Section 1
The Basics

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1.1
What is Medical Imaging?

Like any other specialty, medical imaging and imaging nursing have a complex language all of their own and rely extensively on descriptive terminology. In order to avoid 'jargon overload', clear and concise explanations of procedures, events and equipment will be given, together with an explanation of the correct terminology.

'Medical imaging' is a term that encompasses a whole range of techniques that allow for visualisation of the human body. These techniques (more correctly called modalities) are conventional x-rays (using x-rays to take a picture of a body part), fluoroscopy (a screening method using real-time x-ray images), computed tomography (CT), magnetic resonance imaging (MRI), ultrasound (US) and nuclear medicine (NM). Medical imaging can be combined with minimally invasive techniques to gain diagnostic information leading to intervention by the radiologist and/or surgeon, or even in some cases the nurse and/or radiographer, e.g. venography, tunnelled line insertion, intravenous urograms and barium enemas.

The medical imaging department offers a vital service to all specialties from within the hospital, and patients come from all clinical areas and as referrals from the community and GP surgeries. Specialties such as interventional cardiology, neurology, oncology, hepatic, renal, gastro-intestinal, trauma and fertility all rely on the medical imaging department and the expertise of the radiologist, radiographer and imaging nurse in the diagnosis and treatment of disease. Indeed, recent achievements and advances in medical imaging mean that this is one of the fastest developing and most innovative areas of minimally invasive diagnostic and interventional treatment today.

X-rays

X-rays are part of the electromagnetic spectrum which includes microwaves, infrared light, ultraviolet light, gamma rays and visible light. X-rays are created within the x-ray tube by accelerating particles called electrons at a tungsten target. As the electrons hit the target they come to a sudden halt. Most of the energy released is heat but some of the energy is released in the form of x-rays, and it is these x-rays that are directed out of the tube and focused on the area of interest. Figure 1 shows how x-rays are produced.

As x-rays pass through a material, they are absorbed (attenuated) and the amount of attenuation is related to the density of the material. X-rays pass easily

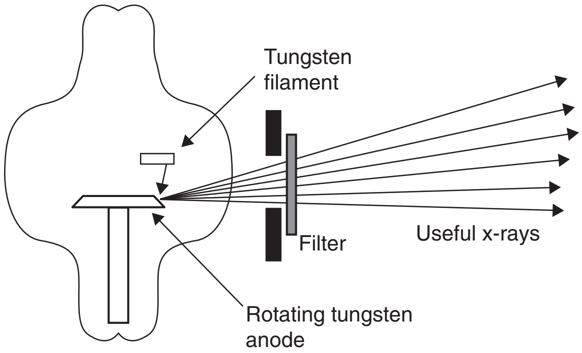

Figure 1 Production of x-rays.

through low-density materials such as soft tissue, wood, glass and plastic, but less easily through dense materials such as bone, lead and concrete.

Placing the area of interest between the x-ray beam and a photographic film creates an image, for example a chest x-ray. As the x-rays pass through the body they are attenuated to varying degrees by different structures. In a chest x-ray, the x-rays pass easily through the air in the lungs and the soft tissues in the chest cavity, but are absorbed by the bone of the ribs. Figure 2 shows an adult chest radiograph.

The x-rays that pass through the body and out the other side expose a cassette containing an intensifier screen which, in turn, converts x-radiation into light. This light is responsible for exposing the photosensitive layer on the film or reader plate* and produces the image. This film, or reader plate, is then developed, or read by a computer. A conventional x-ray examination differentiates bone, soft tissue, fat and air. Contrast media can be used to differentiate the subtle differences in soft tissues, e.g. double-contrast barium enemas, where air is used as a negative contrast, or intravenous urography (IVU), where the iodinated contrast is used as a positive contrast.

No specific patient-care considerations are involved when carrying out a diagnostic x-ray, although departmental protocols must be in place to identify each patient correctly before exposure and, where appropriate, the last menstrual period dates for women of childbearing age should be checked.

Fluoroscopy

Fluoroscopy is continuous exposure to radiation which allows a moving x-ray image to be viewed in real time. Substituting the photographic film with an image intensifier (II) produces fluoroscopy images. The image intensifier allows the

*Digital reader plates are now replacing conventional film/screen radiography.

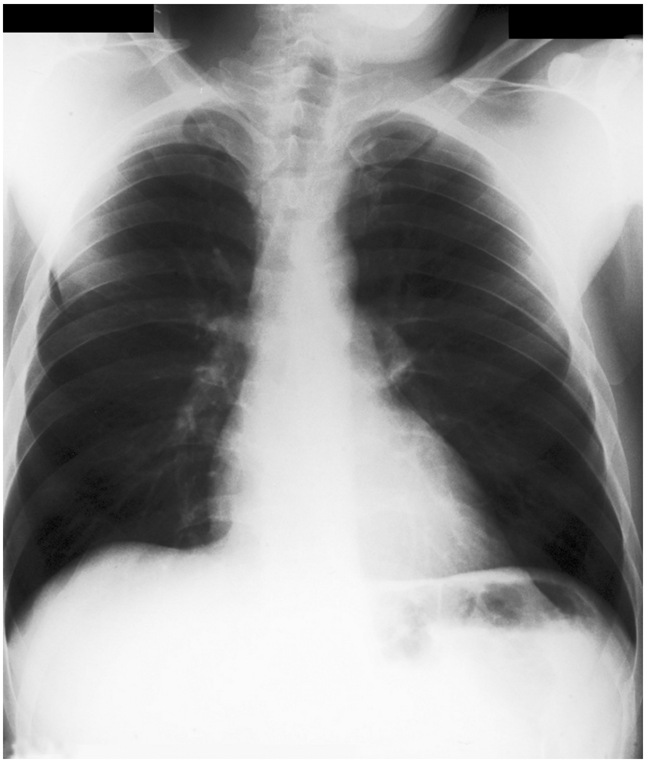

Figure 2 An adult chest radiograph.

magnification of the image to be increased or decreased as required (Figure 3). The real-time images are then displayed on a TV screen. The quality of these images can be varied depending on what is required during the procedure, e.g. low-pulse fluoroscopy produces lower quality images than does high-pulse fluoroscopy, but it is ideal for the positioning of large catheters, etc. When accurate positioning is required, high-pulse fluoroscopy can be used, giving a much higher quality image at a better resolution.

No specific patient-care considerations are involved when carrying out non-invasive fluoroscopy, although departmental protocols must be in place to identify each patient correctly before exposure and, where appropriate, the last menstrual period dates for women of childbearing age should be checked.

Computed tomography (CT)

CT is a specialised way of taking x-ray images that allows two-dimensional cross-sectional images of the body to be taken (tomography means 'slices'). Rotating the x-ray tube through 360° around the body produces the overall image, and a series of images is taken as it rotates (Figures 4, 5). The CT computer then

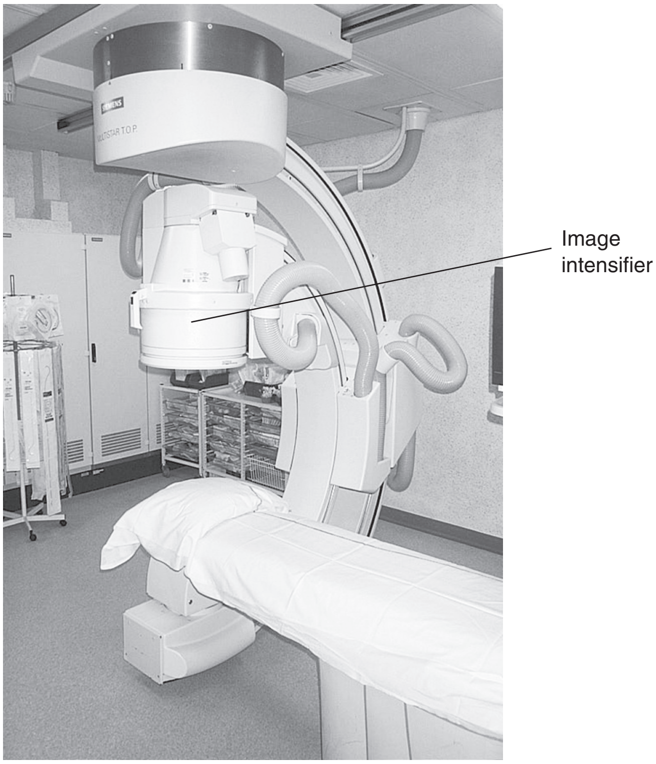

Figure 3 An example of a ‘C’ arm image intensifier used in an interventional suite.

constructs the image to show the organs orientated as if viewed from the feet, looking up towards the head. No specific patient preparation is required. However, studies of the abdomen and pelvis usually require the administration of oral contrast to optimise bowel visualisation. Any intravenous contrast injections require patient sensitivity checks.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) produces images similar in appearance and observational properties to those of the CT scanner. The main advantages to using the MRI over the CT scanner are that MRI eliminates the dangers associated with x-rays, since it does not use ionising radiation, and it can scan in any plane without having to move the patient. In addition, MRI is very sensitive to changes in tissue water content, permitting excellent soft-tissue differentiation.

As its name suggests, it uses powerful magnetic fields (and radiofrequency (RF) energy) to produce the images. However, with such a powerful magnetic field, patients with non-MRI-compatible metal implants must not be examined, as there is a real danger of the implant becoming dislodged by the immense

Figure 4 A CT scanner.

Figure 5 A cross-sectional CT image.

strength of the electromagnet (metal implants are available that can be used safely in the MR scanner). Patients (or staff) fitted with pacemakers must not enter the MRI scanner room as this may interfere with the pacemaker programming, causing it to malfunction and alter the heart rhythm, with detrimental consequences.

The MRI scanner relies on the magnetic characteristic of certain atoms within the body to create its images. These atoms contain even smaller particles called protons. When placed in a strong magnetic field, these protons line up, parallel to the magnetic field. The RF energy is then switched on at a particular frequency to create another magnetic field at right angles to the first. Some of this RF energy is absorbed by the protons, causing them to 'flip' out of alignment. When the RF energy is turned off, the protons return to their original position, which affects the RF signal. The rate at which the protons return to their original position is different for different body tissue types, and is called the decay signal. This decay signal is analysed by the MRI computer and converted to an image.

The MRI scanner (Figures 6, 7) produces clearer and more detailed images of soft tissues (Figure 8) than the CT scanner because it can differentiate between fatty tissue and water, making it a powerful tool in the diagnosis of disease that is particularly associated with an increase in the water content of tissues, e.g. oedema, increased blood supply, etc.

There are specific patient-care considerations involved when carrying out an MRI scan. Strict pre-scan questionnaires must be performed to exclude patients who may have any of the following, all of which could either de-program, migrate or malfunction within the confines of a strong magnetic field:

- Pacemaker/defibrillator
- Cochlea implants
- Aneurysm clips
- Previous metallic fragments in the eyes
- Prosthetic heart valves

Ultrasound

Ultrasound is an imaging technique that uses high-frequency sound waves and their interaction with body tissues to form an image. It is useful in many settings, as it does not use radiation. It works by using a probe containing a crystal which vibrates at a specific frequency. This emits sound waves that pass through the skin and soft tissue. Tissue boundaries within the body reflect the sound. These reflections are detected by the probe and are processed to produce the image. Different probe shapes and frequencies allow the visualisation of a wide range of soft tissues. Modern ultrasound machines now incorporate Doppler duplex scanning, which can observe the direction and velocity of blood flow. Figure 9 shows an ultrasound machine, and Figure 10 shows an ultrasound image of a distal graft anastomosis.

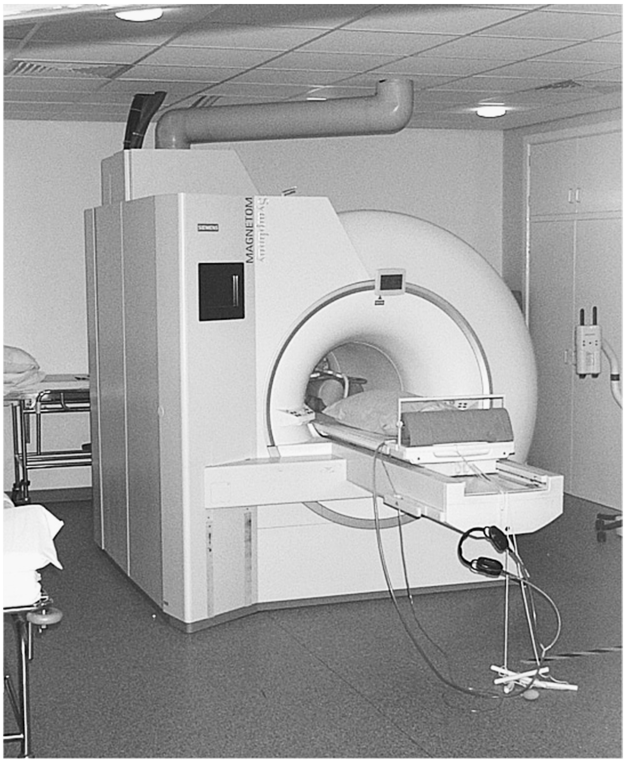

Figure 6 An MRI scanner.

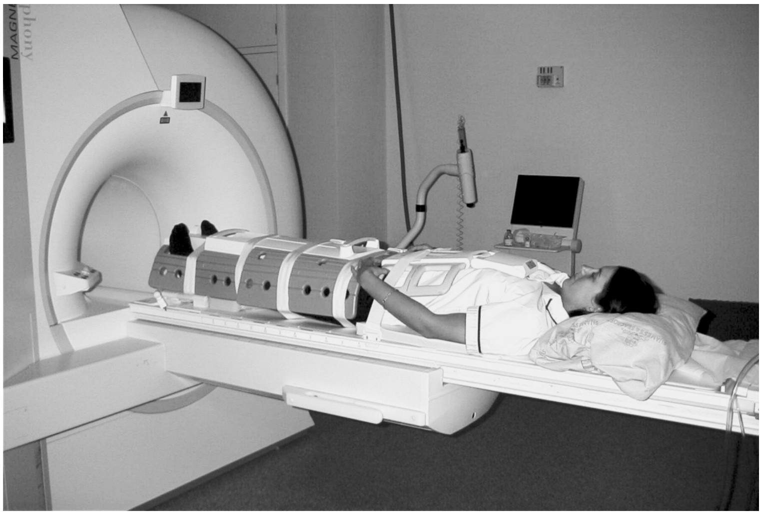

Figure 7 A patient about to undergo a peripheral MRA scan.

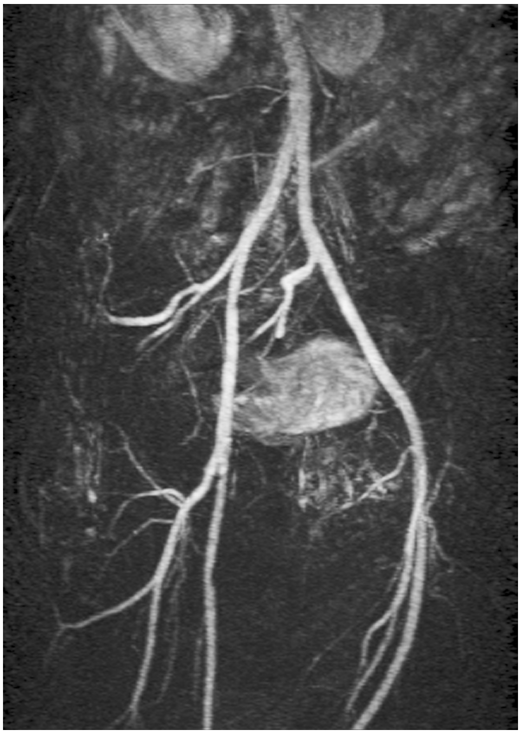

Figure 8 A reconstructed MRI image of the iliac arteries.

No specific patient-care considerations are involved in carrying out an ultrasound scan, although caution should be exercised with women who are less than 12 weeks pregnant.

Nuclear medicine

Nuclear medicine is a sub-speciality of its own and, as such, a proper treatment of this subject is beyond the scope of this text. However, a brief description of what it is and what it is used for is given here.

Radio-isotopes

Radio-isotopes are special radioactive elements that 'emit' radiation. They are used for the diagnosis of disease and also to assess organ function. The thyroid, bones, heart, liver and kidneys can be imaged easily to demonstrate the presence of disease or disorders in function, while certain lesions, particularly malignancies, can be treated directly. The use of radiation in this way is restricted to the nuclear medicine department.

Figure 9 An ultrasound machine.

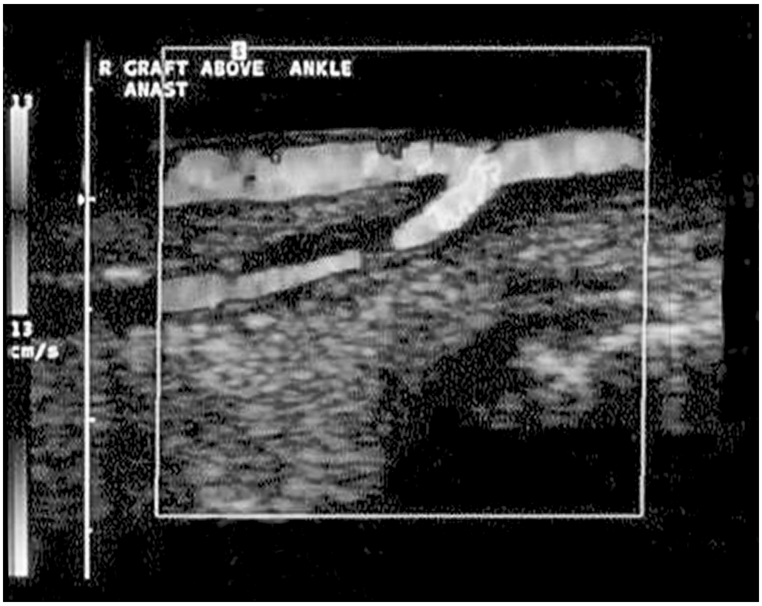

Figure 10 An ultrasound image of a distal graft anastomosis.

Every organ in the body absorbs different substances preferentially; for example, the thyroid readily absorbs iodine, whereas the brain takes up glucose. Once a radioactive form of one of these substances (called a radiopharmaceutical) enters the body, it is incorporated into the normal physiological processes and taken up by the target organ.

The radio-isotope is taken into the body by injection, inhalation or ingestion. The concentration of radioactivity (called a hot spot) can then be detected by a gamma camera, which the patient stands or sits in front of. The camera builds up an image from the different points from which radiation is emitted. This image is then enhanced by a computer to produce the end diagnostic image.

The dose of the chosen radiopharmaceutical given to a patient must be calculated to be just sufficient to obtain the required information before the radioactive substances are excreted in the urine and the emitted radiation reduces to an unusable level. The patient experiences no discomfort during the procedure and after a short time (usually about 6 hours) there is no trace of the radiation.

The details of bone and soft tissue are seen better on MRI and even CT, but a major advantage of radio-isotopes is that they are incorporated into physiological processes; therefore functional information can be acquired. The non-invasive nature of this imaging modality and its capacity to demonstrate a functioning organ from outside the body makes this a very useful diagnostic tool indeed.

Patients who receive permanent implants, or injected or ingested radioisotopes, are temporarily radioactive and thus, unlike other imaging methods, there are very specific patient-care considerations, centred around precautions to protect others from exposure. These considerations include the psychological implications of isolation and the concept of the 'radioactive patient'. Care with radioactive bodily excretions of blood or urine is required, especially as patients are actively encouraged to drink more fluids than normal for certain scans, to help with the absorption of the isotope. In addition, patients are asked to reduce contact with children or women who may be pregnant.

Patients who undergo temporary implants are not released from the hospital until all radioactive sources have been removed.

Radiation therapy

Radiation therapy is a method of targeting a high-energy x-ray beam directly at the lesion, to ablate it. Cancer cells are particularly sensitive to damage by radiation so some cancers can be controlled or eliminated by precise targeted exposure to radiation. There are two methods of administering radiotherapy: from an external source such as a gamma-ray beam (external-beam radiation therapy) or from an internal source, such as radioactive implants (brachytherapy). These can be placed into organ cavities or directly into body tissues. External gamma-ray beam radiation is used to treat a carefully selected part of a patient when a tumour is close to the surface, while brachytherapy is used for deeper lesions.

Patients need to be aware of several effects of radiation therapy. Radiation can cause hair loss, but only in the skin exposed to the radiation and only after several treatments. Nausea is sometimes a problem when treating the abdomen, but it is infrequent. Side-effects from radiation depend on several factors, notably the part of the body being treated and the dose of radiation used, but they generally include tiredness and mild, localised skin irritation at the site where the radiation beam enters or exits the body. Unlike radio-isotope treatments, external-beam radiation does not make a patient radioactive.

Radiation protection

Radiation can have a number of effects on the body. Two possible effects to the unborn child and the developing fetus are genetic effects and the increased risk of cancer due to DNA damage caused by the radiation (somatic effects). The different tissues in the body have different sensitivity to radiation, the most sensitive being bone marrow, skin, eyes and the reproductive organs. The least sensitive are liver, kidneys, muscle, brain, bone, cartilage and connective tissue. Because of these potential risks of radiation, health-care workers in medical imaging departments must take precautions to reduce the radiation dose to both themselves and their patients.

This is implemented easily by any one of three main methods:

(1) Placing a suitable barrier between the worker and the radiation source, e.g. standing behind a lead screen or wearing protective lead clothing.
(2) Increasing the distance between the worker and the radiation source.
(3) Reducing the amount of time spent in the vicinity of the primary radiation source.

X-rays travel in straight lines like light waves and so a shield made from a suitable material will provide adequate protection from x-rays. Such materials include lead, concrete, brick and some specialised plaster coatings. These are very dense materials and so absorb x-rays instead of allowing them to pass through. Just as a hand placed in a light beam casts a shadow, a lead shield will not let x-rays pass through it, thus creating a safe 'shadow' area behind it. The shield should be as close to the source as possible, so that even a small shield can give wide protection. Use of ineffective shielding materials, such as glass, wood, plastic or standing behind a colleague, *does not* offer safe protection.

Lead can be incorporated into rubber, plastics and glass, and all personnel in x-ray controlled environments must wear lead–rubber aprons or stand behind special lead–glass screens in the viewing areas when x-rays are being used. The use of thyroid shields or lead glasses should be available when the potential for higher than average personal doses could be an issue, e.g. the radiologist or scrub nurses standing next to the patient. Well-fitting lead aprons should be worn to give the best coverage possible, but it should be noted that lead–rubber aprons do not provide a total barrier to radiation but *reduce it* to a much safer level (usually half its original intensity). The thickness at which this occurs is called the half-value thickness. This is why, even when wearing lead–rubber aprons, it is prudent to stand away from the radiation source. The lead–rubber must never be folded or left creased, as small, unseen cracks may appear, allowing x-rays to pass through, thus affording much less protection. It is not always possible to see a crack in a lead coat, so they are regularly screened under fluoroscopy in order to identify any defects.

X-radiation obeys the inverse square law, which means that if the distance from the source of radiation is increased by two, then the intensity of the radiation is decreased by four; similarly, if the distance is increased by three, then the intensity is reduced by nine, and so on. Thus, increasing the distance from the radiation source reduces the amount of exposure from that radiation and, clearly, the simplest method of x-ray protection is to stand well back!

Since the radiation dose is dependent on the amount of time spent exposed to radiation, then obviously the less time spent in the vicinity of the radiation reduces the radiation dose received. Health-care staff working in the x-ray department wear a monitoring device (a film badge) or thermoluminescent dosimeter (TLD) which monitors the amount of exposure a person is receiving. These do not prevent overexposure but merely give a measure of it at a later date. Imaging nurses have an annual dose limit of 15 mSv.

The principles of distance, shielding and time limitation must be observed to minimise radiation exposure, as stipulated in the Ionising Radiation Regulations 1999 (Health and Safety Executive, 1999). An important principle for staff to observe is to keep all radiation exposure 'as low as reasonably achievable': known as the 'ALARA Principle'.