

#### Axial DXA

- Used for scanning spine and femur
- X-ray tube voltage ~ 80-140 kV
- Low patient dose (~10  $\mu$ Sv)

#### Peripheral DXA

- Used for scanning forearm and heel
- X-ray tube voltage ~ 40-60 kV
- Very low patient dose (~ 0.1  $\mu$ Sv)

### **What are the key points about DXA?**

- DXA is an excellent example of how the application of radiation physics has produced an indispensable clinical tool
- DXA is firmly established as a low radiation dose and relatively low cost technology
- Combined with imaging capability for fracture identification DXA is likely to continue to be used for the diagnosis and management of osteoporosis for some time