Principles of operation of DXA systems

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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

What kinds of electromagnetic radiation are there?
• X and gamma – very short wavelength (1 nm = 10⁻⁹ m) and very high photon energy (1 keV = 10³ eV)
X and gamma rays

Wave length is 50,000 times smaller than light
Photon energy is 50,000 times larger than light

Radio waves (mobile phones)

Wave length 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• Superseded by x-ray absorptiometry

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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?

[Diagram of an x-ray tube]

- copper anode
- tungsten target
- x-rays
- load collimator to shape the x-ray beam
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?

- 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 cm² (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.

What types of x-ray absorptiometry are there?

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

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?

- Scattering and scattering deposit some of the x-ray energy in the patient - this is the radiation dose.
**What is the x-ray spectrum for SXA?**

- High voltage = 80 kV
- Maximum x-ray photon energy = 80 keV
- Average x-ray photon energy ≈ 45 keV

**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 cm²

**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?**

- For a given thickness the attenuation increases with the density of the material
- This is the basis of x-ray bone densitometry methods
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 cm².

What does a DXA scanner look like from the outside?

Patient in position for a lumbar spine scan.

What is inside a DXA scanner?

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?

Many detectors

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 µSv)

Fan-beam DXA
- Latest technology
- Scan time 30-60 sec
- Better image quality
- Low patient dose (~10 µSv)

What do pDXA scanners look like?

pDXA of the forearm

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 µSv)

Peripheral DXA
- Used for scanning forearm and heel
- X-ray tube voltage ~ 40-80 kV
- Very low patient dose (~ 0.1 µSv)
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