1 Introduction to X-rays

What are X-rays?

X-rays are a form of **ionising radiation.** Radiation is the transfer of energy in the form of particles or waves. Visible light, radio waves, and ultraviolet waves are all examples of radiation and form part of the electromagnetic spectrum. X-rays contain more energy than visible light and ultraviolet waves. In fact, X-rays have sufficient energy to cause ionisations, which is a process whereby radiation removes an outer-shell electron from an atom, hence the term ionising radiation. In this way, ionising radiation is able to cause changes on a molecular level in biologically important molecules (e.g. DNA).

Uses of ionising radiation include conventional plain radiographs (often simply referred to as X-rays), fluoroscopy, computed tomography (CT), nuclear medicine, and positron emission tomography (PET).

How are X-rays produced?

X-rays are produced by focusing a high-energy beam of electrons onto a metal target (e.g. tungsten) (Figure 1.1). The electrons hit the metal target and some will have enough energy to knock out another electron from the inner shell of one of the metal atoms. As a result, electrons from higher energy levels then fill up this vacancy and X-rays are emitted in the process. Producing X-rays this way is extremely inefficient (~0.1%), so most of the energy is wasted as heat. For this reason, X-ray tubes need to have advanced cooling mechanisms. The X-rays produced then pass through the patient and onto a detector mechanism which produces an image.

Chest X-rays for Medical Students: CXRs Made Easy, Second Edition.
Christopher Clarke and Anthony Dux.

Companion website: www.wiley.com/go/clarke-cxr-2e

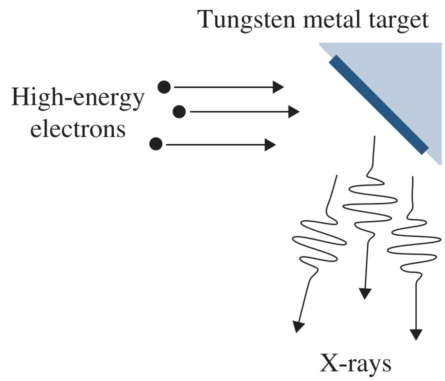

Figure 1.1 X-ray production.

How do X-rays make an image?

X-rays can either pass through the body or be absorbed by tissues. While passing through a patient, the X-ray beam is absorbed in proportion to the cube of the atomic number of the various tissues through which it passes. A simple way to think about this is to remember that the denser a structure is, the more X-rays are absorbed.

Any X-rays that are not absorbed are detected by the detector plate. By convention, the greater the number of X-rays hitting a detector, the blacker the image will be. Therefore, the less dense a material is, the more X-rays get through and the blacker the image will be. Conversely the more dense a material is, the more X-rays are absorbed and the image appears whiter. In summary, materials of high density (e.g. bone) appear whiter than materials of low density (e.g. air).

It is also important to remember the following points:

1. The resulting image on the detector is a **two-dimensional (2D) representation of a three-dimensional (3D) structure.** Remember you are usually not seeing a single structure but the combined density of all the structures that an X-ray beam passes through. For example, when looking at a rib on a chest X-ray, you are also looking at the overlying subcutaneous fat, lung, and chest wall musculature. It is also important to note that the shade of grey is not only determined by the density of tissue, but also its thickness. Thicker tissues absorb more X-rays and turn the radiograph whiter.
2. **Structures can only be seen if there is sufficient contrast with surrounding tissues.** Contrast is the difference in absorption between one tissue and another.

The five densities on an X-ray

All images are comprised of a combination of the following five densities (Figure 1.2).

How are X-ray images (radiographs) stored?

Almost all hospitals use a computer-based digital radiograph storage system for storing X-ray images. This system is known as **P**icture **A**rchiving and **C**ommunication **S**ystem (**PACS**). Doctors and other healthcare professionals

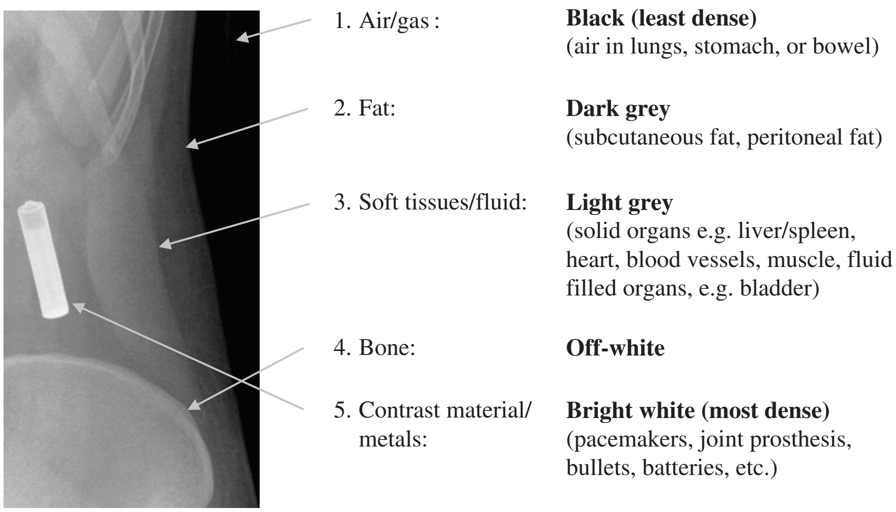

Figure 1.2 The spectrum of tissues of different densities as seen on a plain radiograph. This example is of a patient who swallowed a battery.

are able to view the images (radiographs) on a computer screen, making it easy to manipulate the image (e.g. changing the contrast, zooming in/out, etc.) and view images anywhere within the hospital.

Hazards and precautions

Ionising radiation hazards

As mentioned earlier, ionising radiation has the potential to damage cells. Actively dividing cells are particularly sensitive to radiation (e.g. bone marrow and gonads). Damage takes many forms, including cell death, mitotic inhibition, and chromosome/genetic damage leading to mutations.

The radiation dose from a chest X-ray is relatively low and equivalent to approximately three days of background radiation (Table 1.1). Having said this, patients often receive multiple X-rays during a hospital visit and over their lifetime; therefore, the cumulative dose increases over time. It is therefore important to optimise the radiation dose to as low as reasonably achievable, while still obtaining an image of good diagnostic quality.

The safety of patients and the use of ionising radiation for medical exposures are subject to specific legislation in the UK – the Ionising Radiation (Medical Exposure) Regulations or IRMER.

The Ionising Radiation (Medical Exposure) Regulations (IRMER)

IRMER is UK legislation and lays down the basic measures for radiation protection for patients. It refers to three main people involved in protecting the patient:

1. The **Referrer** – a qualified doctor or other accredited health professional (e.g. emergency nurse practitioner) requesting the exposure.

   Must provide adequate and relevant clinical information to enable the practitioner to justify the exposure.

Table 1.1 Comparison of typical doses from sources of exposure.

Source of exposure	Typical effective radiation dose (mSv)	Equivalent period of natural background radiation[1]	Lifetime additional risk of fatal cancer per exposure
Limb and joint radiograph (except hip)	<0.01	<1.5 days	1 in a few million
Chest radiograph	0.02	3 days	1 in a million
Transatlantic flight	0.08	12 days	1 in 200 000
Abdominal radiograph	0.5	3 months	1 in 30 000
CT head	2	1 year	1 in 10 000
CT chest	8	3.6 years	1 in 2500

1 UK average = 2.7 mSv per year
Data taken from 'Patient dose information: guidance by Public Health England', published 4 September 2008 and 'Ionising radiation: dose comparisons by Public Health England', published 18 March 2011.

2. The **Practitioner** – usually a radiologist, who justifies the exposure.
   Decides on the appropriate imaging and justifies any exposure to radiation on a case-by-case basis. The potential benefit must outweigh the risk to the patient. (For example, a CT head scan on a one year-old adds a 1/500 lifetime risk of cancer and increases the risk of cataract formation. The benefit of this scan must therefore outweigh these risks to the child.)
3. The **Operator** – usually a radiographer, who performs practical aspects.
   Ensures that the above two stages have been completed appropriately and keeps all justifiable exposure as low as reasonably possible by:
   i. minimising the number of radiographs taken;
   ii. focusing the X-ray beam on the area of interest;
   iii. minimising the use of mobile X-ray;
   iv. keeping exposure as low as reasonably achievable.

In women of reproductive age

- Minimise radiation exposure of the abdomen and pelvis.
- Ask any woman of reproductive age if they could be pregnant and avoid radiation exposure to them. The most critical periods are the first and second trimester. From the standpoint of future development, the foetus is considered to be most radiosensitive during the second trimester when foetal organogenesis is taking place. X-rays of the abdomen and pelvis should be delayed, if possible, to a time when foetal sensitivity is reduced (i.e. post 24 weeks' gestation, or ideally until the baby is born).
- Exposure to remote areas (chest, skull, and limbs) may be undertaken with minimal fetal exposure at any time during pregnancy.