Introduction to imaging: Ionising radiation

In the first part of our new series about medical imaging, **John Frank** looks in detail at imaging techniques that use ionising radiation

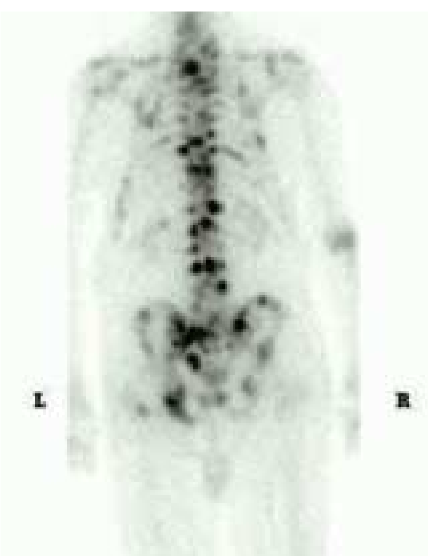

Fig 1 Bone scan showing semi-anatomical representation of the central skeleton and multiple areas of abnormally increased activity, typical of metastatic disease. In this case, the primary could be any disease that metastasises to bone, such as breast, bronchus or prostate

What imaging techniques are there?

There are four basic methods of imaging the body, using x rays, gamma rays, sound waves, or magnetism. Each method has its own place; the techniques are complementary, not mutually exclusive. In the first part of this series, I concentrate on using ionising radiation.

What is ionising radiation?

Ionising radiation is part of the electromagnetic spectrum and is used in imaging techniques in the form of either x rays—for conventional radiography and computed tomography—or gamma rays for imaging in nuclear medicine. The energy of an x ray determines the penetrating power of the beam and is measured in kilovolts (kV). The energy can be varied by the radiographer to suit the specific examination (see box 1).

Box 1

Energy of x rays

For hospital practice, x rays are chosen with an appropriate energy between about 30 kV and 150 kV. The energy of the gamma ray, which is measured in kiloelectron volts (keV), is specific to the isotope and is not variable. The commonest isotope used in nuclear medicine is technetium-99, although other isotopes are used, such as the gas krypton-81 for ventilation studies in lung disease and indium-111, which produces gamma rays with energies of 171 keV and 245 keV.

Nuclear medicine

Imaging with x rays and nuclear medicine compared

X rays provide anatomical information whereas nuclear medicine images provide physiological information. Although the images in nuclear medicine are vaguely anatomical—for example, in bone scans (fig 1)—they usually show the metabolism of the organ and allow altered metabolic states to be seen. A less anatomical but more metabolic image is shown in fig 2. These types of scan are extremely sensitive to disease but not specific to a particular disease. By using both the anatomical and physiological information obtained,

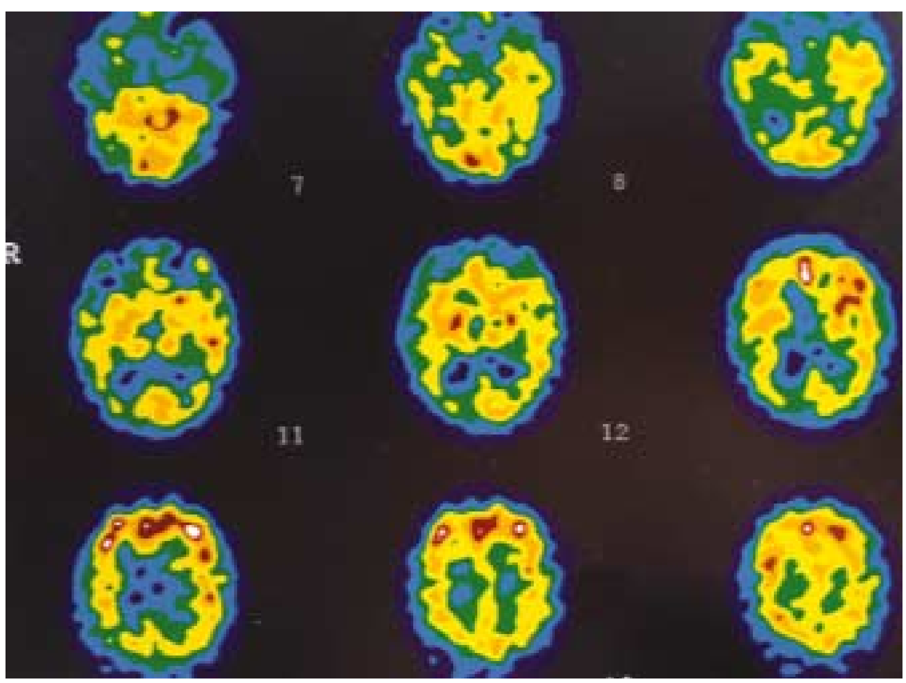

Fig 2 Scan of the brain showing diminished metabolism in the parietal and occipital regions in a patient with Alzheimer's disease

we can understanding better the underlying pathology and are better placed to diagnose the problem and guide the clinician in further investigations and treatment.

How is the radiation used?

Both x ray imaging and the techniques of nuclear medicine use ionising radiation. X rays actually pass through the patient and are detected by the x ray film or the computed tomography scanner. In nuclear medicine studies, however, carrier molecules labelled with a radioactive tracer, usually metastable ^{99}Tc, are injected into the patient. Because the patient is injected with the tracer, he or she becomes the source of the radiation and emits gamma rays.

A patient who has been injected with a radioactive tracer is slightly radioactive, but the activity is constantly falling. This is due to both the physical half life ($t_{1/2}$) of the isotope—the time required for the activity to fall to 50%—and the physiological breakdown and excretion of the carrier molecules by the patient (the biological half life).

Does making a patient radioactive put them at risk?

For isotopes with a short half life given in normal diagnostic doses, the patient or anyone else is not at risk and radiation levels are well within the normal range of background radiation—exposure is equivalent to watching television. Patients who have had a diagnostic scan can go near pregnant women or children without causing them any harm. It is important to inform the patients about this because they may worry needlessly, associating radiation with atomic bombs or Chernobyl.

However, therapeutic administration of isotopes is different. Patients may be given an isotope with a longer halflife, such as iodine-131, in the treatment of thyrotoxicosis and thyroid cancer. This has a half life of 8 days; the length of time that the patient is radioactive is greater.

Some isotopes are excreted via the kidneys and bladder. Care must be taken in patients with urinary incontinence, to avoid contamination of their bedding and chairs even with isotopes with short half lives. This is more important when patients are treated with isotopes with longer half lives, such as ^{131}I.

Can radioactive isotopes be given to pregnant women?

Normally radioactive isotopes are not given to pregnant women, but in cases of suspected pulmonary emboli the risk of not treating a pregnant woman with pulmonary emboli is far greater than the risk to the fetus of giving a small dose of radioactive tracer. To minimise the dose to the fetus, half the normal dose of lung agent is given. The lung agent used is albumen macroaggregates labelled with ^{99}Tc, to show the lung perfusion, and the patient also breathes in ^{81}Kr gas to show the ventilation.

Techniques using x rays

How is an x ray produced?

X rays, first discovered by Röntgen in 1895, are produced when a stream of electrons is fired from a cathode and hits the anode. The anode is usually made of tungsten mounted on steel, and is angled so that the x rays leave the tube and can be collimated into a beam, which is aimed at whatever

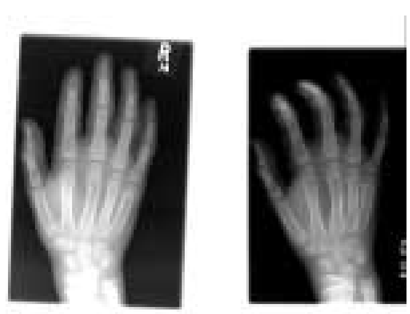

Fig 3 X ray of a hand. Differential attenuation of the x rays shows bones and soft tissues

Fig 4 Barium meal. The x ray tube is at the bottom and the image intensifier opposite. The patient lies on the couch, and the image is displayed on the screen just to the right of the image intensifier

Glossary

Image intensifier—instead of x rays striking a cassette containing film, the rays strike a crystal, which emits light. This is collected and amplified by a computer to produce an image

Tomography—instead of the x ray tube and table being fixed, the tube rotates around the patient on the table. This gives slices through the patient, and the image can be recorded on film or on an image intensifier system, which is the basis of computed tomography

Computed tomography—the tube rotates around the patient and a computer produces the image from the raw data. Modern scanners also move the patient through the ring at the same time as the x rays are produced. This gives enough data to produce three dimensional reconstructions

Half life—time taken for the dose of an isotope to decay to 50% of the original dose. This varies from isotope to isotope

Gamma rays—part of the electromagnetic spectrum used for medical imaging in nuclear medicine. The higher the energy in keV (kiloelectron volts), the greater the penetrating power

Collimator—used to focus a beam of x rays and are made of moveable pieces of metal within a box attached to the tube. The box also has a light beam within it, so you can see the area that will be exposed to the x rays. Collimators are also needed in nuclear medicine because the gamma rays are emitted from the patient in all directions. To avoid scatter, a special collimator made of lead with holes in it allows only gamma rays perpendicular to the camera head to be used to create the image

part of the body is to be imaged. The penetrating power of the beam is dependent on the applied voltage.

What do the different shades of black, white, and grey on a film indicate?

The rays pass through the area under investigation, and depending on the tissues, a variable amount is absorbed—this is known as differential attenuation. The exact amount of whiteness depends on how much calcium or other heavy metal is present. Bone—containing calcium—absorbs almost all of the rays and so shows up as white, fat absorbs much less, and air absorbs none so it appears black. The rays can then be imaged either using film, to get a conventional x ray (see fig 3), or can be detected using special equipment to get digital radiographs, or computed tomographs.

Ionising radiation can be teratogenic and damage the developing fetus. You must, therefore, always check that women of childbearing age are not pregnant before exposing them to ionising radiation, and, if in doubt, you must test for pregnancy.

Useful websites

- Royal College of Radiologists (www.rcr.ac.uk)
- British Nuclear Medicine Society (www.bnms.org.uk)
- Society of Nuclear Medicine (www.snm.org)
- British Medical Ultrasound Society (www.bmus.org)
- How Stuff Works (www.howstuffworks.com)

When do you use barium in imaging?

Apart from bones, conventional x ray machines can also be used to image blood vessels using water soluble contrast media, and the stomach and bowel using barium. Barium studies may be used rather than endoscopy when the patient is frail, may not tolerate sedation, or refuses to have a tube inserted into them. However, for studies of the upper gastrointestinal tract, the number of barium meals done has fallen, as endoscopy is much more readily available in the United Kingdom. The equipment is rather different to a standard x ray room, because instead of an x ray film, an image intensifier displays the image on a screen (see fig 4).

Barium sulphate is a dense metallic liquid which absorbs all incident x rays, so where there is a lot of it, the image is white. Air is also given in the form of effervescent granules with a sip of water, so double contrast studies are obtained. The air fills the stomach and so allows the wall to be visualised, making it easier to see small lesions (see fig 5).

How do you prepare a patient for a barium meal?

There are no special preparations needed for a barium meal, simply tell the patient not to take anything orally for six hours before the study. The large bowel can also be studied with barium, but here the patient needs rather more preparation in the form of purgatives and laxatives to clear out the bowel. You must warn the patient about the effect of these laxatives, which may cause stomach ache as well as sending the patient rushing to the toilet.

What is computed tomography?

Computed tomography uses x rays, but the x ray tube rotates around the patient as the table moves, creating a vast number of images (see fig 6). The x rays are processed by computer to form axial, coronal, or sagittal images. These may be adjusted by the radiologist to show detail of the soft tissue; bone; or, in the thorax, lung. The principle behind the computed tomograph image is differential absorption of x rays by various tissues. The only difference is that the images are produced by computer rather than directly on film (see fig 7).

What must you consider before ordering a computed tomography scan?

Modern computed tomography scanners are able to image the whole chest or abdomen in around 30 seconds, which is one breath-hold, so even patients with severe lung disease can manage without discomfort. This is important, because to get high quality sharp images, the patient needs to hold their breath during the exposure. This needs to be made clear to the patient when you see them, before sending the request to the imaging department.

You should give full and relevant information about the patient on the request form and remember to state exactly what you want to know. You must have a provisional diagnosis in mind when writing the request form. If the request form is incomplete or unhelpful, you may well get an angry phone call from the imaging department.

What preparation is needed before a computed tomography scan?

For scans of the abdomen and pelvis, some preparation is needed before the procedure. The patient is asked to refrain from

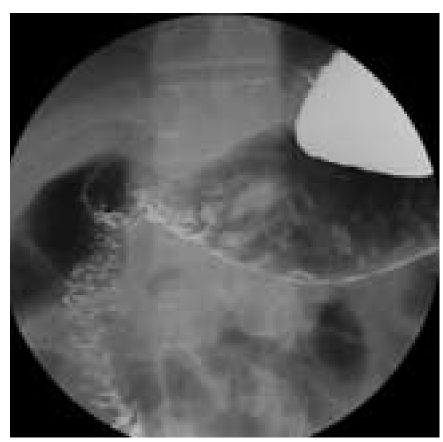

Fig 5 Barium meal. A pool of barium lies in the fundus of the stomach and barium outlines the body, the pylorus, and the proximal duodenum. These are also filled with air

Fig 6 A modern computed tomography scanner. The patient lies on the couch and is moved through the scanner. The x ray tube is behind the cladding, and, as it rotates, it can be quite noisy

eating or drinking for four hours before the appointment and is then given gastrograffin—a dilute liquid containing iodine used to opacify the bowel, making interpretation easier. For a scan of the abdomen, patients are given gastrograffin 20 minutes before the scan. But if the pelvis is to be imaged too, gastrograffin is given four and two hours before the scan.

For all computed tomography scans, ask the patient to change into a gown, and to remove all jewellery if possible before the scan. Occasionally, when the vessels need to be identified and blood flow to organs delineated, contrast has to be injected, and this is done using a pump. The radiographer or the attending doctor will set up an intravenous line using a cannula to allow a rapid injection.

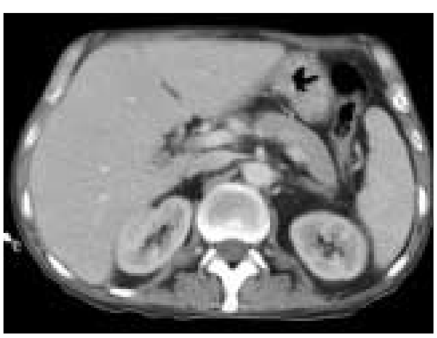

Fig 7 A computed tomography image of the upper abdomen, viewed as if looking from the feet towards the head. It shows the liver, pancreas, lower end of spleen, kidneys, aorta, inferior vena cava, and a vertebral body. The ribs, chest, the latissimus dorsi muscles lying behind the vertebral body can also be seen

What are the side effects of the contrast?

Sometimes the patient may feel hot as a result, but usually this is the only reaction they have. Rarely, the patient comes out in a rash after receiving the contrast, and patients who are asthmatic or have a history of previous reaction to contrast need to be made known to the imaging department before they attend. The request form will have a section for you to complete in such cases, and the risks will be explained to the patient by the radiologist.

John W Frank *consultant in nuclear medicine and radiology, Charing Cross Hospital, London W6 8RF*
jfrank@hhnt.org

I thank R Quest for her help in preparing the glossary.

Further reading

- *Making the best use of a department of clinical radiology: guidelines for doctors.* 5th ed. London: Royal College of Radiologists, 2003

Most textbooks are aimed at radiologists or doctors, not at students, but the following may help to answer specific problems:

- Grainger RG, Allison DJ, Adam A, Dixon AK, eds. *Grainger and Allison's diagnostic radiology: a textbook of medical imaging.* London: Churchill Livingstone, 2001
- Maisey MN, Britton KE, Collier BD, Siraj QH, eds. *Clinical nuclear medicine.* London: Chapman and Hall, 1998
- Taylor A, Schuster DM, Alazraki N. *A clinician's guide to nuclear medicine.* Reston: Society for Nuclear Medicine, 2000
- Meire H, Cosgrove D, Dewbury K, Farrant P, eds. *Clinical ultrasound: abdominal and general.* London: Churchill Livingstone, 2000
- Sanders R. Clinical sonography: a practical guide. London: Lippincott, Williams, and Wilkins, 2000