## CHAPTER 1

# Radiology Introduction

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## 1.1 Section/Chapter Order

The sections are arranged so they go through the various imaging modalities, starting with plain radiology, then ultrasound, CT and MR. The chapters in each section go from simple to more complex where information from the previous chapters is used.

This introductory chapter provides an overview of the different modalities covered in the book, the rationale for their use and an explanation of common terminology. Our advice is to scan this initially. Then, as you read other parts of the book, you will be encouraged to return to relevant parts in this chapter to refresh your memory.

Each of the remaining chapters starts with a clinical case and the images used in the acute situation. There are then questions asking for a differential diagnosis and preliminary interpretation of the images. The imaging modality is then explained along with a review of the relevant anatomy. The chapter concludes with the questions being reviewed and answers provided.

## 1.2 Imaging Modalities

Through this book you will develop an overview of each imaging modality and its advantages and limitations. Often, the best way to learn this is using examples of normal anatomy and pathology so you will be referred to relevant images in the other chapters.

Don't get bogged down in the technical aspects of physics and scan acquisition (unless you are particularly interested). Radiology interpretation is primarily pattern based and appreciating the image is the most important bit.

Radiological terminology will be introduced here and throughout the book. It helps to understand what these terms mean as they crop up throughout radiology reports. Being able to link the terminology with what you can see in the image is a vital step in using these investigations appropriately.

## 1.3 Ionising Radiation

It helps to divide the imaging modalities into those which expose the patient to ionising radiation and those which don't.

| Exposure to ionising radiation | No exposure to ionising radiation |
|---|---|
| ☢ | 🚫 |
| X-ray | Ultrasound |
| CT (computed tomography) | MRI (magnetic resonance imaging) |
| Nuclear medicine | |

Ionising radiation is a type of energy released in the form of electromagnetic waves (e.g. gamma/X-rays) or particles (neutrons, beta or alpha). In diagnostic radiology, it is nearly all in the form of high-energy electromagnetic waves. Ionising particles are used more in clinical oncology.

As these waves are high energy, they can displace the electrons from atoms in the body, which causes them to ionise. This ionisation can cause mutations in DNA and has the potential to induce cancers at high doses or cumulative low doses. For this reason, any ionising radiation exposure must be justified.

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Companion website: www.wiley.com/go/DiagnosticImaginginAcuteCare

The benefit from the diagnostic test should outweigh the future cancer risk.

**TABLE 1.1**

**Approximate radiation doses for various types of exposure.**

| | |
|---|---|
| Dental X-ray | 0.005 mSv |
| 100 g of Brazil nuts | 0.01 mSv |
| Chest X-ray | 0.014 mSv |
| Transatlantic flight | 0.08 mSv |
| Nuclear power station worker average annual occupational exposure (2010) | 0.18 mSv |
| V/Q perfusion component | 1 mSv |
| Computed tomography (CT) scan of the head | 1.4 mSv |
| UK average annual radiation dose | 2.7 mSv |
| Low-dose CT chest | 1.5 mSv |
| CT pulmonary angiography (CTPA) | 6.1 mSv |
| Average annual radon dose to people in Cornwall (UK) | 6.9 mSv |
| Whole-body CT | 10 mSv |
| Positron emission tomography (PET)/CT | 22 mSv |

***Source:*** Public Health England/Crown/Public domain.

Radiation dose in medicine is measured in millisievert units (mSv). As this is an abstract unit, it is useful to think about the dose in relation to the natural background radiation (Table 1.1). This varies from region to region, largely because of radon gas emission. Background radiation from the cosmos and ingested food also contributes. However, calculating the exact risk of developing cancer from a particular radiological test is an inexact process, extrapolated from the high doses of exposure at Hiroshima and Nagasaki. It is estimated that 1 mSv exposure has approximately a 1 in 20 000 risk of causing a fatal cancer.

## 1.4 X-ray (Plain Radiography)

This is the oldest of the radiology modalities and well recognised by most healthcare staff. A few key points are worth keeping in mind when looking at plain films.

- They are a 2D representation of the 3D structures of the body. Hence overlapping of structures is a common problem.
- High-density structures appear white. Other names for high density are opacity or opacification. A dense region in a bone is called sclerosis.
- Low-density structures appear black. Other names for low density are lucent or lucency. A low-density region in a bone is called lytic.

X-rays are still used a great deal and are very useful, particularly for assessing structures of very high density (**bones**, MSK Chapter 4 – Figure 4.10; **joints**, MSK Chapter 2 – Figure 2.1; **metal implants**, MSK Chapter 2 – Figure 2.4, etc.) or very low density (**lungs**, Resp Chapter 12 – Figure 12.2 or **bowel gas,** Abdo Chapter 20 – Figure 20.6). Another big advantage is their relatively low exposure to ionising radiation.

The limitations with plain radiographs become evident with intermediate-density structures, like **most organs, muscle, tendons** (MSK Chapter 5 – Figure 5.7) and **ligaments**. They tend to appear as homogenous grey shadows. **Joint effusions** are visible in certain joints (MSK Chapter 3 – Figure 3.12) but you will not be able to differentiate between simple fluid, pus or blood.

## 1.5 Computed Tomography

### 1.5.1 Scan Acquisition

The annual number of CT scans performed in the NHS increased from 1 million to 6 million from 1997 to 2020.

CT relies on X-rays and so exposes the patient to ionising radiation. The method for acquiring an image is similar to plain radiography, with an X-ray source firing through the patient to a detector. In CT this X-ray source is rotated around the patient (tomography) as they are advanced through the scanner. This allows the whole body to be covered in a matter of seconds. The results are analysed electronically (computed) and the scan subsequently displayed in a picture archiving and communications system (PACS) system.

A CT scan contains hundreds (or sometimes thousands) of cross-sections through the patient. This is the key difference from plain radiography. A useful analogy is to think of a building. A traditional plain X-ray is like taking a photograph of a building, resulting in an image with 2D representation of a 3D structure. CT is like having the blueprints of the building, with detailed floor plans on every level.

### 1.5.2 Multiplanar Reformatting (MPR)

Each pixel of a CT image is actually a cube in 3D space, termed a voxel. Because of this, PACS software allows CT scans to be instantly reformatted into any desired anatomical plane. Axial, coronal and sagittal planes are the standard ones and are used at least 90% of the time. Occasionally it may be useful to create oblique planes along a certain part of anatomy (Figure 1.2).

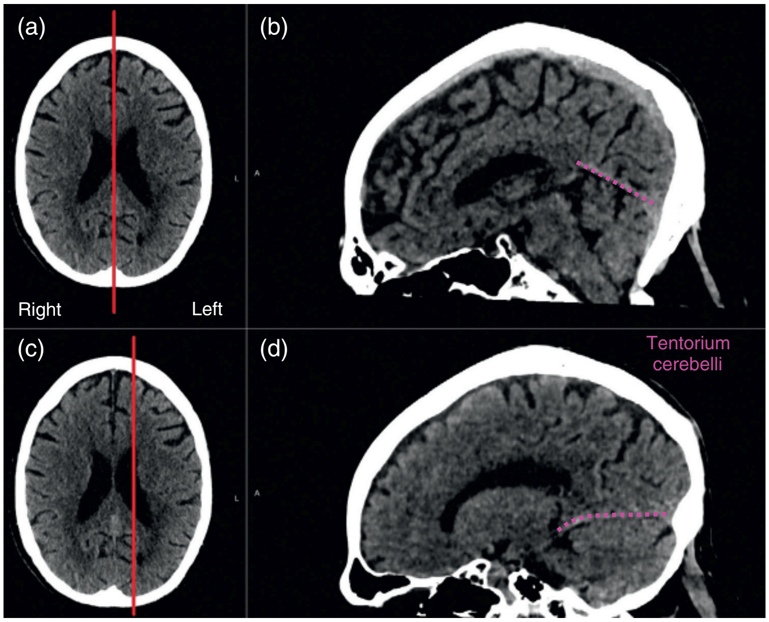


**FIGURE 1.1** Axial (a) and sagittal views (b). The latter is taken in the midline as demonstrated by the red localiser line in image (a). When viewing a sagittal slice which is not in the midline (d), it is not always apparent which side of the body is being imaged. This is a common problem with neuro imaging as the brain and spine are anatomically symmetrical. By referring to the axial slice and localiser line (c), we can see that (d) is showing the left side.

### 1.5.3 Anatomical Planes and Orientation

The convention in radiology is that the image is viewed as if the patient is facing the practitioner. This initially applied to x-rays taken in a frontal projection but has been continued into CT imaging where the axial plane is predominantly used. Consequently, **the left-hand side of the screen will relate to the patient's right-hand side** (Figure 1.3). The convention also applies if you are viewing MRI or ultrasound. Note, however, that this rule is used when interpreting images taken in the axial and coronal planes. Orientating images in the sagittal plan is different and will be discussed below.

1.5.3.1 Sagittal Plane When viewing a CT or MRI in the sagittal plane, it is necessary to have the image linked to a different plane (axial or coronal) so you can tell whether the left or right of the midline is being examined. A localiser line can then be used to cross-reference the location on the sagittal image (Figures 1.1 and 1.4).

## 1.6 Reformatting 3D

Modern CT also allows 3D reformatting of scans, allowing the viewer to inspect the anatomy from any angle. This works best for dense structures, like bones (Head Chapter 29 – Figure 29.6) or angiograms (Abdo Chapter 22 – Figure 22.2). It is less effective at viewing organs or low-density structures (e.g. tendons).

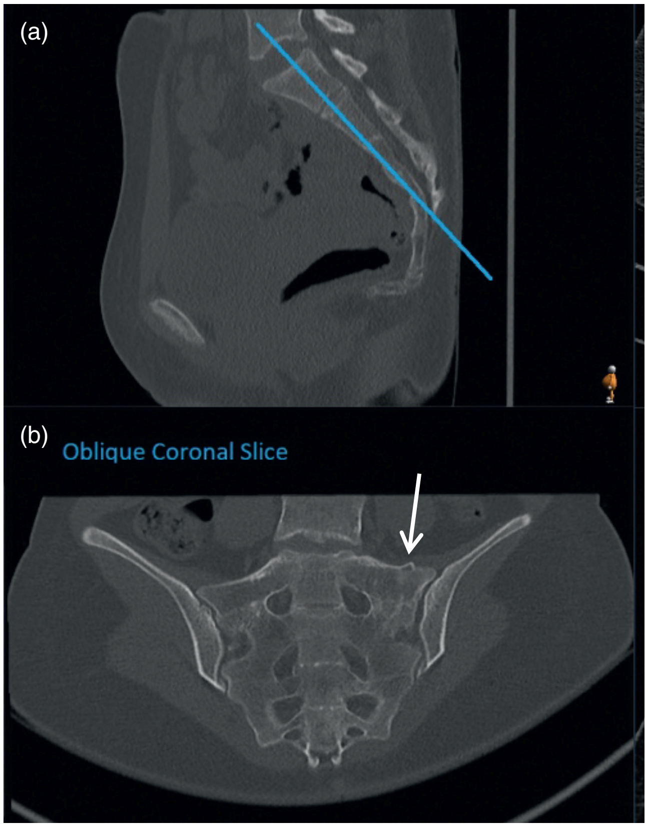


**FIGURE 1.2** CT sacrum – bone window: (a) sagittal view (b) oblique coronal slice. CT scans can be manipulated so oblique images can be produced. This is demonstrated in (b) with the orientation of the oblique plane shown on the sagittal image (a). This type of manipulation is undertaken when searching for a suspected abnormality which is not visible on the classic axial, coronal and sagittal planes. In this case, using the oblique orientation enables a fracture of the left sacral ala (white arrow) to be seen more clearly.

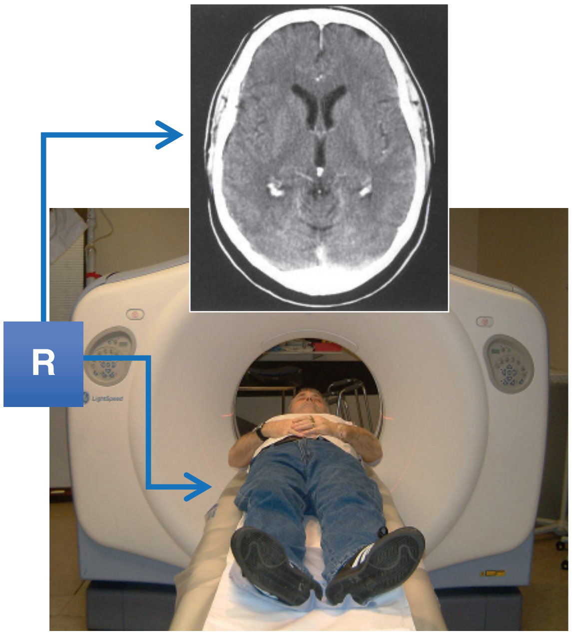


**FIGURE 1.3** Orientation of a patient in the CT scanner and axial cranial scan. The scan is interpreted as if you are looking up to the patient's head, from their feet. Hence **the right side of the patient is on the left side of the screen**. Source: Driscoll et al. (2023)/John Wiley & Sons.

3D reformatting is useful in certain areas, for instance spotting skull fractures (Head Chapter 29 – Figure 29.10). However, it has poor resolution compared to the 2D CT slices, so should not be relied upon on its own.

### 1.6.1 Maximum Intensity Projection (MIP)

This is a software tool which provides a better overview of structures which extend over multiple adjacent slices, for example vessels (Head Chapter 27 – Figure 27.5). The slice thickness of the image is increased and only the brightest voxel across the thickened slice is shown. As a result, a winding vessel can be viewed along its course.

## 1.7 Density of Tissues and Hounsfield Units

### 1.7.1 Density of Tissues

Density on CT follows the same pattern as plain radiography, i.e. bones are **high density** so appear white and lungs are **low density** so appear black. The difference

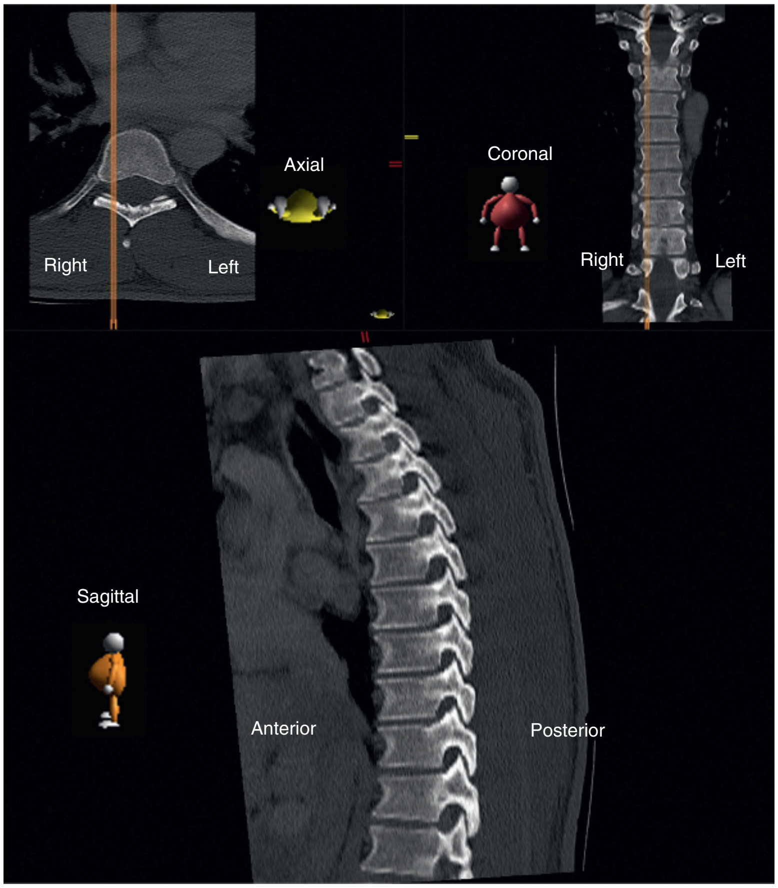
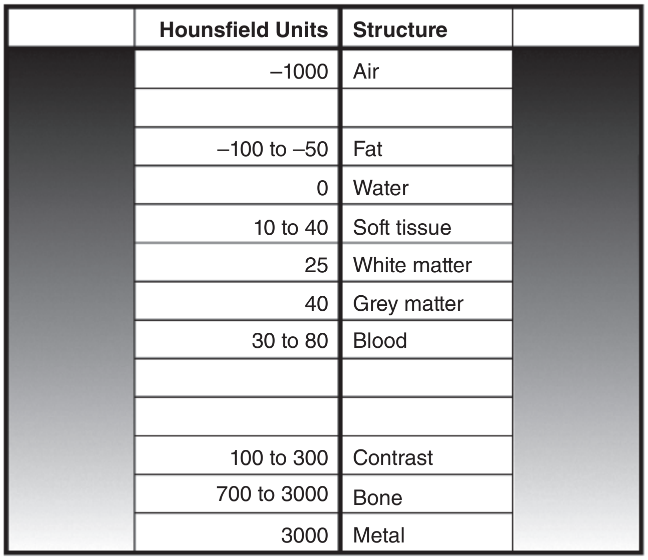


**FIGURE 1.4** First observe the sagittal image. On its own, it is very difficult to appreciate whether we are viewing the left- or right-sided facet joints. We need to use the localiser line (orange) on the axial or coronal plane to confirm the position of the sagittal slice. In this case we are viewing the right-sided facet joints.



| Hounsfield Units | Structure |
|---|---|
| –1000 | Air |
| | |
| –100 to –50 | Fat |
| 0 | Water |
| 10 to 40 | Soft tissue |
| 25 | White matter |
| 40 | Grey matter |
| 30 to 80 | Blood |
| | |
| | |
| 100 to 300 | Contrast |
| 700 to 3000 | Bone |
| 3000 | Metal |

**FIGURE 1.5** The Hounsfield Unit (HU) scale. Water is fixed at 0 and air is fixed at −1000, the density values of other substances lying accordingly along the scale. Hence structures appear darker on the image as HU decreases. Note that the density of blood changes depending on whether it is flowing, clotted or chronic (see 'blood density' section below).

with CT is that this density can be measured and given a value on the Hounsfield unit scale (Figure 1.5).

### 1.7.2 Hounsfield Units

1.7.2.1 Windowing Windowing changes the brightness and contrast to aid inspection of certain structures. It is useful to have common windowing presets for, for example, **brain** (Figure 1.6), **soft tissue**, **lung** (Resp Chapter 10 – Figure 10.2) and **bone**. For convenience, these will usually have hot keys on the keyboard (typically numbers).

While using the **brain windows**, the brain parenchyma is readily apparent and contrasts with cerebrospinal fluid (CSF) which appears black (Figure 1.6a). However, on this window, the bone appears as a featureless white mass. For greater detail, for example inspecting the skull vault's inner and outer tables, the **bone window** must be used (Figure 1.6b). Note, however, that when using this setting, the brain cannot be clearly seen. Therefore, the viewer needs to make an **active decision** which window setting to use when inspecting different parts of the body. This is one of the fundamental differences between inspecting a plain xray and a CT scan.

> Using an inappropriate CT window to view a structure increases the chance of missing abnormalities.

### 1.7.3 Blood on CT

The density of blood on CT changes depending on its state (Figure 1.7). Flowing blood has the same density as soft tissues such as the brain (30–40 HU). After clotting, this increases to a maximum of around 90 HU. Over several weeks it declines as the haematoma is broken down and is either resorbed or becomes a seroma with the density of water (HU = 0).

It is possible to have a combination of densities. Figure 1.8a shows the density of an acute blood clot with areas of unclotted active bleeding.

In summary, an acute blood clot is bright on CT, making it easy to spot, especially in the cranium (Head Chapter 29 – Figure 29.8). Delayed presentations of bleeding are more challenging as the blood will start to break down and become darker (Figure 1.8b). The same concept applies whether the blood is intra-arterial (Head Chapter 28 – Figure 28.9a), venous or extravascular (Figure 1.8).

## 1.8 Contrast

Intravenous contrast is an extremely important addition to CT scans as it significantly improves the detection of pathology. Indeed, for certain studies contrast is mandatory, for example trauma CT (Abdo Chapter 18) and CTPA (Cardiac Chapter 17).

Depending on the clinical question, different contrast phases (i.e. timings) will be used to emphasise certain regions of anatomy (Table 1.2). The contrast is introduced via a vein, usually in the arm. The contrast flows into the superior vena cava (SVC) and right side of the heart before filling the pulmonary arteries. CTPAs are taken at this stage, which usually occurs around 30 seconds after injection. It is possible to trigger CT scans when the contrast is in the desired location. This is called **bolus tracking** (Cardiac Chapter 17 – Figure 17.2). Contrast then continues to the left side of the heart and into the systemic arterial tree. Subsequently, it is taken up by capillary beds in organs before filling the venous system (including the portal veins).

After 10 minutes, most of the contrast will have been excreted by the kidneys and lie in the ureters and bladder.

## 1.9 Artefacts

### 1.9.1 Movement

Although CT is performed relatively quickly, movement is still an issue. This may be an unco-operative patient moving during the scan (Figure 1.9) or unavoidable

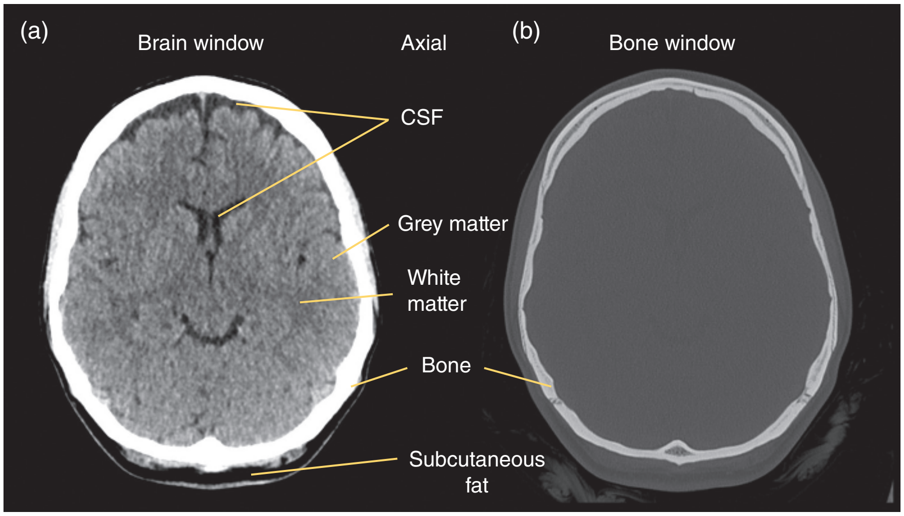


**FIGURE 1.6** Axial CT head on brain (a) and bone (b) windows – unenhanced. Familiarise yourself with the appearance of the brain and CSF spaces on CT. Remember it is necessary to use **brain windows** to properly see the brain and CSF. **Bone windows** are required to assess for skull fractures (Head Chapter 29).

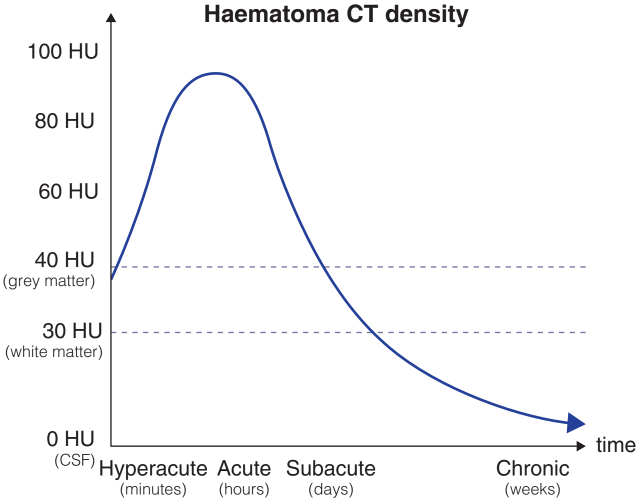


**FIGURE 1.7** Changes in density of blood on CT over time.

respiratory or cardiac motion (Cardiac Chapter 16 – Figure 16.2). There are several techniques which help minimise these problems and these will be discussed in the relevant chapters.

## 1.9.2 Photon Starvation

If foreign objects are present and of sufficient density and thickness (e.g. hip replacement, Figure 1.10), they can block the X-ray beam and result in a '**photon starvation**' artefact. This manifests as black bands radiating out from the offending object which can mask nearby anatomy.

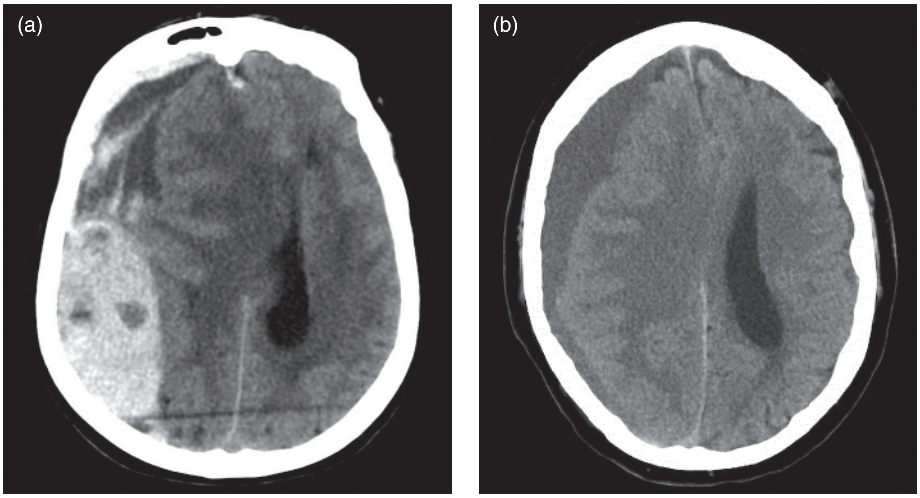


**FIGURE 1.8** (a) CT head – brain window – axial view. This unenhanced CT head demonstrates a large right-sided subdural extending from the occipital to the frontal area. (b) CT head – brain window – axial view. This is a different patient with a right subacute, subdural haematoma (1–2 weeks old). Note the density is similar to that of brain tissue (isodense), making these more difficult to appreciate.

**TABLE 1.2**

**Contrast phase, timing and use.**

| Contrast phase | Timing of scan after IV contrast bolus | Use |
|---|---|---|
| Non-enhanced/ unenhanced | No contrast given | Head CTs are usually taken without contrast to improve detection of intracranial haemorrhage (Head Chapter 29 – Figure 29.8).<br>Spine and MSK CT is also performed without contrast, as the primary interest is fractures and dislocations (Spine Chapter 25 – Figure 25.3; MSK Chapter 4 – Figure 4.11).<br>In the torso, unenhanced scans are used to detect calcification, e.g. renal calculi (Abdo Chapter 21 – Figure 21.6). |
| Pulmonary arterial phase | 30 seconds | CTPA scans are performed in this phase to look for pulmonary emboli (Cardiac Chapter 17 – Figure 17.5). |
| Arterial phase | 40 seconds | Useful to identify arterial bleeding (Abdo Chapter 22 – Figure 22.5), arterial occlusions (Head Chapter 28 – Figure 28.11) and dissection. |
| Portal venous phase | 70–80 seconds | Useful in the abdomen and pelvis in acute surgical patients (Abdo Chapter 20 – Figure 20.5). |
| Delayed phase | 6–10 minutes | Used to identify damage to the urinary tract (not shown). |

**FIGURE 1.9** Axial CT head on bone windows showing movement artefact. The image appears blurry, significantly reducing the detection of facial bone fractures.

## 1.10 Nuclear Medicine

This modality also exposes patients to ionising radiation, but it differs from X-ray and CT because the patient takes in the radioactive pharmaceuticals. This could be via intravenous injection, inhalation or by mouth.

The patient is then positioned inside a special detector called a gamma camera. This records the radiation emitted from the patient with areas of increased radioactivity described as ‘**avid**’ or ‘**hot**’.

Nuclear medicine studies show functional information about the body, but have much less anatomical definition compared to X-ray and CT.

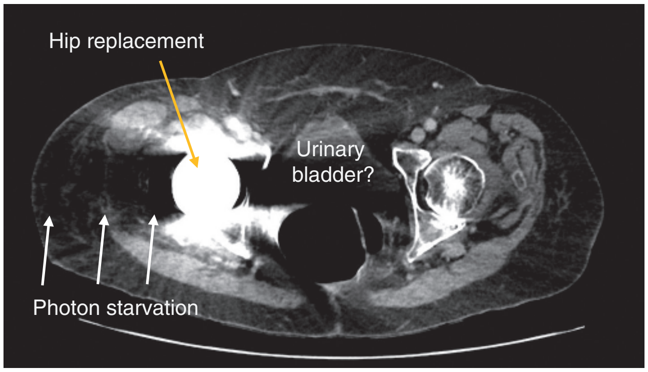


**FIGURE 1.10** Axial CT pelvis on soft tissue windows showing photon starvation from a right hip replacement. The dense material blocks the whole X-ray beam, resulting in black bands across the image, masking organs like the urinary bladder.

## 1.11 V/Q Scan (Ventilation/ Perfusion)

This is used to investigate pulmonary embolism in patients under 40 years with a normal chest X-ray. It is preferable to CTPA because the radiation dose is lower (Table 1.1). It involves injecting radiopharmaceuticals into the veins and observing which segments of the lungs are perfused (Cardiac Chapter 17 – Figure 17.3). It is also possible to get the patient to inhale radioactive gas to see if there is a ventilation/perfusion mismatch. This component is not always performed as ventilation is likely to be normal if the chest X-ray is normal.

## 1.12 Positron Emission Tomography (PET)

This is used extensively in cancer care. The patient is injected with a radiopharmaceutical called fluorodeoxyglucose F18 (FDG) which mimics glucose in the body. Any region with increased metabolic activity will attract the FDG and become avid. Normal metabolically active tissues such as the brain and myocardium can be ignored, as can the urinary tract, where FDG is naturally secreted.

Any additional areas of metabolic activity could represent malignancy; for certain cancers (e.g. squamous cell carcinomas), this is highly sensitive for metastatic disease spread. However, the specificity of PET is limited, as pathologies such as infection and inflammation also increase metabolic activity.

PET images are invariably combined with CT scans (PET/CT). This overcomes the anatomical limitations of the PET images to give highly accurate anatomical and functional information (Resp Chapter 13 – Figure 13.2). The downside of PET/CT is a relatively high radiation dose (Table 1.1).

## 1.13 Magnetic Resonance Imaging (MRI)

### 1.13.1 Basic Physics

Magnetic resonance imaging does not expose patients to ionising radiation. Instead, the patient is exposed to a strong magnetic field and radio waves, neither of which poses a long-term health risk.

All the hydrogen atoms in the body align along the plane of the magnetic field. The radio waves then knock the atoms out of alignment. By recording the way that the atoms realign to the field, it is possible to build an image which shows information about the composition of different tissues.

MRI scans take longer than CT, usually in the order of 20–60 minutes, and are loud. Hearing defenders are therefore routinely offered to all patients. The scanner is also narrower and longer so claustrophobic patients can become distressed. Some may require sedation or even general anaesthetic to undergo an MRI.

### 1.13.2 Contraindications

Because of the strong magnetic field, ferrous metals cannot be taken near the scanner. In practice, most modern medical implants and prosthetics are MRI compatible, but there are certain cases which still pose issues.

- *Recent surgery*: it is standard practice to wait six weeks after surgery before performing MRI scans, regardless of whether any device has been implanted.
- *Active implantable metal devices (e.g. pacemakers, nerve stimulators, drug infusion pumps, shunts and cochlear implants)*: most modern versions of these devices are MRI conditional, meaning they can be scanned under certain circumstances. Due to the internal power and electrical circuits, MRI scanning can reset or reprogram the device. Provisions should therefore be made before scanning, such as having an appropriate technician available to reset the device.
- *Non-active implantable metal devices (e.g. joint replacements, heart valves, aneurysm clips and stents)*: these are generally OK to scan but will cause localised artefact, affecting image quality (Figure 1.11a).
- *Metallic fragments around the eyes* (e.g. from welding incidents) are an absolute contraindication. When there is a relevant history, an orbital X-ray of the orbits will be performed to assess for this prior to MRI.

Tattoos are nearly always safe, even if they contain traces of metal.

### 1.13.3 Basic Sequences

It is not necessary to understand the physics underlying each MRI sequence. However, knowing the brightness of the tissues of the body is fundamental to interpreting the images (Table 1.3). Structures such as cortical bone and tendons (MSK Chapter 2 – Figure 2.6) will be dark on all MRI sequences, simply because there is a lack of hydrogen atoms to return a signal (MSK Chapter 3 – Figures 3.6 and 3.8).

1.13.3.1 T1 Often termed the anatomical sequence, T1 is good for reviewing normal anatomy (MSK Chapter 3 – Figure 3.6). As **fat is bright**, the subcutaneous tissue and bone marrow will be bright. The white and grey matter of the brain therefore have appropriate relative shades (grey matter is darker than white matter) (Head Chapter 28 – Figure 28.3). **Fluid is dark on T1**.

A limited number of tissues are bright on T1. Knowing this list can be useful for problem solving.

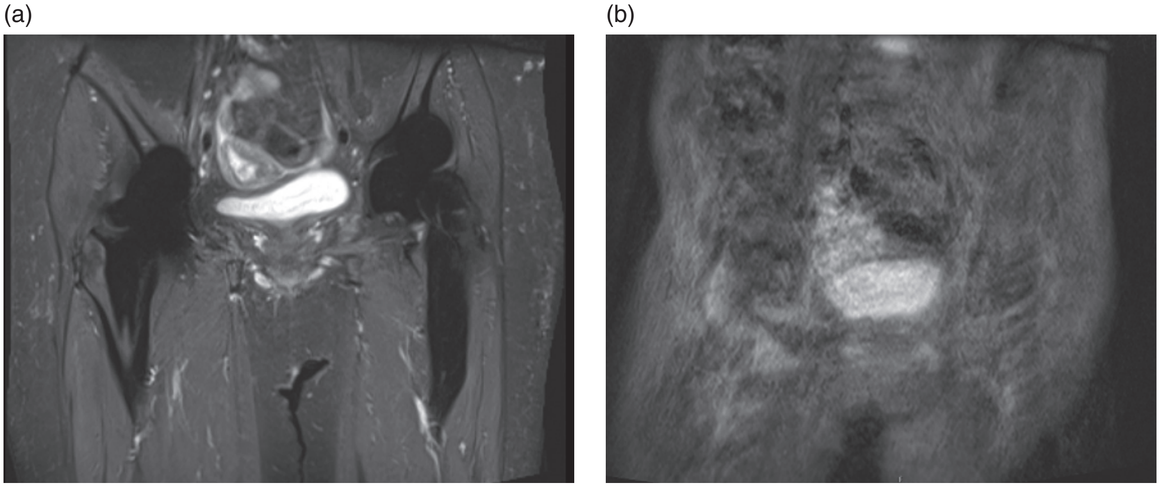


**FIGURE 1.11** (a) Coronal MRI STIR sequence of the pelvis. There are bilateral hip replacements resulting in **metal artefact**. (b) Coronal MRI STIR sequence of the pelvis. There is significant **movement artefact** resulting in blurring.

**TABLE 1.3**

**MRI sequences.**

| Standard sequences | | Fluid | Fat | Tendons and cortical bone |
|---|---|---|---|---|
| T1 | | Dark | Bright | Dark |
| T2 | | Very bright | Bright | Dark |
| FLAIR (used in neuro imaging) | | Dark | Bright | Dark |
| **Fat-saturated sequences** | | | | |
| PD FS (used in MSK imaging) | | Bright | Dark | Dark |
| STIR (used in MSK imaging) | | Very bright | Dark | Dark |
| **Special sequences** | | | | |
| DWI (used mainly in neuro imaging) | DWI trace (B1000) | Dark | Dark | Dark |
| | ADC trace | Bright | Dark | Dark |

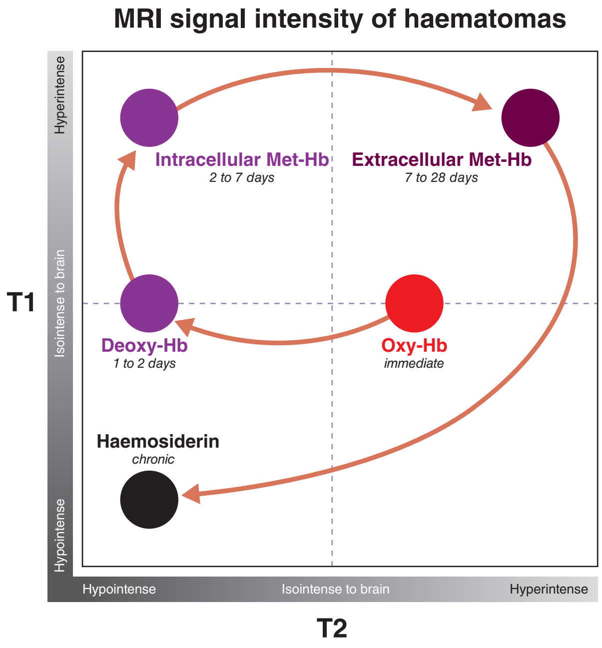


**FIGURE 1.12** MRI signal intensity of haematomas. Hyperacute haemorrhage (hours old): T1 intermediate and T2 intermediate. Acute haemorrhage (1–2 days old): T1 intermediate and T2 dark. Subacute haemorrhage (2–7 days old): T1 bright and T2 dark. Late subacute haemorrhage (1–4 weeks old): T1 bright and T2 bright. Chronic haemorrhage (older than a month): T1 dark and T2 dark.

- Fat
- Blood breakdown products (Figure 1.12)
- Melanin
- Proteinaceous fluid
- Contrast agents

1.13.3.2 T2 The key difference with a T2 sequence is that **fluid is bright**. Hence it is also termed a fluid-sensitive sequence. This can be remembered with the aide mémoire '**WW2 (Water White 2)**'. For this reason, T2 is used to look for pathology (which usually manifests as oedema). On a standard T2 sequence fat remains bright. Consequently, this sequence is most often used for neuro imaging, where fat is separated from the anatomy of interest (Head Chapter 28 – Figure 28.3 and Spine Chapter 25 – Figure 25.5).

1.13.3.3 Fluid Attenuated Inversion Recovery (FLAIR) This type of T2 sequence is used mainly in neuro imaging. With FLAIR, the brightness of most tissues is exactly the same as T2 but the **CSF is suppressed** (becomes dark). This helps to pick up oedema in parts of the brain which are adjacent to CSF (Head Chapter 28 – Figures 28.3 and 28.8).

1.13.3.4 Short Tau Inversion Recovery (STIR) This is used extensively in MSK and spine imaging. It is also a type of T2 sequence but unlike FLAIR, the **fat is suppressed** (becomes dark) (Spine Chapter 25 – Figure 25.5). With fat in the soft tissues and bone marrow being suppressed, it is possible to pick up oedema in these tissues. This makes STIR highly sensitive for traumatic injuries (Spine Chapter 25 – Figure 25.7).

1.13.3.5 Proton Density Fat Suppression (PDFS) This is also a popular sequence in MSK imaging. The fat is suppressed (i.e. becomes dark). Fluid is bright (but not quite as bright as it is on T2 or STIR). This allows assessment of oedema from injuries. It also nicely shows the hyaline cartilage in joints so can be used to assess for early joint disease (MSK Chapter 3 – Figure 3.11).

1.13.3.6 Diffusion Weighted Imaging (DWI) This shows the relative movement of water molecules on a microscopic level. Certain pathologies result in restricted diffusion, so this is a useful sequence to characterise abnormalities previously identified on other sequences. DWI is extremely sensitive to strokes (Head Chapter 28 – Figures 28.4 and 28.12). However, it has poor spatial resolution compared to other sequences and is prone to artefacts at the skull base. Consequently it should not be used in isolation.

### 1.13.4 Appearance of Blood on MRI

Just as with CT, the appearance of blood on MRI varies depending on its age. However, this is a more complicated assessment, requiring the use of both T1 and T2 signal (Figure 1.12). This combined analysis can only be relied upon in the brain. If there are bleeds elsewhere in the body then other chemical processes disrupt the reliable evolution of a haematoma.

### 1.13.5 Artefacts

1.13.5.1 Metal Artefact Metal implants (even non-ferrous types) will stop the magnetic field being uniform and thus affect image quality. This effect is most pronounced next to the implant (Figure 1.11a).

1.13.5.2 Movement Because MRI scans take a long time to acquire, they are even more susceptible to movement artefact than CT. Furthermore, the process of producing the image means its quality is affected by any body movement in the scanner, not just in the part being moved.

It is not uncommon for the scan to be abandoned due to excessive patient movement. This should be a consideration when selecting patients for MRI, with adequate pain relief and sedation provided beforehand.

1.13.5.3 DWI – T2 Shine-through The DWI sequence must always be viewed in conjunction with the apparent diffusion coefficient (ADC). This is because bright areas on the DWI can be caused by an artefact called 'T2 shine-through' (Figure 1.13). The ADC is required to exclude this and confirm true diffusion restriction (compare this figure with Head Chapter 28 – Figure 28.13).

## 1.14 Ultrasound

### 1.14.1 Basic Physics

Ultrasound **does not** expose patients to ionising radiation. Instead, high-frequency vibrations are used which have no long-term health risk.

The ultrasound probe surface vibrates millions of times a second. Therefore, its frequency is measured in megahertz (MHz). When applied to the skin with a coupling gel, these vibrations travel through the body and reflect off tissues, returning to the probe. The returning vibrations are detected and processed to form an image which is a 2D fan shape.

This analysis takes into account how strong the return signal is and how far it has travelled (Pelvis Chapter 6 – Figure 6.3).

### 1.14.2 Using the Machine

Various types of ultrasound machine exist, from large cumbersome units to handheld pocket devices. Regardless of the type, they all have similar components and are used in a similar way.

1.14.2.1 Probe or Transducer This is where the ultrasound is emitted from. The side touching the patient may be straight (linear) or curved (curvilinear). Either way, there should be a marker at one end, which corresponds to the orientation on the screen (Figure 1.14).

Ultrasound is usually performed through the skin but probes exist to perform internal ultrasound (Pelvic Chapter 7 – Figure 7.2) and endoscopic ultrasound.

1.14.2.2 Screen This is where the image is viewed. Some handheld machines will link to mobile phone screens or tablets.

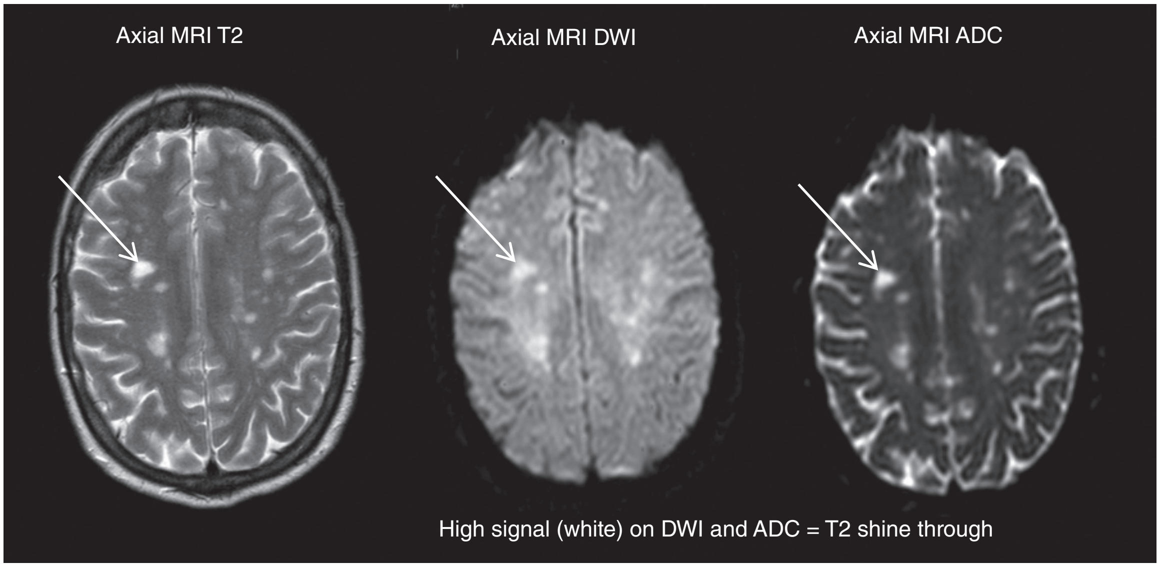


**FIGURE 1.13** Axial MRI T2, DWI and ADC sequences, demonstrating 'T2 shine-through'. The T2 sequence shows multiple high-signal T2 lesions in the white matter, the largest in the right frontal lobe (white arrow). These lesions are high-intensity signals (white) on the DWI. However, before this can be called diffusion restriction, correlation with ADC is required. These lesions are also bright on ADC. This therefore represents represents a 'T2 shine-through' artefact, rather than true diffusion restriction. In this case the lesions represent chronic small vessel disease.

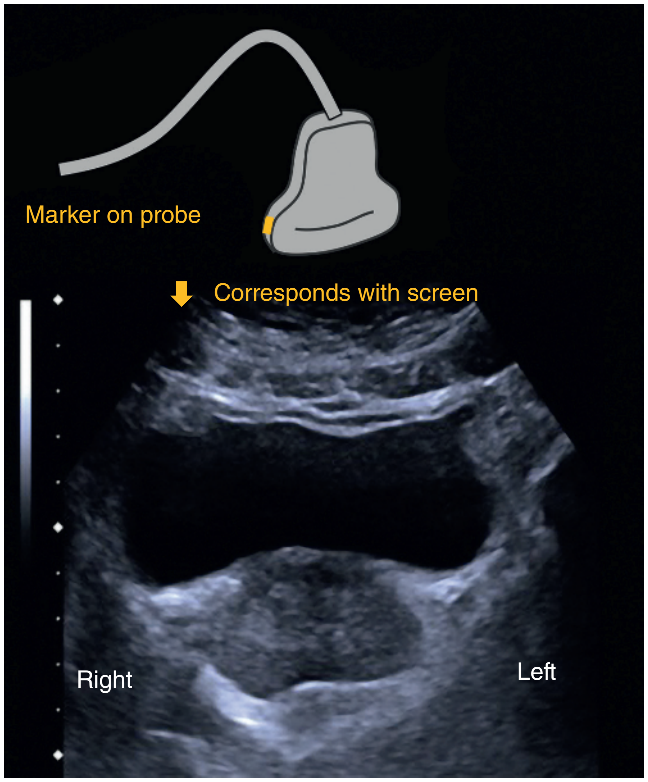


**FIGURE 1.14** Axial ultrasound of the pelvis, showing orientation of the probe. In keeping with the imaging convention elsewhere, the patient's right side is on the left side of the screen. In the longitudinal plane, the cranial side goes on the left side of the screen by convention (Pelvis Chapter 7 – Figures 7.2 and 7.4).

1.14.2.3 Buttons There will be a way to manipulate the image; this could be via real buttons or a touch screen interface. Below are listed the commonly used buttons.

- *Depth*: controls the depth of tissues visible on the screen. Reducing depth to focus on anatomy of interest improves the image quality.
- *Frequency modulation*: higher frequency shows more detail. Lower frequency gives better penetration of deeper tissues. One of the operator skills is judging the optimal balance between these conflicting properties.
- *Zoom*: electronically zooms into a section of the screen. Beware, this does not improve image quality.
- *Gain*: changes the brightness of the image but does not alter overall image quality.
- *Doppler mode*: this enables the direction of blood flow to be seen (Pelvis Chapter 8 – Figure 8.2 and Cardiac Chapter 15 – Figure 15.6).

Dedicated ultrasound machines will also have a keyboard to label the images.

## 1.14.3 Terminology

- *Anechoic*: black appearance on an ultrasound image. This suggests either fluid content (Pelvic Chapter 6 – Figure 6.3) or a lack of ultrasound waves returning from this region (Abdo Chapter 19 – Figure 19.9).
- *Hypoechoic*: dark grey appearance on ultrasound image. This usually suggests a solid structure which allows some vibrations to pass through. Many organs appear like this, for example the prostate (Pelvis Chapter 6 – Figure 6.3).
- *Isoechoic*: middle grey appearance on ultrasound image. Slightly more reflective than hypoechoic

tissues but still allows passage of the ultrasound waves.

- *Hyperechoic*: bright grey or white on the ultrasound image. Structures which completely block the vibration transmission appear white because more of the sound waves are returning to the probe. Examples include gas and bone. As the vibrations are completely reflected, the deeper tissues will appear black (Pelvic Chapter 7.2 – Figure 7.2, bowel gas).

### 1.14.4 Artefacts

1.14.4.1 Posterior Acoustic Shadowing This is what happens when the ultrasound beam hits a completely reflective surface. All the waves are reflected back to the probe and the deeper tissues become black. It is often the result of calcification (Abdo Chapter 19 – Figure 19.9) or bone (Resp Chapter 10 – Figure 10.10).

1.14.4.2 Posterior Acoustic Enhancement This can be thought of as the opposite to posterior acoustic shadowing. The waves can travel through fluid with zero reflections, which results in a stronger signal returning from deeper tissues (Pelvis Chapter 9 – Figure 9.3). A fluid-filled cyst is one common example of a structure demonstrating posterior acoustic enhancement

1.14.4.3 Edge Artefact If the ultrasound beam hits a rounded object, the edges will reflect the ultrasound beam downwards and away from the probe, reducing the return signal and creating vertical dark bands (Pelvis Chapter 9 – Figure 9.3).

### 1.14.5 Ultrasound in Trauma

1.14.5.1 eFAST (Extended Focused Assessment Using Sonography in Trauma) Scanning This is a quick systematic scan of the torso, looking for life-threatening conditions. It can detect:

- pneumothorax
- haemothorax
- cardiac tamponade (Cardiac Chapter 14 – Figure 14.6)
- free fluid (peritoneal haemorrhage) (Abdo Chapter 18 – Figure 18.7).

Its limitations include the following.

- It is operator dependent (i.e. it is only as good as the practitioner holding the probe).
- It may miss small volumes of fluid (less than 200 ml).
- It is unlikely to show the source of the bleeding, especially in the abdomen.
- There may be limited views if there is excessive surgical emphysema or free gas in the abdomen.
- It has poor sensitivity in deeper regions like the thoracic aorta and retroperitoneum.

## 1.15 Take-home Tips on Radiology Modalities

- *Plain radiology*: ubiquitous but only provides static 2D images. It is good for looking at bone, lungs and bowel gas but has limited resolution of soft tissues.
- *CT*: this is much more versatile than plain radiology, especially if contrast is given. However, greater radiation doses are used and it requires the viewer to manipulate the image. Compared to MRI, it provides a poor view of the spinal cord.
- *Nuclear medicine*: provides functional information about the body but has much less anatomical definition compared to X-ray and CT. It is also unlikely to be available within the time frame in which the acute physician works.
- *MRI*: this is very good for viewing soft tissues in neuro and MSK systems. The disadvantage is that it takes longer than X-ray, CT and US and is not tolerated well by unstable or claustrophobic patients.
- *Ultrasound*: this is increasingly available inside and outside hospital. The limitations are that the US beam is blocked by gas and bone and the image quality is very dependent on the skill of the operator.

## Further Resources

Driscoll, P.A., Goode, P.N. and Skinner, D.B. (2023) ABC of major trauma: Rescue, resuscitation with imaging, and rehabilitation. Hoboken, NJ, USA: Wiley Blackwell.

www.radiologyinfo.org/en/info/safety-xray

www.gov.uk/government/publications/medical-radiation-patient-doses

www.gov.uk/government/publications/ionising-radiation-dose-comparisons/ionising-radiation-dose-comparisons

*Diagnostic Imaging Dataset Annual Statistical Release 2021/22 Version 1.* www.england.nhs.uk/statistics/wp-content/uploads/sites/2/2022/12/Annual-Statistical-Release-2021-22-PDF-1.3-MB.pdf