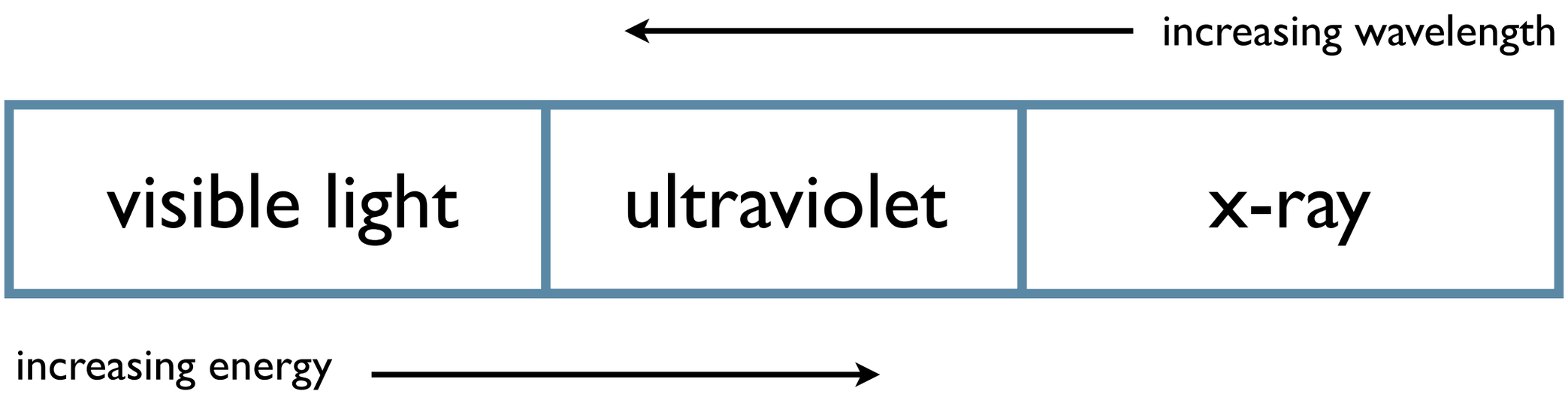
X-Rays and endoscopes

What are X-rays?

'X-ray' refers to electromagnetic radiation with a wavelength between 0.01nm - 10nm.

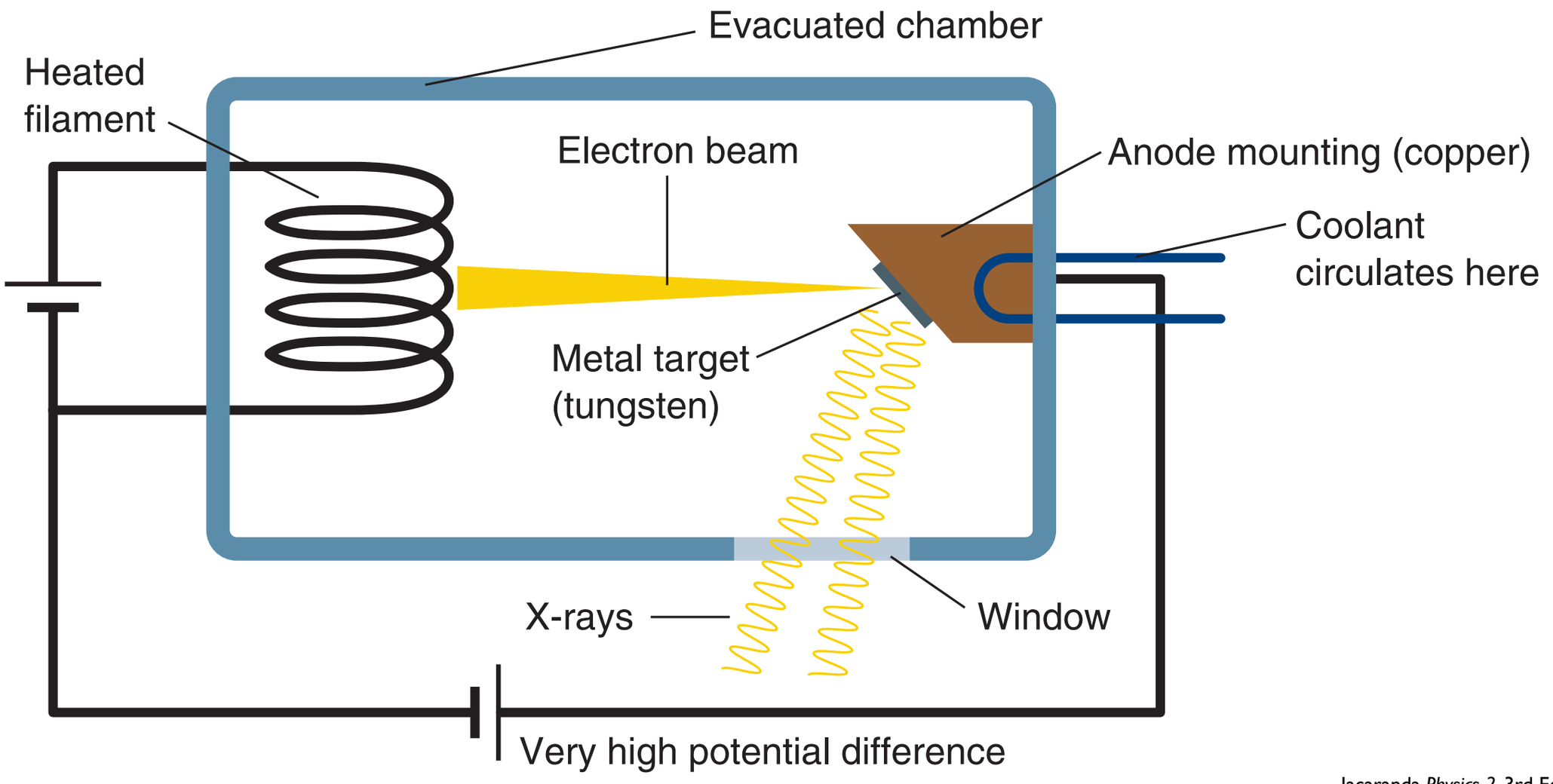


X-rays are used in imaging because their energy is sufficiently high to penetrate human tissue. They were first studied systematically in 1895 by Wilhelm Röntgen (he later received a Nobel prize).

http://en.wikipedia.org/wiki/File:Roentgen2.jpg
http://en.wikipedia.org/wiki/Xray#Sources

Making X-rays

X-rays are generated using similar principles to a discharge tube. Electrons travel inside an evacuated tube and strike a tungsten anode. X-rays are released during this collision.



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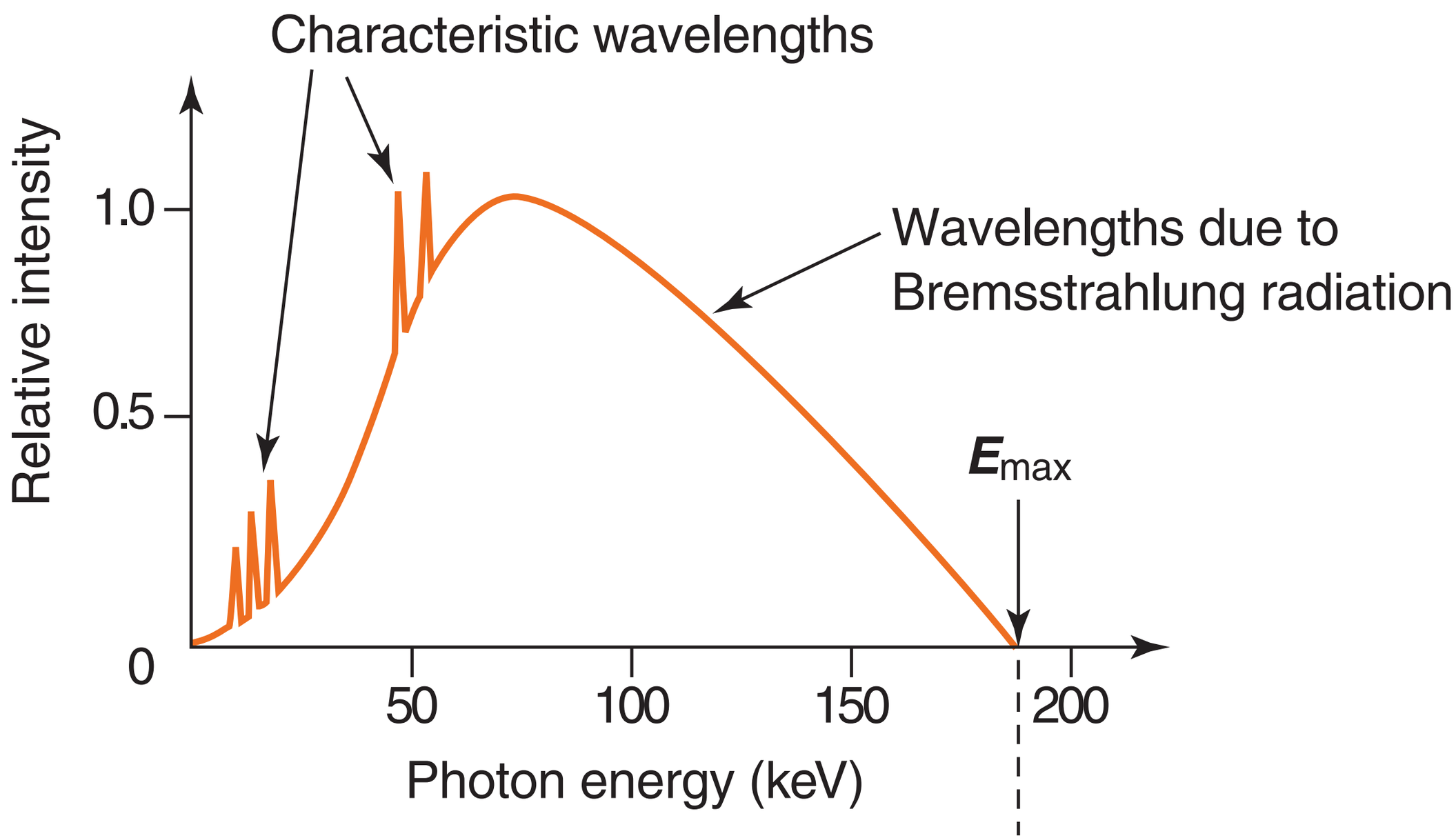
continued...

- Only a very small percentage (~1%) of the energy reaching the anode is released as x-ray radiation. The rest is released as heat. This necessitates cooling systems.
- Tungsten is used as the anode target because of its high melting point (3400˚C). Sometimes the target rotates quickly to spread the heat.
- The angle of anode is used to direct x-rays out of the device. Very high voltages (25kV - 250kV).

Releasing X-ray photons

There are two main mechanisms by which x-ray photons are released in the anode:

- **Braking** (*Bremsstrahlung)* radiation. The electron slows as it strikes the target, and the lost kinetic energy is released in a photon of X-ray radiation. This produces a spectrum of energies.
- X-ray **fluorescence**. If an electron strikes a target atom, it may excite (and liberate) a bound electron. As other electrons drop down to fill its place, X-ray radiation of specific energy is released.



Typical output of X-ray generator. The spikes are due to fluorescence and the spectrum due to braking radiation.

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Questions

1. Calculate the photon energy of the following X-ray wavelengths:

   a) 10nm
   b) 0.1nm
   c) 0.01nm

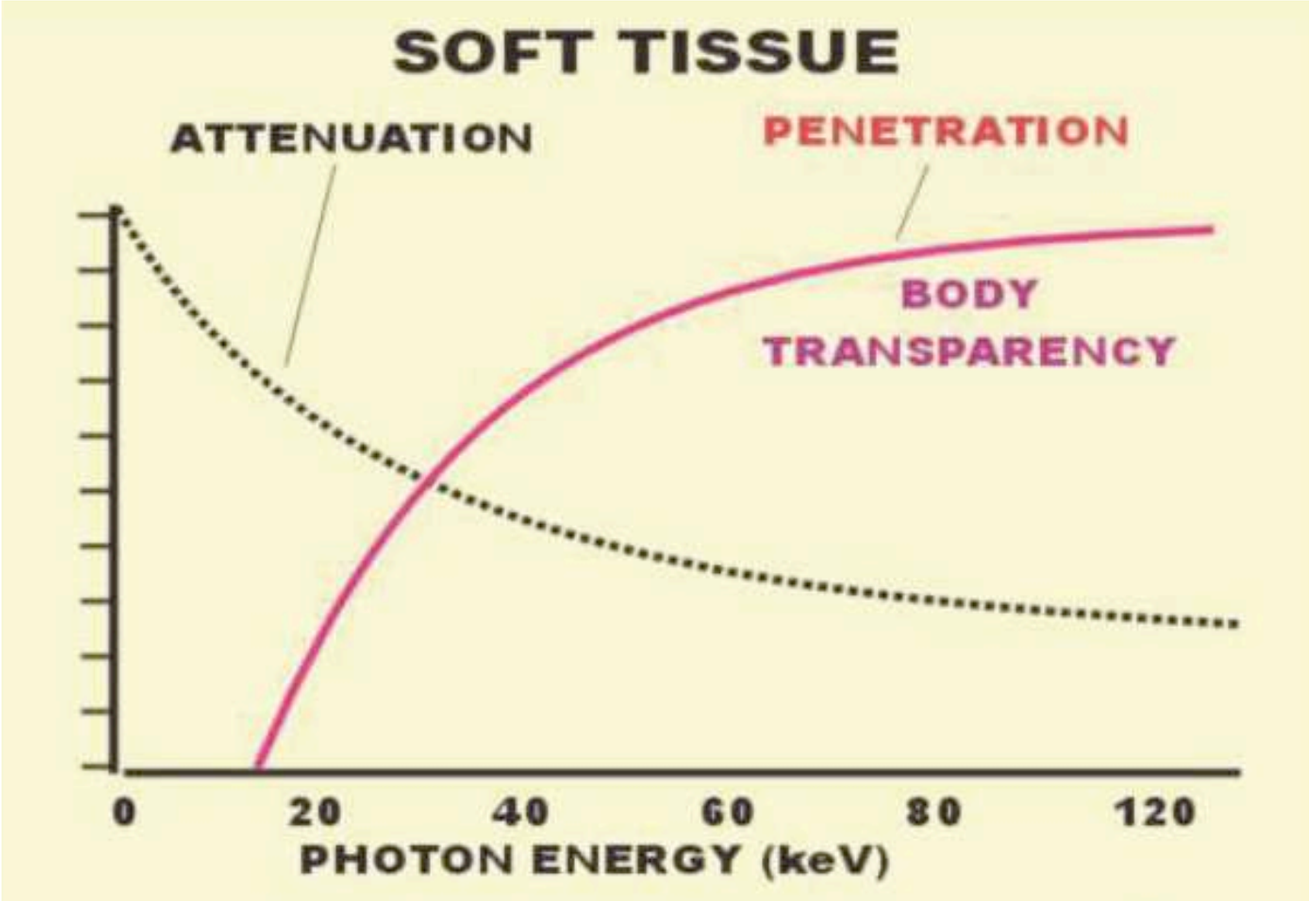
2. Convert these energies to electron volts (1eV = 1.602×10^{-19} J).

3. Ultrasound strikes a fat-soft tissue then a soft tissue-bone interface. Calculate the fraction of original wave intensity which returns to the detector.

Soft and hard X-rays

We classify X-rays as 'hard' or 'soft' depending on their penetrating ability. The boundary between the two categories is roughly 10keV (~0.1nm).

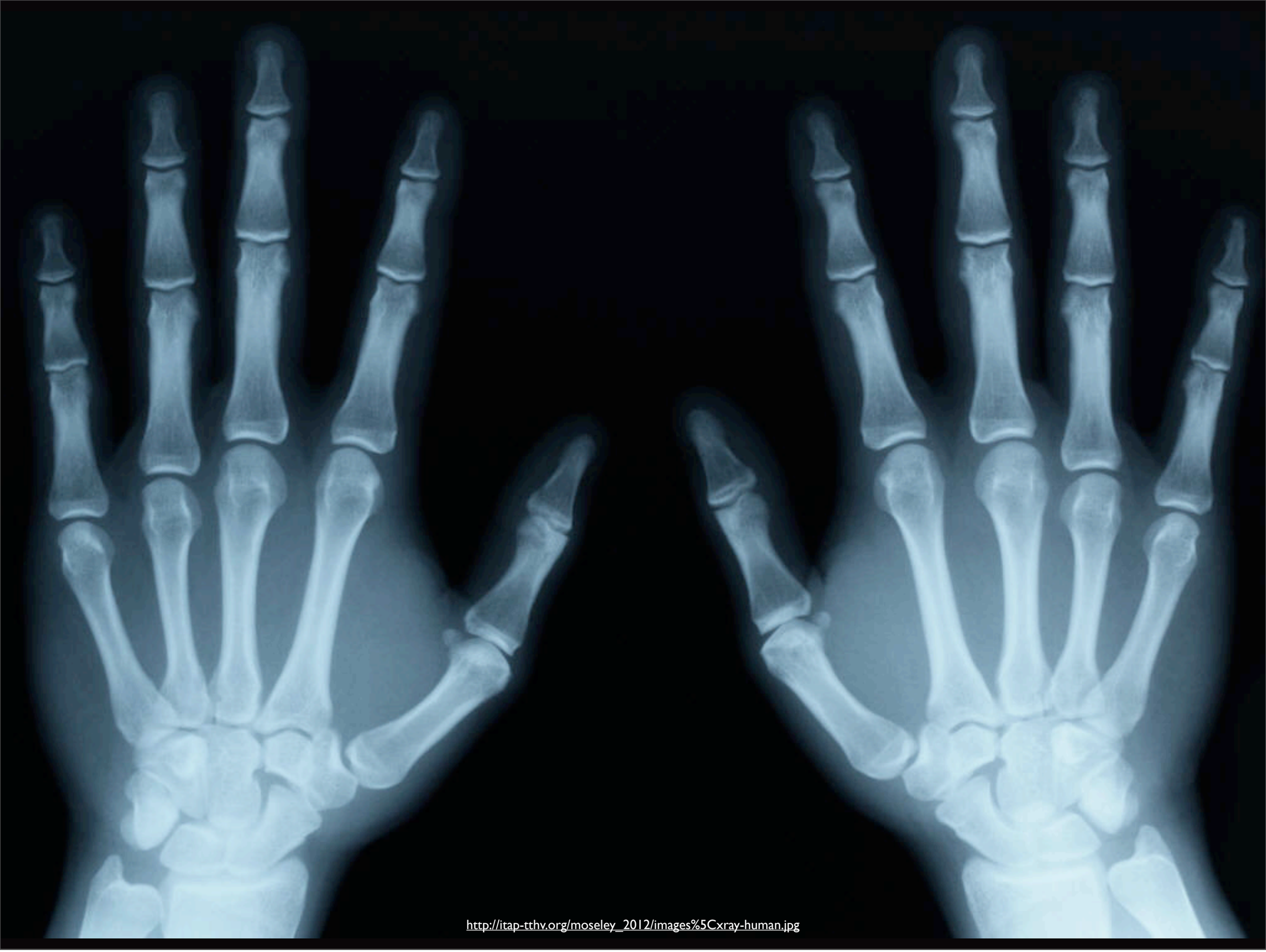
Hard X-rays are required for imaging. We try to eliminate soft X-rays because they expose patients to unnecessary radiation.



http://www.sprawls.org/visuals/XRAYCON/softtissue.jpg

Imaging with X-rays

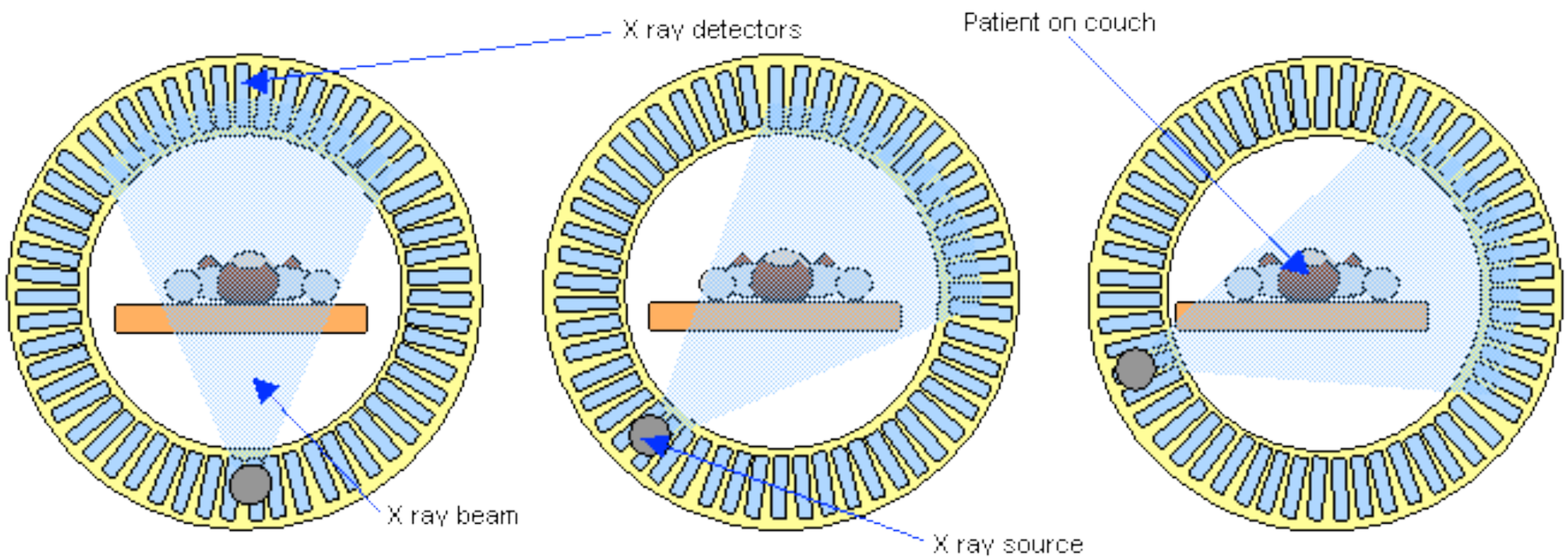
- The X-rays pass through the body and are absorbed by different structure in different amounts (eg. bones absorb more than muscle).
- A detector on the other side of the body captures the remaining radiation, which is made into an image. Photographic film was the earliest detector.
- The spacing of detectors determines maximum image **resolution**. Usually around 30keV provides the best **contrast** between different tissue.



http://itap-tthv.org/moseley_2012/images%5Cxray-human.jpg

CAT scans

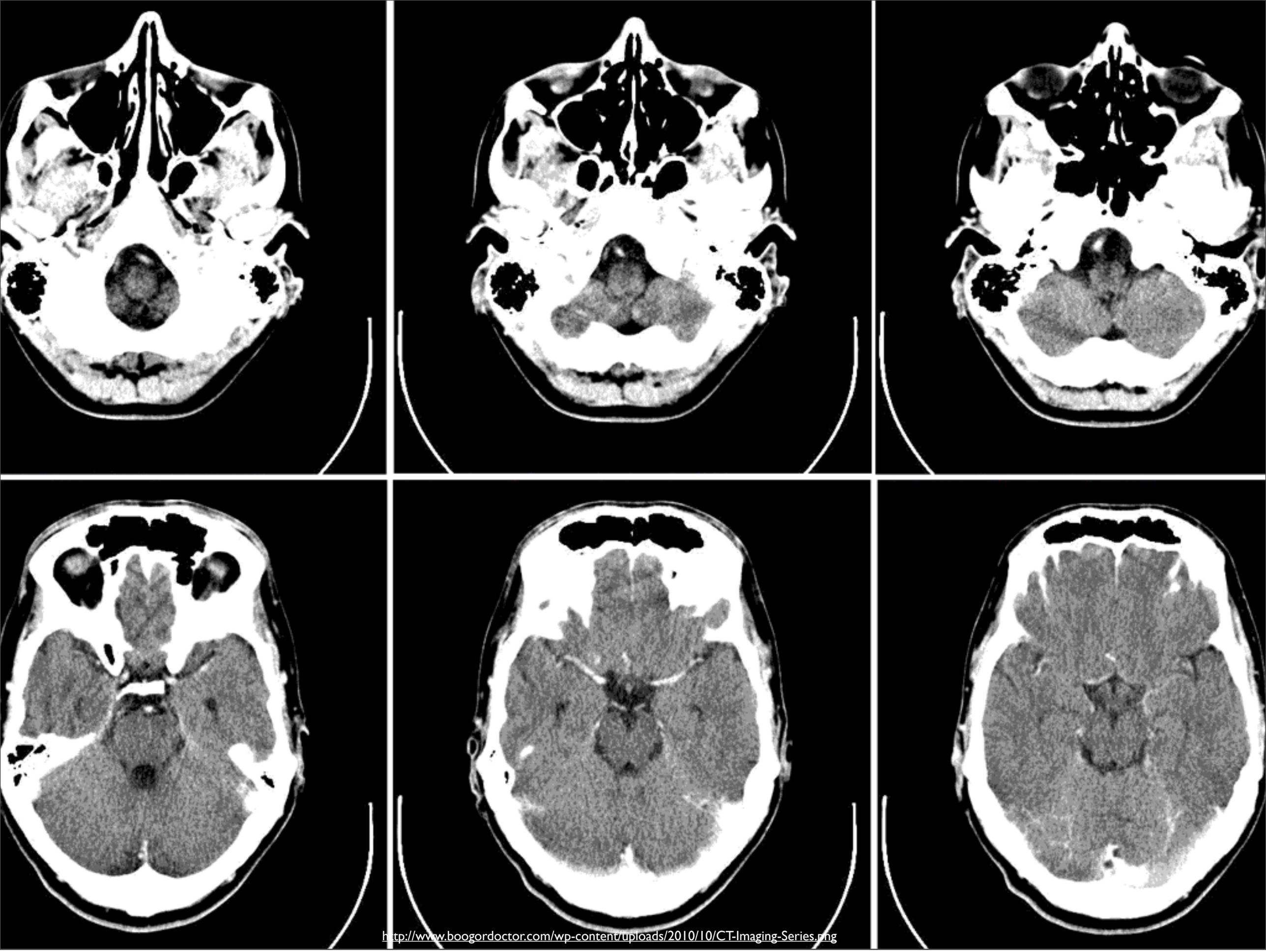
CAT (computer axial tomography) scans are produced from multiple X-rays taken through a variety of angles. An X-ray source (and array of detectors) rotate around a patient taking multiple snapshots.



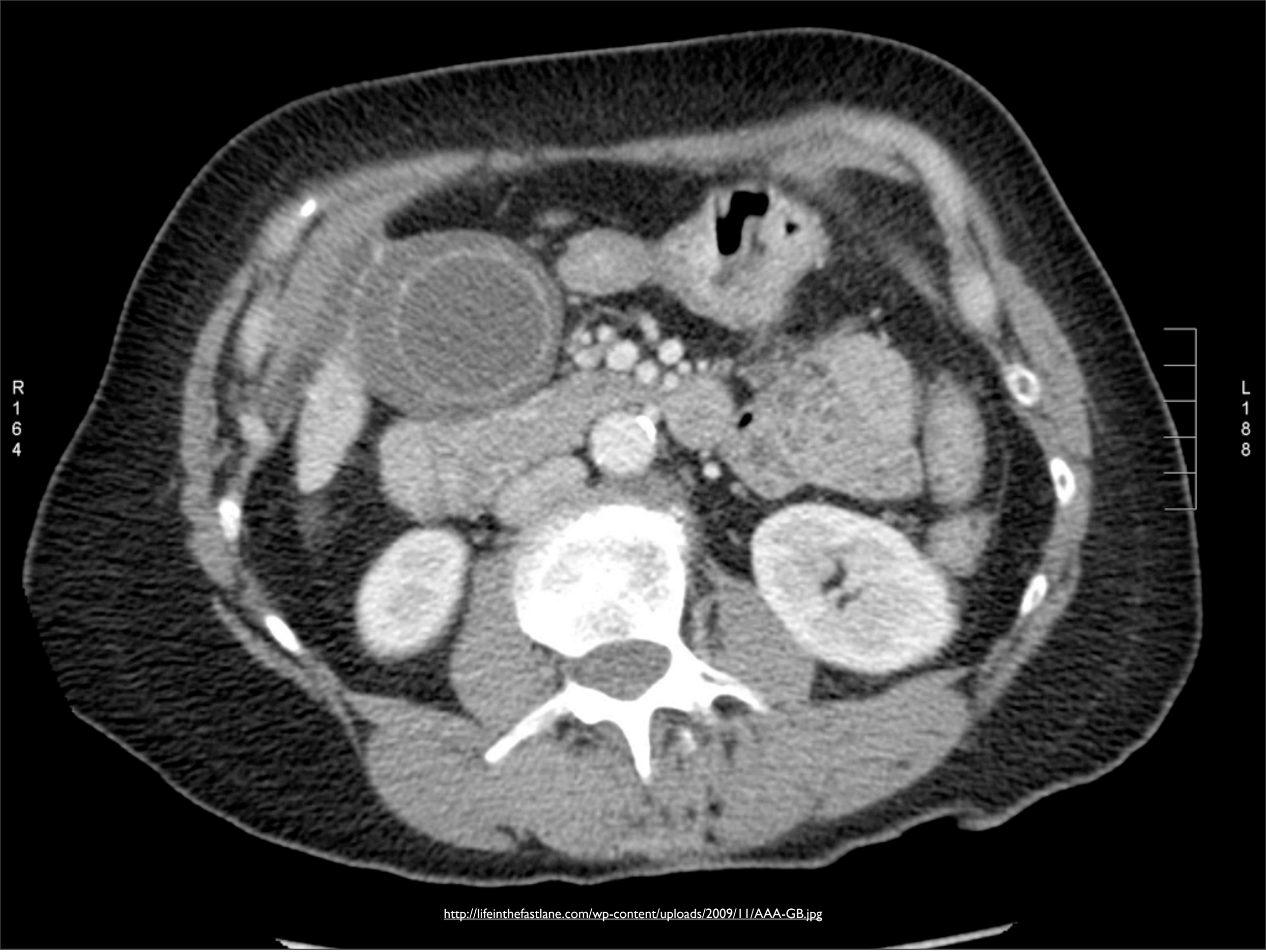
A computer combines the snapshots into one image

http://www.schoolphysics.co.uk/age16-19/Medical%20physics/text/CT_scanning/index.html

http://www.herbalifenutritionalproducts.com/wp-content/uploads/Brilliance_CT_3.jpg



http://www.boogordoctor.com/wp-content/uploads/2010/10/CT-Imaging-Series.png



http://lifeinthefastlane.com/wp-content/uploads/2009/11/AAA-GB.jpg

X-ray vs CAT

CAT scans are more expensive and expose the patient to higher levels of radiation but are preferable to X-rays in a number of situations:

- They have a much higher resolution (so they can show fine detail).
- They can image soft tissue much better than X-rays (and so can see different organs etc).
- It is possible to see behind bone (eg. the skull) because of the way that multiple scans are used.

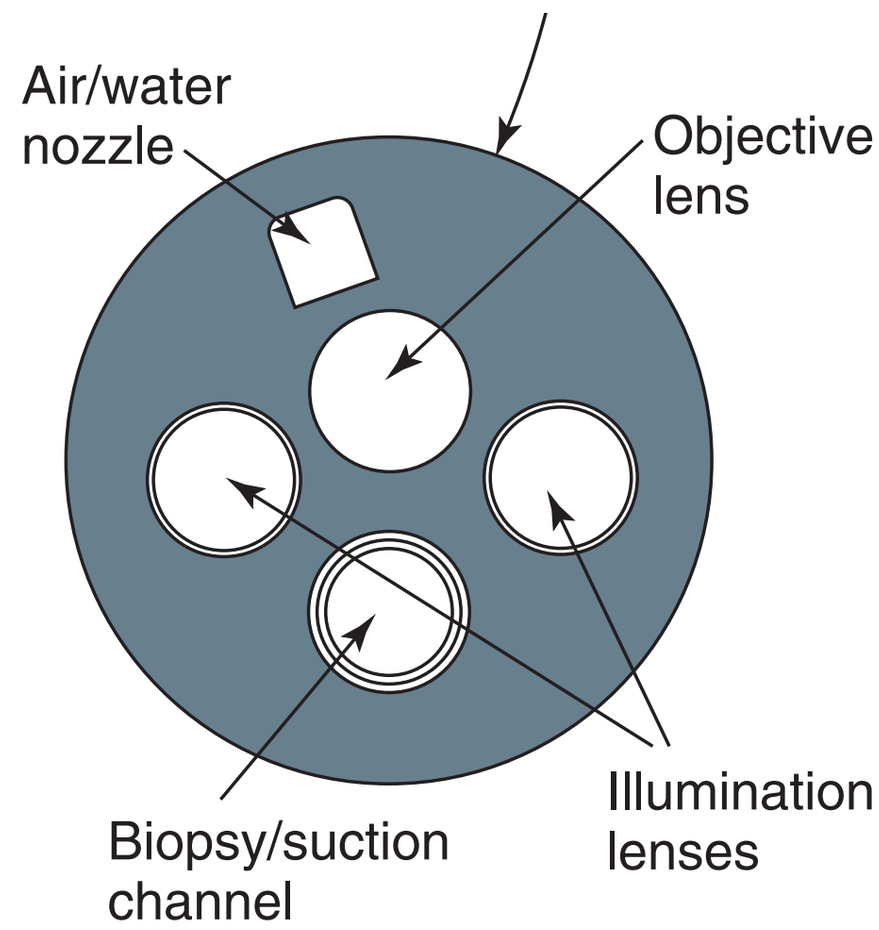
Homework

1. Print one X-ray of a bone fracture and one X-ray of something else. Discuss the contrast and resolution of each.
2. Find and print a CAT scan and X-ray of the same part of the body. Compare the two images as diagnostic tools.

Endoscopes

An endoscope is a way of imaging the human body with visible light (EM radiation). A small probe is inserted through a body opening:

Light travels to and from the probe via fibre optic systems. The incoming light illuminates the region in focus while the returning light carries an image to the operator.



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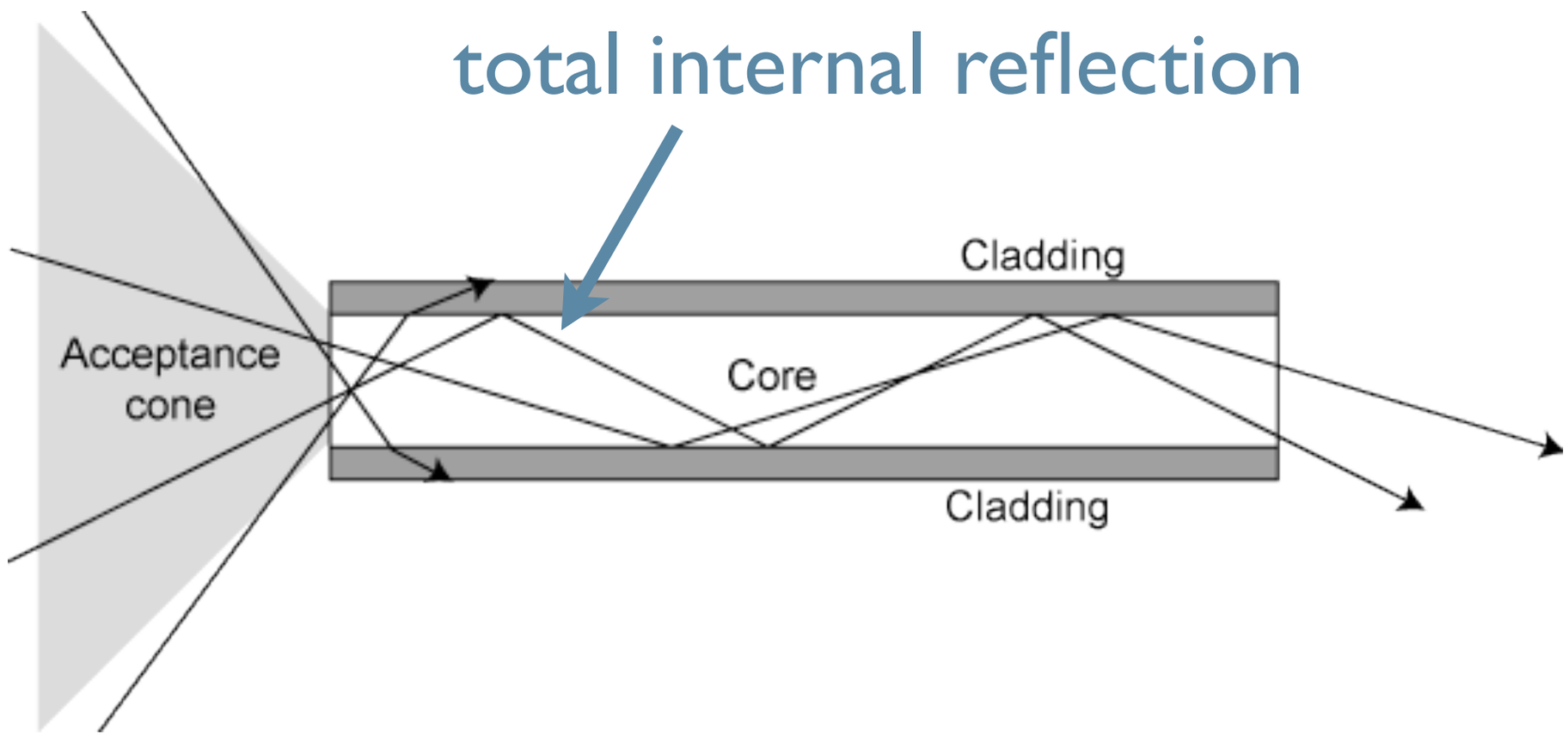
Fibre optics

Fibre optics work on the principle of total internal reflection. Each strand has a glass core surrounded by a cladding with lower refractive index.



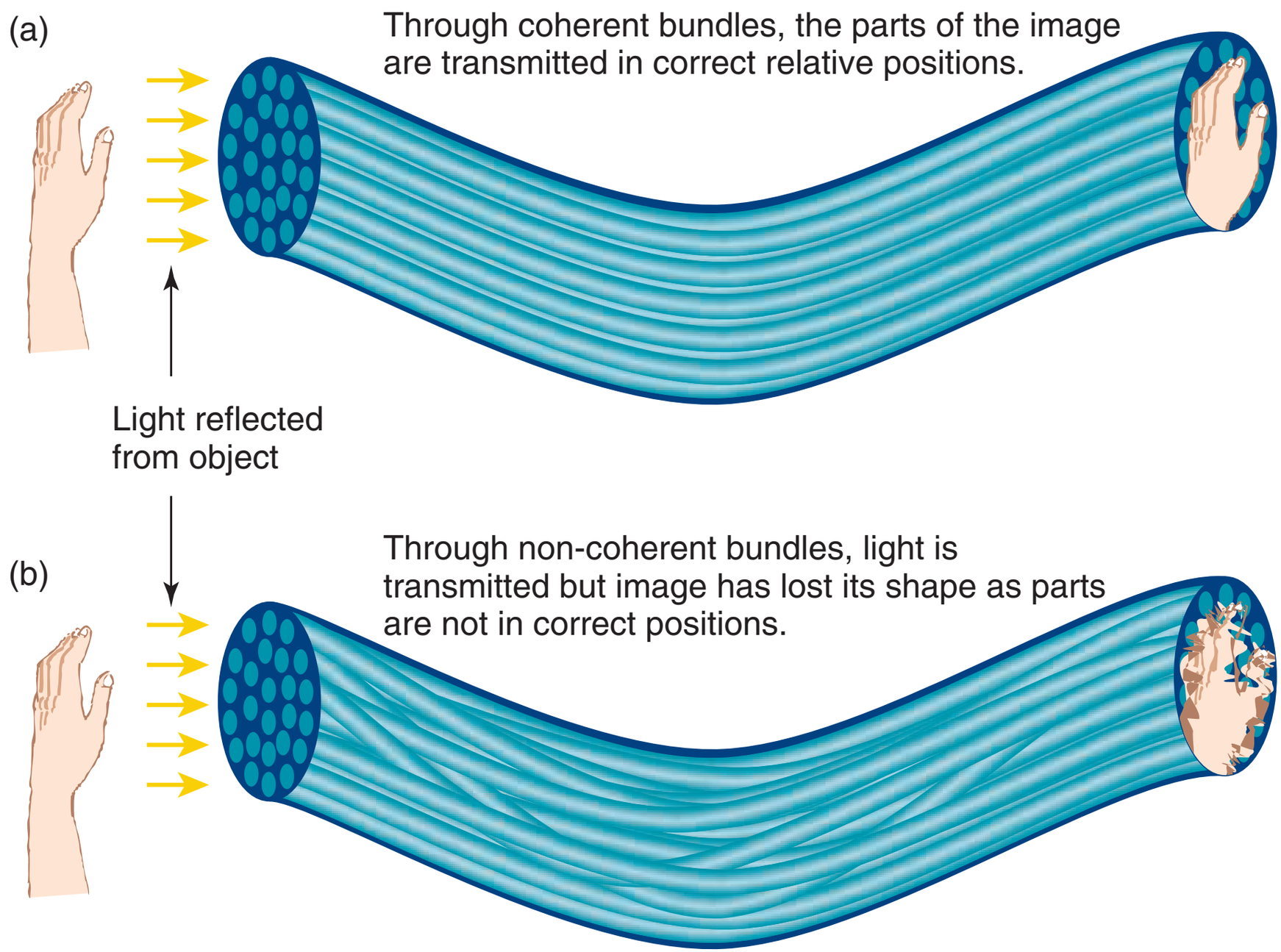
http://www.pacificcable.com/images/Fiber-Optic-Diagram.png

Coherent bundles

A fibre optic bundle (a group of fibre optic strands) can be coherent or incoherent:

- In **coherent** bundles each strand is the same length and has the same orientation at both ends of the cable. They are more expensive.
- **Incoherent** bundles do not have the same orientation at both ends, and each strand is not necessarily the same length. They are cheaper.

Each has a purpose in endoscope technology.



Coherent bundles must be used to carry the image from the probe, but incoherent bundles are fine for the incoming light to the probe.

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Putting it together

Endoscope inserted into body

↓

Light travels down incoherent bundles, illuminates body

↓

Light (image) travels back through coherent bundles

↓ ↓ ↓

realtime viewing | video camera | still camera

NAME OF PROCEDURE	PLACE OF INSERTION OF ENDOSCOPE	PURPOSE OF PROCEDURE
Arthroscopy	Through skin near joint	To examine joints and carry out repairs such as removal of torn cartilage
Bronchoscopy	Through bronchial tubes	To examine trachea and lungs to show problems such as inflammation, bronchitis, cancer and tuberculosis
Colonoscopy	Through the anus	To detect problems such as polyps, tumours, ulceration and inflammation in the colon and large intestine
Colposcopy	Through the vagina	To look for problems such as inflammation and cancer in the vagina and cervix (in females)
Cytoscopy	Through the urinary tract	To examine the bladder, urethra and opening of the prostate gland (in males)
Endoscope biopsy	Through a natural opening or through an incision	To remove specimens of tissue for examination and analysis by a pathologist
Gastroscopy	Through the mouth	To look for the source of problems such as bleeding from the lining of the oesophagus, stomach and duodenum
Laparoscopy	Through an incision in the abdominal wall	To examine abdominal organs including the stomach, liver and fallopian tubes (in females)

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Further details

- The endoscope shaft is controllable, so that it will bend in the required direction.
- The shaft may contain tubes for blowing water or carbon dioxide into the body (to clean lenses or inflate cavity for better viewing).
- The shaft may also contain tubes for sucking biological samples from the body for analysis. This is called a **biopsy**. Often there are other attachments to cut/manipulate tissue

Homework

Find and print three images of different body structures obtained by endoscopy.