8 Diagnostic imaging

Aggressive bone disease

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The radiograph is the first imaging technique for destructive lesions in bones. There is considerable experience required in the interpretation of these films, especially with regard to whether the lesion is benign or malignant (Figure 8.24 calcification in tumours of muscle, tendon and subcutane - ous fat. When a lesion is detected, there needs to be an early decision as to whether this is benign or malignant. If there is a suspicion of malignancy on the radiograph, or any uncer - tainty , then local staging is indicated. This is best performed by MRI for both bone and soft-tissue lesions (Figure 8.25) . At this stage, it is likely that a biopsy will be indicated, and preferably under image guidance. Soft-tissue and bone biopsy needles may be guided by CT , ultrasound or interventional MRI systems. The route of puncture should avoid vital struc - tures and must be agreed with the surgeon, who will perform local excision if the lesion proves to be malignant. Care should be taken to avoid contaminating other compartments. In all circumstances, samples are best sent for both histopathological and microbiological examination. It may be di ffi cult to tell on imaging whether or not a lesion is infected, and histology often provides a clear diagnosis in inflammatory conditions. Bone scintigraphy is useful in detecting whether a lesion is solitary or multiple, although whole-body MRI is becoming available. Summary box 8.11 Imaging of aggressive lesions in bone /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF

(a) Figure 8.24 A n t e r o p o s t e r i o r (a) a n d l a t e r a l (b) r a d i o

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of the distal femur with breach of the cortex medially and soft-tissue extension seen anteriorly and posteriorly (arrows). The location and appearances are consistent with osteosar

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Articular cartilage damage

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Articular surface disease is di ffi cult to detect using non-invasive techniques. MRI is probably the best method, although it is not - sensitive to early chondral changes (Figure 8.21). Higher field strength magnets (3 tesla and above) with dedicated surface coils - provide more precise assessment; however, MR arthrography - is currently the imaging ‘gold standard’. A dilute quantity of gadolinium DTPA is introduced into the joint by needle punc ture under fluoroscopic, CT or ultrasound guidance, which is followed by an MRI examination. Using this technique, more subtle changes in the articular surface can be seen, including thinning, fissuring and ulceration. However, early softening of articular cartilage will not be visible. MR arthrography is also useful for detecting labral tears in the shoulder or hip, and in the assessment of patients who have undergone a previous meniscectomy . The triangular fibrocartilage of the wrist is also di ffi cult to assess fully without MR or CT arthrography (Figure 8.22). - In the shoulder, rotator cu ff trauma and degenerative changes can be studied using ultrasound or MRI. In experienced hands, ultrasound has a higher accuracy rate because image resolution is better and because the mechanical integrity of the cu ff can be tested by dynamically stressing it (Figure 8.23). MRI has the advantage of being ab le to show abnormalities in the subcortical bone. In the majority of arthropathies and degenerative disor - ders, serial imaging is useful. Changes in films taken weeks or months apart are far easier to see and interpret than a single snapshot study .

Figure 8.19 Axial T2-weighted fat-suppressed image of the wrist in a patient with rheumatoid arthritis demonstrates synovitis manifested as increased signal dorsal to the carpal bones (arrow). (a) (b) Figure 8.20 Ultrasound of the wrist (a) shows thickening of tissues on the dorsal aspect of the radiocarpal joint (arrow). (b) There is increased /f_l ow on power Doppler ultrasound in this patient with wrist synovitis and rheumatoid arthritis. Figure 8.21 Coronal magnetic resonance imaging of the knee demon- strates a focal osteochondral abnormality of the medial femoral con- dyle, with full-thickness loss of the articular cartilage and abnormality of the subchondral bone (arrow). Figure 8.22 Coronal computed tomography arthrogram of the wrist showing a central perforation of the triangular /f_i brocartilage with con- trast extending into the distal radioulnar joint (arrow) and radiocarpal articulation.

Summary box 8.10 Imaging techniques for joint disease /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF

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Basic principles of imaging methods

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Conventional radiography Although it is over 120 years since the discovery of x-rays by - Roentgen in 1895, conventional radiography continues to play a central role in the diagnostic pathway of many acute orthopaedics. X-rays emitted from an x-ray source are absorbed to vary ing degrees by di ff erent materials and tissues and therefore cause di ff erent degrees of blackening of radiographic film, resulting in a radiographic image. This di ff er ential absorption is dependent partly on the density and the atomic number of di ff erent substances. In general, higher density tissues result in a greater reduction in the number of x-ray photons and reduce the amount of blackening caused by those photons. In terms of conventional radiographs, a large di ff erence in tissue structure and density is required before an appreciable di ff erence is man ifested radiographically . The di ff erent densities visible consist of air, fat, soft tissue, bone and mineralisation, and metal. Dif ferent soft tissues cannot be reliably distinguished as, in broad terms, they possess similar quantities of water (Figur e 8.1 Manipulation of x-ray systems and x-ray energies, as used in circumstances such as mammography , may allow better dif fer entiation between some soft-tissue structures. Despite this inherent lack of soft-tissue contrast, conventional radiography has many advantages. It is cheap, universally available , easily reproducible and comparable with prior examinations and, in many instances, has a relatively low dose of ionising radiation in contrast to more complex examinations. However, injudi cious repeat radiography , particularly of the abdomen, pelvis and spine, can easily result in doses similar to CT . The lack of soft-tissue contrast allows little assessment of the internal architecture of many abdominal organs. To ob ate this problem, techniques emplo ying the administration of contrast material combined with radiography have long been used. These techniques include intravenous urography (IVU) and barium examinations (Figur e 8.2) . IVU involves a series of radiographs taken before and after contrast injection, but has been largely superseded by CT urog raphy , which is more accurate in detecting and defining pathology (Figure 8.3 further modification of conventional x-rays uses fluorescent screens to allow real-time monitoring of organs and structures as opposed to the ‘snapshot’ images obtained with radiographs. This is used to follow the passage of barium through the bowel, obtaining dedicated images at specific points of interest only . Motility of the bowel can also be assessed in this way . Fluoros copy is used extensively in interventional radiology , allowing the operator to guide catheters and wires into the patient while monitoring their position in real time. Naturally , with the more sustained use of ionising radia tion, the cumulative doses tend to be greater than when obtain ing a conventional radiograph. Ultrasound Ultrasound is the second most commonly used method of imaging. It relies on high-frequency sound waves generated by a transducer containing piezoelectric material. The generated sound waves are reflected by tissue interfaces and, by ascertain ing the time taken for a pulse to return and the magnitude and direction of a pulse, it is possible to form an image. Medical ultrasound uses frequencies in the range 3–20 /uni00A0 MHz. The higher the frequency of the ultrasound wave, the gr eater the resolution of the image, but the less depth of view from the skin. Consequently , abdominal imaging uses transducers with - - -) . - - vi -) . A - - - -

Figure 8.1 Supine abdominal radiograph of a patient with small bowel obstruction demonstrates multiple dilated small bowel loops. The different densities visible are air (within the bowel), bones, soft tissues and fat. The different soft tissues, subcutaneous and intra-abdominal, cannot be differentiated. Figure 8.2 Barium swallow examination showing a malignant stricture (arrow) due to an oesophageal carcinoma.

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Figure 8.3 Coronal maximum intensity projection image from a computed tomography intravenous urogram shows a transitional cell carcinoma in the left renal pelvis (arrow) with normal excretion of contrast on the right. Figure 8.4 Longitudinal transvaginal ultrasound scan of the uterus demonstrates thickening of the endometrium in a patient during the secretory phase of the menstrual cycle. Figure 8.5 Transverse ultrasound image of the liver in a patient with colorectal cancer shows a solitary liver metastasis. (a) (b) Figure 8.6 Sagittal ultrasound image of the liver (a) in a patient with cirrhosis demonstrates nodularity of the liver surface and extensive ascites. Doppler ultrasound (b) illustrates portal vein /f_l ow with a normal direction.

and venous disease, in which stenotic lesions cause an alter ation in the normal velocity . Furthermore, di ff use parenchymal diseases, such as cirrhosis, may cause an alteration in the nor mal Doppler signal of the blood vessels of the a ff ected organ. The advantages of ultrasound are that it is cheap and easily available. It is the first-line investigation of choice for assessment of the liver, the biliary tr ee and the renal tract (Figures 8.5 and 8.6) . Ultrasound is also the imaging method of choice in obstetric assessment and gynaecological disease. High-frequency transducers have made ultrasound the best imaging technique for the evaluation of thyroid and testicular disorders, in terms of both di ff use disease and focal mass lesions. It is also an invaluable tool for guiding needle placement in interventional procedures such as biopsies and drainages, allowing direct real-time visualisation of the needle during the procedure. Ligament, tendon and muscle injuries are also probably best imaged in the first instance by ultrasound (Figure 8.7). The ability to stress ligaments and to allow tendons to move during the investigation gives an extra dimension, which greatly improves its diagnostic value. T he use of ‘panoramic’ or ‘extended field of view’ ultrasound (Figure 8.8) provides images that are more easily interpreted by an observer not performing the examination, and are of particular assistance to surgeons planning a procedure.

Ultrasound will demonstrate most foreign bodies in soft tissues, including those tha t are not radio-opaque. tor dependent, and most of the information is obtained during - the actual process of scanning as opposed to reviewing the static images. Another drawback is that the ultrasound wave - is highly attenuated by air and bone and, thus, little infor ma - tion is gained with regard to tissues beyond bony or air-filled structures; alternative techniques may be required to image these areas. Summary box 8.4 Ultrasound /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF

Figure 8.7 Ultrasound of the dorsal surface of the wrist shows the normal /f_i brillar pattern of the extensor tendons. There is increased /f_l uid (arrow) within the tendon sheath in this patient with extensor tenosynovitis. Figure 8.8 Panoramic ultrasound of the calf. The normal muscle /f_i bres and the fascia can be identi /f_i ed over an area measuring approximately 12 cm. Strengths No radiation Inexpensive Allows interaction with patients Superb soft-tissue resolution in the near /f_i eld Dynamic studies can be performed First-line investigation for hepatic, biliary and renal disease Endocavity ultrasound for gynaecological and prostate disorders Excellent resolution for breast, thyroid and testis imaging Good for soft tissue, including tendons and ligaments Excellent for cysts and foreign bodies Doppler studies allow assessment of blood /f_l ow Good real-time imaging to guide interventional biopsies and drainages Weaknesses Interpretation only possible during the examination Visualisation of structures can be hampered by overlying gas and bone, and body habitus may also impact on the scan Long learning curve for some areas of expertise Resolution dependent on the machine available Images cannot be reliably reviewed away from the patient

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Conventional radiography Although it is over 120 years since the discovery of x-rays by - Roentgen in 1895, conventional radiography continues to play a central role in the diagnostic pathway of many acute orthopaedics. X-rays emitted from an x-ray source are absorbed to vary ing degrees by di ff erent materials and tissues and therefore cause di ff erent degrees of blackening of radiographic film, resulting in a radiographic image. This di ff er ential absorption is dependent partly on the density and the atomic number of di ff erent substances. In general, higher density tissues result in a greater reduction in the number of x-ray photons and reduce the amount of blackening caused by those photons. In terms of conventional radiographs, a large di ff erence in tissue structure and density is required before an appreciable di ff erence is man ifested radiographically . The di ff erent densities visible consist of air, fat, soft tissue, bone and mineralisation, and metal. Dif ferent soft tissues cannot be reliably distinguished as, in broad terms, they possess similar quantities of water (Figur e 8.1 Manipulation of x-ray systems and x-ray energies, as used in circumstances such as mammography , may allow better dif fer entiation between some soft-tissue structures. Despite this inherent lack of soft-tissue contrast, conventional radiography has many advantages. It is cheap, universally available , easily reproducible and comparable with prior examinations and, in many instances, has a relatively low dose of ionising radiation in contrast to more complex examinations. However, injudi cious repeat radiography , particularly of the abdomen, pelvis and spine, can easily result in doses similar to CT . The lack of soft-tissue contrast allows little assessment of the internal architecture of many abdominal organs. To ob ate this problem, techniques emplo ying the administration of contrast material combined with radiography have long been used. These techniques include intravenous urography (IVU) and barium examinations (Figur e 8.2) . IVU involves a series of radiographs taken before and after contrast injection, but has been largely superseded by CT urog raphy , which is more accurate in detecting and defining pathology (Figure 8.3 further modification of conventional x-rays uses fluorescent screens to allow real-time monitoring of organs and structures as opposed to the ‘snapshot’ images obtained with radiographs. This is used to follow the passage of barium through the bowel, obtaining dedicated images at specific points of interest only . Motility of the bowel can also be assessed in this way . Fluoros copy is used extensively in interventional radiology , allowing the operator to guide catheters and wires into the patient while monitoring their position in real time. Naturally , with the more sustained use of ionising radia tion, the cumulative doses tend to be greater than when obtain ing a conventional radiograph. Ultrasound Ultrasound is the second most commonly used method of imaging. It relies on high-frequency sound waves generated by a transducer containing piezoelectric material. The generated sound waves are reflected by tissue interfaces and, by ascertain ing the time taken for a pulse to return and the magnitude and direction of a pulse, it is possible to form an image. Medical ultrasound uses frequencies in the range 3–20 /uni00A0 MHz. The higher the frequency of the ultrasound wave, the gr eater the resolution of the image, but the less depth of view from the skin. Consequently , abdominal imaging uses transducers with - - -) . - - vi -) . A - - - -

Figure 8.1 Supine abdominal radiograph of a patient with small bowel obstruction demonstrates multiple dilated small bowel loops. The different densities visible are air (within the bowel), bones, soft tissues and fat. The different soft tissues, subcutaneous and intra-abdominal, cannot be differentiated. Figure 8.2 Barium swallow examination showing a malignant stricture (arrow) due to an oesophageal carcinoma.

a frequency of 3–7 /uni00A0 MHz, while higher frequency transducers are used for superficial structures, such as musculoskeletal and breast ultrasound. Dedicated transducers have also been developed for endocavity ultrasound, such as transvaginal scanning and transrectal ultrasound of the prostate, allowing high-frequency scanning of organs by reducing the distance between the probe and the organ of interest (Figure 8.4 further application of dedicated probes has been in the field of endoscopic ultrasound, allowing exquisite imaging of the wall of a hollow viscus and the adjacent organs such as the biliary tree and pancreas. Reflection of an ultrasound wave from moving objects such as red blood cells causes a change in the frequency of the ultrasound wave. By measuring this frequency change, it is). A possible to calculate the speed and direction of the movement. This principle forms the basis of Doppler ultrasound, whereby velocities within major vessels, as well as smaller vessels in organs such as the liver and the kidneys, can be measured.

Figure 8.3 Coronal maximum intensity projection image from a computed tomography intravenous urogram shows a transitional cell carcinoma in the left renal pelvis (arrow) with normal excretion of contrast on the right. Figure 8.4 Longitudinal transvaginal ultrasound scan of the uterus demonstrates thickening of the endometrium in a patient during the secretory phase of the menstrual cycle. Figure 8.5 Transverse ultrasound image of the liver in a patient with colorectal cancer shows a solitary liver metastasis. (a) (b) Figure 8.6 Sagittal ultrasound image of the liver (a) in a patient with cirrhosis demonstrates nodularity of the liver surface and extensive ascites. Doppler ultrasound (b) illustrates portal vein /f_l ow with a normal direction.

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Bowel obstruction

Bowel obstruction

The plain abdominal radiograph is a useful tool in diagnosing bowel obstruction. Small bowel obstruction can generally be distinguished from large bowel obstruction by virtue of the following: the small bowel lies centrally in the abdomen while the large bowel lies peripherally; the valvulae conniventes (folds) of the small bowel traverse the entire width of the lumen while the haustra of the large bowel do not; and the calibre of the small bowel is typically less than the large, even when obstructed (typical measurements in obstruction: small bowel 3.5–5 /uni00A0 cm, large bowel 5–8 /uni00A0 cm). However, it must be stressed that a normal plain radio - graph does not exclude an obstruction – if there is persistent concern, further imaging is indicated; CT is the modality of choice, having largely superseded the contrast follow-through or enema, particular ly in the acute setting. The key to diagnosis of a mechanical obstruction of either small or large bowel on CT , and di ff erentiation from paralytic ileus, is identification of a transition zone from dilated proximal bowel to collapsed distal bowel. In small bowel obstruction if no obvious cause such as a mass, volvulus or intussusception is identified, then the most likely aetiology is adhesional. There is no need to give oral contrast for a suspected bowel obstruction CT as fluid in the lumen is a natural contrast agent and, in any case, oral con - trast may well not reach the point of obstruction by the time of the scan. CT is also invaluable to diagnose complications of bowel obstruction suc h as perforation and ischaemia. If there is ongoing uncertainty after CT as to whether the diagnosis is mechanical obstruction or a paralytic ileus, delayed plain abdominal radiographs obtained 1 and 4 hours after ingestion of dilute Gastrografin (typically 75 /uni00A0 mL Gastrografin mixed with 75 /uni00A0 mL water) can be useful to assess if contrast reaches the colon. Gastrografin also has an osmotic e ff ect that can, on occasion, be therapeutic . Closed loop obstruction, where the bowel is obstructed at two points, often in close proximity to each other and fre - quently related to an internal hernia or adhesional band, is a particular type of small bowel obstruction prone to developing ischaemia. It should be suspected at CT if the bowel is dilated distal to a transition point with a further transition point more distally (Figure 8.36). Leo George Rigler , 1896–1979, American radiologist, described the double-wall sign in pneumoperitoneum. Demetrius Chilaiditi , 1883–1975, Greek radiologist.

Figure 8.36 Coronal computed tomography showing a failed renal transplant in the right iliac fossa and second transplant in the left iliac fossa. There has also been a right hemicolectomy. There is proximal small bowel obstruction with dilated /f_l uid- /f_i lled small bowel loops. Distal to the /f_i rst point of obstruction (large arrow) there are dilated thick-walled /f_l uid- /f_i lled loops in the pelvis with some adjacent free /f_l uid, which could be followed to a second point of obstruction (small arrow). Laparotomy con /f_i rmed a closed loop obstruction secondary to an adhesive band with ischaemia in the segment of small bowel between the points of obstruction. Figure 8.37 E r e c t c h e s t r a d i o g r a p h s h o w i n g s u b d i a p h r a g m a t i c f r e e gas (arrow) consistent with hollow organ perforation. Figure 8.38 Plain abdominal radiograph showing an abnormal appearance to the gastric wall, which is very clearly visualised owing to the presence of gas both inside the lumen and outside the lumen (arrow). This is Rigler's sign of hollow organ perforation, in this case due to a duodenal ulcer.

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Computed tomography

Computed tomography

There has been a great deal of development in CT technology over the last 30 years from the initial conventional CT scanners through to helical or spiral scanners and the current multi- detector machines. CT scanners consist of a gantry containing the x-ray tube, filters and detectors, which revolve around the patient, acquiring information at di ff erent angles and projec - tions. This information is then mathematically reconstructed to produce a two-dimensional grey-scale image of a slice through the body . This technique overcomes the problem of di ff erent structures, which is inherent in superimposition of conventional radiography . Improvements in gantry design, development of more sensitive detectors and an increase in the number of detectors have resulted in an increase in spatial resolution, as well as the speed at which the images are acquired. In early CT scanners, the table on which the patient was positioned moved in between the gantry revolution to allow imaging of an adjacent slice. Modern scanners allow for continuous movement of the table and the patient during the gantry revolution, thus greatly reducing the scan time. With modern equipment, it is now not only possible to obtain images of the chest, abdomen and pelvis in under 10 seconds but these axial images can also be reformatted in multiple planes with practically no degradation in image quality . In addition, CT has a far higher contrast resolution than plain radiographs, allowing the assessment of tissues with similar attenuation characteristics. As with radiographs, the natural contrast of tissues is further augmented by the use of intravenous iodinated contrast medium. Rapid scanning of a volume of tissue also allows the scans to be performed at di ff erent phases of enhancement, which is advantageous in identifying di ff erent diseases. For instance, very early scanning during the arterial phase is ideally suited to the examination of the arterial tree and hypervascular liver lesions, whereas scanning performed after a delay may be better suited to the identification of other solid organ pathology such as renal Jacques Lisfranc de St. Martin , 1790–1847, Professor of Surgery and Operative Medicine, Paris, France. contrast injection, can be used to assess the ureters and bladder (Figure 8.3) . Furthermore, it is possible to obtain scans during several phases including the arterial and venous phases in the same patient, which may aid in the identification and charac - terisation of lesions. CT is widely used in thoracic, abdominal (Figure 8.9),) and neurological (Figure 8.10), musculoskeletal (Figure 8.11 trauma imaging. The thinner collimation and improved spa - tial resolution have also resulted in the development of newer techniques such as CT angiography , virtual colonoscopy and virtual bronchoscopy . Furthermore, three-dimensional images can be reconstructed from the ra w data to aid in surgical plan - ning and to provide virtual endoluminal views in virtual colo - noscopy for example . The disadvantage of CT compared with ultrasound and conventional radiography lies largely in the increased costs and the far higher doses of ionising radiation. For instance, a CT scan of the abdomen and pelvis has a radi - ation dose equivalent to approximately 500 chest radiographs.

Figure 8.9 Axial computed tomography scan of a patient with acute pancreatitis demonstrates a swollen oedematous pancreas (arrow) with extensive peripancreatic free /f_l uid (curly arrow). Figure 8.10 Axial computed tomography scan of the head following intravenous contrast demonstrates a large mass lesion in the left frontal region (arrow) in a patient with a large left frontal meningioma. (a) (b) Figure 8.11 Coronal computed tomography (a) and axial reformats /uni00A0 (b) of the foot in a patient involved in a

road traf /f_i c accident demon

strates Lisfranc fracture dislocation with a comminuted fracture of the base of the second metatarsal (arrows).

Computed tomography /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF Magnetic resonance imaging Over the last 20 years, MRI has become an integral part of the imaging arsenal with ever-expanding indications. MRI relies on the fact that nuclei containing an odd number of protons have a characteristic motion in a magnetic field (precession) and produce a magnetic moment as a result of this motion. In a strong uniform magnetic field such as an MRI scanner, these nuclei align themselves with the main magnetic field and result in a net magnetic moment. A brief radiofrequency pulse is then applied to alter the motion of the nuclei. Once the radiofrequency pulse is removed, the nuclei realign themselves with the main magnetic field (relaxation) and in the process emit a radiofrequency signal that can be recorded, spatially encoded and used to construct a grey-scale image. The specific tissue characteristics define the manner and rate at which the nuclei relax. This relaxation is measured in two ways, referred to as the T1 and T2 relaxation times. The relaxation times and the proton density determine the signal from a specific tissue. There are a large number of imaging sequences that can be used by applying radiofrequency pulses of di ff erent strengths and durations. The image characteristic and signal intensity from di ff erent tissues ar e governed by the pulse sequence employed and whether it is T1 weighted or T2 weighted. For instance, fat, methaemoglobin and mucinous fluid are bright on T1-weighted images, whereas water and thus most patho logical processes, which tend to increase tissue water content, are bright on T2-weighted images. Cortical bone, air, haemo siderin and ferromagnetic materials are of very low signal on all pulse sequences. In general, T1-w eighted images are supe rior in the delineation of anatomy , while T2-weighted images tend to highlight pathology better. For added tissue contrast, intrav enous gadolinium may be administered. Other more lymph node imaging. MRI’s exquisite contrast resolution, coupled with a lack of ionising radiation, is very attractive in imaging, particularly of tissues that hav e relatively little natural contrast. MRI also has the adv antage of multiplanar imaging, as images can be acquired in any plane prescribed. It has traditionally been used extensively in the assessment of intracranial, spinal and mus - culoskeletal disorders (Figures 8.12 , 8.13 and 8.14) , allowing a global assessment of bony and soft-tissue structures. More recent developments have resulted in new indications and applications. Today , MRI is commonly used in oncological imaging, such as staging of rectal carcinoma and gynaecologi - cal malignancies, identification and characterisation of hepatic - - -

Strengths High spatial and contrast resolution Contrast resolution enhanced by ability to image in multiple phases, including arterial, venous and delayed Rapid acquisition of images in one breath-hold Imaging of choice for the detection of pulmonary masses Allows global assessment of the abdomen and pelvis Excellent for liver, pancreatic, renal and bowel pathology Three-dimensional reconstruction allows complex fracture imaging Multiplanar reconstruction and three-dimensional imaging, e.g. CT angiography and colonoscopy Ability to guide intervention such as percutaneous biopsy and drainage Weaknesses High radiation dose Poor soft-tissue resolution of the peripheries and super /f_i cial structures Patient needs to be able to lie /f_l at and still Less readily available than plain /f_i lms and ultrasound Figure 8.12 T2-weighted axial magnetic resonance imaging scan of the head in a patient with a large left-sided oligodendroglioma (arrow). Figure 8.13 Sagittal T2-weighted magnetic resonance imaging scan of the lumbar spine demonstrates disc herniation (arrow) in a patient with acute back pain.

masses and assessment of the biliary tree (magnetic resonance cholangiopancreatography [MRCP]; Figure 8.15). MRI has become increasingly important in imaging of the small bowel, for example in Crohn’s disease, where repeated imaging with ionising radiation can incur a significant radiation dose over time. Magnetic resonance (MR) angiographic techniques allow non-invasive angiographic assessment of the cranial and peripheral circulation (Figure 8.16) and cardiac imaging. Di ff usion-weighted imaging is a relatively new type of MRI sequence that exploits the di ff erent rates of Brownian motion between di ff erent tissues. Tissues with greater cellular density have low er rates of di ff usion of water molecules, and this dif ference can be exploited to distinguish benign and malignant or inflammatory lesions in a variety of organs as malignant or inflammatory lesions tend to have greater density of cells. in comparison with other imaging techniques, and it is time-consuming with respect to image acquisition and interpretation. Images are easily degraded by motion, including respiratory and cardiac motion. T he use of respiratory and cardiac gating can minimise this, although bowel peristalsis can still be a problem. The long acquisition times require a cooperative patient who can lie very still, which can be di ffi cult especially in claustrophobic individuals or those in pain. Furthermore, because of the use of high-strength magnetic fields, patients with some metallic implants, such as some aneurysm clips and prosthetic heart valves, and those with implanted electronic devices, such as pacemakers and defibrillators, cannot be examined. Some newer implants may , however, be MRI compatible, and patients with joint replacements can be studied safely . Summary box 8.6 Magnetic resonance (MR) imaging /uni25CF Nuclear medicine In other imaging techniques using ionising radiation such as - CT and conventional radiography , the individual is exposed to ionising radiation from an external source and the radiation transmitted through the patient is recorded. In nuclear medicine, however, a radioactive element or radionuclide such

Figure 8.14 Coronal magnetic resonance imaging scan of the knee demonstrates extensive serpiginous areas of altered signal intensity in the distal femur and

proximal tibia (arrows) in a patient with bone infarcts secondary to oral corticosteroids. Figure 8.15 Magnetic resonance cholangiopancreatography image demonstrates dilated intrahepatic ducts and proximal common bile duct (CBD) secondary to multiple calculi in the distal CBD (arrow). This type of imaging has the potential to alter cholecystectomy sur gical planning. Strengths No ionising radiation Excellent soft-tissue contrast Best imaging technique for Intracranial lesions Spine Bone marrow and joint

lesions Other uses Staging MRCP MR angiography Breast malignancy Pelvic malignancy Cardiac imaging MR enterography Diffusion-weighted imaging Weaknesses Absolute contraindications Ocular metallic foreign bodies

Cochlear implants Cranial aneurysm clips Relative contraindications Pacemakers First trimester of pregnancy Claustrophobia Long scan times so patients may not be able to keep still, especially if in pain Limited availability Expensive

as technetium, gallium, thallium or iodine is administered to the patient as part of a radiopharmaceutical agent, and a detector such as a gamma camera is then used to record and localise the emission from the patient, thus forming the image. The radionuclide is chosen and coupled with other compounds such that it is distributed and taken up in the tissues of interest. Therefore, a variety of radionuclides are required for imaging of di ff erent tissues. Nuclear medicine also di ff ers from other means of imaging, which are largely anatomically based, as it also provides functional information. Radionuclide imaging is widely used in bone imaging with very high sensitivity for assessing metastatic disease, metabolic bone disease, established arthropathies and occult infection and traumatic injuries (Figure 8.17) , although many of these applica tions are being replaced by MRI. In genitourinary disease, dynamic imaging can be perfor med to assess renal perfusion and function including obstruction, to investigate renovascular hypertension and to evaluate renal transplants. Radionuclide imaging is also commonly used in thyroid and parathyroid disorders, ischaemic cardiac disease, detection of pulmonary emboli and assessment of occult infection and inflammatory bowel disease. Positron emission tomography (PET) is an extension of nuclear medicine, in which a positron-emitting substance such 18 as F is tagged and used to assess tissue metabolic characteristics. 18 The most commonly used radiolabelled tracer is F-2-fluoro 2-deoxy- /d.sc -glucose (FDG), although other tracers can also be used in order to assess metabolic functions such as oxygen and glucose consumption and blood flow. Radioisotope decay causes the emission of a positron, which subsequently, within a few millimetres, collides with and annihilates an electron to produce a pair of annihilation photons. The drawbacks have been high cost, very limited availability and relatively low spatial resolution. The last of these has been addressed by PET/CT systems combining simultaneous PET imaging and CT, allowing the two sets of images to be registered so that more precisely. This modality has significantly improved the accuracy of cancer staging for a range of malignancies and is also useful in inflammatory conditions and imaging pyrexia of unknown origin. Summary box 8.7 Radionuclide imaging /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF -

Figure 8.16 Maximum intensity projection image from a magnetic res onance angiogram demonstrates the abdominal aorta, common and external iliac arteries as well as parts of the pulmonary, mesenteric and renal vasculature. Strengths Allows functional imaging Allows imaging of the whole body Bone scan has a high sensitivity for metastatic bone disease, fractures and infection

PET scanning is valuable in the detection of metastatic cancer Weaknesses Speci /f_i c agents are required for speci /f_i c indications

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Computed tomography

There has been a great deal of development in CT technology over the last 30 years from the initial conventional CT scanners through to helical or spiral scanners and the current multi- detector machines. CT scanners consist of a gantry containing the x-ray tube, filters and detectors, which revolve around the patient, acquiring information at di ff erent angles and projec - tions. This information is then mathematically reconstructed to produce a two-dimensional grey-scale image of a slice through the body . This technique overcomes the problem of di ff erent structures, which is inherent in superimposition of conventional radiography . Improvements in gantry design, development of more sensitive detectors and an increase in the number of detectors have resulted in an increase in spatial resolution, as well as the speed at which the images are acquired. In early CT scanners, the table on which the patient was positioned moved in between the gantry revolution to allow imaging of an adjacent slice. Modern scanners allow for continuous movement of the table and the patient during the gantry revolution, thus greatly reducing the scan time. With modern equipment, it is now not only possible to obtain images of the chest, abdomen and pelvis in under 10 seconds but these axial images can also be reformatted in multiple planes with practically no degradation in image quality . In addition, CT has a far higher contrast resolution than plain radiographs, allowing the assessment of tissues with similar attenuation characteristics. As with radiographs, the natural contrast of tissues is further augmented by the use of intravenous iodinated contrast medium. Rapid scanning of a volume of tissue also allows the scans to be performed at di ff erent phases of enhancement, which is advantageous in identifying di ff erent diseases. For instance, very early scanning during the arterial phase is ideally suited to the examination of the arterial tree and hypervascular liver lesions, whereas scanning performed after a delay may be better suited to the identification of other solid organ pathology such as renal Jacques Lisfranc de St. Martin , 1790–1847, Professor of Surgery and Operative Medicine, Paris, France. contrast injection, can be used to assess the ureters and bladder (Figure 8.3) . Furthermore, it is possible to obtain scans during several phases including the arterial and venous phases in the same patient, which may aid in the identification and charac - terisation of lesions. CT is widely used in thoracic, abdominal (Figure 8.9),) and neurological (Figure 8.10), musculoskeletal (Figure 8.11 trauma imaging. The thinner collimation and improved spa - tial resolution have also resulted in the development of newer techniques such as CT angiography , virtual colonoscopy and virtual bronchoscopy . Furthermore, three-dimensional images can be reconstructed from the ra w data to aid in surgical plan - ning and to provide virtual endoluminal views in virtual colo - noscopy for example . The disadvantage of CT compared with ultrasound and conventional radiography lies largely in the increased costs and the far higher doses of ionising radiation. For instance, a CT scan of the abdomen and pelvis has a radi - ation dose equivalent to approximately 500 chest radiographs.

Figure 8.9 Axial computed tomography scan of a patient with acute pancreatitis demonstrates a swollen oedematous pancreas (arrow) with extensive peripancreatic free /f_l uid (curly

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Computed tomography /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF Magnetic resonance imaging Over the last 20 years, MRI has become an integral part of the imaging arsenal with ever-expanding indications. MRI relies on the fact that nuclei containing an odd number of protons have a characteristic motion in a magnetic field (precession) and produce a magnetic moment as a result of this motion. In a strong uniform magnetic field such as an MRI scanner, these nuclei align themselves with the main magnetic field and result in a net magnetic moment. A brief radiofrequency pulse is then applied to alter the motion of the nuclei. Once the radiofrequency pulse is removed, the nuclei realign themselves with the main magnetic field (relaxation) and in the process emit a radiofrequency signal that can be recorded, spatially encoded and used to construct a grey-scale image. The specific tissue characteristics define the manner and rate at which the nuclei relax. This relaxation is measured in two ways, referred to as the T1 and T2 relaxation times. The relaxation times and the proton density determine the signal from a specific tissue. There are a large number of imaging sequences that can be used by applying radiofrequency pulses of di ff erent strengths and durations. The image characteristic and signal intensity from di ff erent tissues ar e governed by the pulse sequence employed and whether it is T1 weighted or T2 weighted. For instance, fat, methaemoglobin and mucinous fluid are bright on T1-weighted images, whereas water and thus most patho logical processes, which tend to increase tissue water content, are bright on T2-weighted images. Cortical bone, air, haemo siderin and ferromagnetic materials are of very low signal on all pulse sequences. In general, T1-w eighted images are supe rior in the delineation of anatomy , while T2-weighted images tend to highlight pathology better. For added tissue contrast, intrav enous gadolinium may be administered. Other more lymph node imaging. MRI’s exquisite contrast resolution, coupled with a lack of ionising radiation, is very attractive in imaging, particularly of tissues that hav e relatively little natural contrast. MRI also has the adv antage of multiplanar imaging, as images can be acquired in any plane prescribed. It has traditionally been used extensively in the assessment of intracranial, spinal and mus - culoskeletal disorders (Figures 8.12 , 8.13 and 8.14) , allowing a global assessment of bony and soft-tissue structures. More recent developments have resulted in new indications and applications. Today , MRI is commonly used in oncological imaging, such as staging of rectal carcinoma and gynaecologi - cal malignancies, identification and characterisation of hepatic - - -

Strengths High spatial and contrast resolution Contrast resolution enhanced by ability to image in multiple phases, including arterial, venous and delayed Rapid acquisition of images in one breath-hold Imaging of choice for the detection of pulmonary masses Allows global assessment of the abdomen and pelvis Excellent for liver, pancreatic, renal and bowel pathology Three-dimensional reconstruction allows complex fracture imaging Multiplanar reconstruction and three-dimensional imaging, e.g. CT angiography and colonoscopy Ability to guide intervention such as percutaneous biopsy and drainage Weaknesses High radiation dose Poor soft-tissue resolution of the peripheries and super /f_i cial structures Patient needs to be able to lie /f_l at and still Less readily available than plain /f_i lms and ultrasound Figure 8.12 T2-weighted axial magnetic resonance imaging scan of the head in a patient with a large left-sided oligodendroglioma (arrow). Figure 8.13 Sagittal T2-weighted magnetic resonance imaging scan of the lumbar spine demonstrates disc herniation (arrow) in a patient with acute back pain.

masses and assessment of the biliary tree (magnetic resonance cholangiopancreatography [MRCP]; Figure 8.15). MRI has become increasingly important in imaging of the small bowel, for example in Crohn’s disease, where repeated imaging with ionising radiation can incur a significant radiation dose over time. Magnetic resonance (MR) angiographic techniques allow non-invasive angiographic assessment of the cranial and peripheral circulation (Figure 8.16) and cardiac imaging. Di ff usion-weighted imaging is a relatively new type of MRI sequence that exploits the di ff erent rates of Brownian motion between di ff erent tissues. Tissues with greater cellular density have low er rates of di ff usion of water molecules, and this dif ference can be exploited to distinguish benign and malignant or inflammatory lesions in a variety of organs as malignant or inflammatory lesions tend to have greater density of cells. in comparison with other imaging techniques, and it is time-consuming with respect to image acquisition and interpretation. Images are easily degraded by motion, including respiratory and cardiac motion. T he use of respiratory and cardiac gating can minimise this, although bowel peristalsis can still be a problem. The long acquisition times require a cooperative patient who can lie very still, which can be di ffi cult especially in claustrophobic individuals or those in pain. Furthermore, because of the use of high-strength magnetic fields, patients with some metallic implants, such as some aneurysm clips and prosthetic heart valves, and those with implanted electronic devices, such as pacemakers and defibrillators, cannot be examined. Some newer implants may , however, be MRI compatible, and patients with joint replacements can be studied safely . Summary box 8.6 Magnetic resonance (MR) imaging /uni25CF Nuclear medicine In other imaging techniques using ionising radiation such as - CT and conventional radiography , the individual is exposed to ionising radiation from an external source and the radiation transmitted through the patient is recorded. In nuclear medicine, however, a radioactive element or radionuclide such

Figure 8.14 Coronal magnetic resonance imaging scan of the knee demonstrates extensive serpiginous areas of altered signal intensity in the distal femur and proximal tibia (arrows) in a patient with bone infarcts secondary to oral corticosteroids. Figure 8.15 Magnetic resonance cholangiopancreatography image demonstrates dilated intrahepatic

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as technetium, gallium, thallium or iodine is administered to the patient as part of a radiopharmaceutical agent, and a detector such as a gamma camera is then used to record and localise the emission from the patient, thus forming the image. The radionuclide is chosen and coupled with other compounds such that it is distributed and taken up in the tissues of interest. Therefore, a variety of radionuclides are required for imaging of di ff erent tissues. Nuclear medicine also di ff ers from other means of imaging, which are largely anatomically based, as it also provides functional information. Radionuclide imaging is widely used in bone imaging with very high sensitivity for assessing metastatic disease, metabolic bone disease, established arthropathies and occult infection and traumatic injuries (Figure 8.17) , although many of these applica tions are being replaced by MRI. In genitourinary disease, dynamic imaging can be perfor med to assess renal perfusion and function including obstruction, to investigate renovascular hypertension and to evaluate renal transplants. Radionuclide imaging is also commonly used in thyroid and parathyroid disorders, ischaemic cardiac disease, detection of pulmonary emboli and assessment of occult infection and inflammatory bowel disease. Positron emission tomography (PET) is an extension of nuclear medicine, in which a positron-emitting substance such 18 as F is tagged and used to assess tissue metabolic characteristics. 18 The most commonly used radiolabelled tracer is F-2-fluoro 2-deoxy- /d.sc -glucose (FDG), although other tracers can also be used in order to assess metabolic functions such as oxygen and glucose consumption and blood flow. Radioisotope decay causes the emission of a positron, which subsequently, within a few millimetres, collides with and annihilates an electron to produce a pair of annihilation photons. The drawbacks have been high cost, very limited availability and relatively low spatial resolution. The last of these has been addressed by PET/CT systems combining simultaneous PET imaging and CT, allowing the two sets of images to be registered so that more precisely. This modality has significantly improved the accuracy of cancer staging for a range of malignancies and is also useful in inflammatory conditions and imaging pyrexia of unknown origin. Summary box 8.7 Radionuclide imaging /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF -

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res onance angiogram demonstrates the abdominal aorta, common and external iliac arteries as well as parts of the pulmonary, mesenteric and renal vasculature. Strengths Allows functional imaging Allows imaging of the whole body Bone scan has a high sensitivity for metastatic bone disease, fractures and infection PET scanning is valuable in the detection of metastatic cancer Weaknesses Speci /f_i c agents are required for speci /f_i c indications

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Computed tomography

CT is the main imaging method for the investigation of intra- cranial and intra-abdominal injuries and vertebral fractures. With current multidetector scanners a comprehensive exam - ination of the head, spine, chest, abdomen and pelvis can be completed in less than 5 minutes. Traditionally the CT scanner was referred to as ‘the doughnut of death’, as imaging could lead to delays in emergency treatment. Howev er, as the avail - ability of scanners and the speed of scanning has dramatically increased, it has become standard practice to use CT early in the assessment of trauma patients. Emergency departments have CT scanners co-located to the resuscitation or trauma bays or patients can be assessed and treated while on the CT table. CT examination of the head is accurate in identifying treatable intracranial injuries (Figures 8.30 and 8.31) and should not be delayed by radiography of peripheral injuries, as there is declining success in cases of intracranial collection when treated after the initial 3–4 hours. In comparison, iden - tification of more widespread injuries, such as di ff use axonal injury , is relatively poor. Examination of facial injuries and cervical spine fractures can also be carried out at the same time as this only adds seconds to the examination. There is evidence tha t CT of the abdomen and pelvis is of benefit in multiple trauma when there is a head injury , as it often shows - unexpected abnormalities; this may a ff ect the immediate man - agement, especially if the patient deteriorates. Chest CT with intravenous contrast agent is valuable in identifying vascular and lung injuries and is the most accurate way of demonstrating haemothorax and pneumothorax. The position of chest drains can be identified, allowing adjust ment /uni00A0 of position if necessary . Abdominal and pelvic CT is usually undertaken as an extension to the chest CT . If an abdominal examination is performed, the pelvis should be included to avoid missing pelvic injuries and fr ee pelvic fluid. CT is an excellent means of identifying hepatic, splenic (Figure 8.32) and renal injuries. Delayed examination after assessment of the pelvicalyceal system in cases of renal trauma. Pancreatic and duodenal injuries may also be identified, but detection of these injuries may be more prob lematic. Using CT , the accuracy of detection of bowel or mesenteric injuries is less than it is for solid organ injury , and these injuries should be suspected when there is free intraperitoneal fluid without an identifiable cause (Figure 8.33). Close clinical follow-up and early repeat scanning with oral contrast can often reveal the bowel or mesenteric injury in patients with free fluid with no other cause identified. The image data may be reconstructed into thinner slices for the diagnosis of injuries to the thoracic and lumbar spine and for the better delineation of pelvic and acetabular frac - tures. Complex intra-articular fractures of the peripheral skel - eton, such as calcaneal and tibial plateau fractures , may be usefully examined by dedicated thin-section studies provided this does not delay the treatment of other more serious injuries (Figure 8.34) . CT angiography may be used to demonstrate vascular injuries in the limbs in those with penetrating injuries or complex displaced fractures.

Figure 8.30 Computed tomography of the head in a patient with head injury shows bilateral large frontal extradural collections (arrow). Figure 8.31 Computed tomography of the head following head trauma shows a skull fracture with a large depressed component (arrow).

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Degenerative disease

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Synovitis Radiographs are usually the first-line imaging investigation performed for the examination of joints. Typical changes of a degenerative or an erosive arthropathy are well known and understood. However, early arthropathy will be missed on radiographs and, with the advent of disease-modifying drugs, it is important to detect early synovitis before it is even apparent on clinical examination. Gadolinium diethyl triamine penta-acetic (DTPA)-enhanced MRI is the most sensitive method for detecting synovial thickening of numerous joints, but ultrasound is also sensitive, albeit more and in laborious to perform. Ultrasound shows e ff usions and synovial thickening clearly , and shows the increased blood flow around the a ff ected joints without the use of contrast agents (Figures 8.19 and 8.20). Degenerative disease

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Gastrointestinal haemorrhage

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HAZARDS OF IMAGING

Contrast media

HAZARDS OF IMAGING Contrast media

There has been a dramatic increase in the use of contrast agents in recent years, mainly related to the increasing use of CT . Potential problems include allergic reaction and nephrotoxic ity . Reactions are rare: serious reactions occur in about 1:2500 cases and life-threatening reactions in fewer than 1:100 /uni00A0 000 cases. The risk of sudden death, however, has not changed with the new agents. Local policies for dealing with pa tients at increased risk vary between departments and, indeed, between countries. Premedication with steroids given at least 6 hours before the contrast can reduce the incidence and severity of anaphylactoid reactions but there is no evidence it reduces the risk of death. Low-osmolality contrast media (LOCMs) or iso-osmolar media are up to 10 times safer than the older ionic media. Most serious reactions occur shortly after injection, so observation of the patient for 30 minutes after injection with the intravenous cannula still in situ is recommended for higher risk individuals. In patients with diabetes or renal impairment, a recent creatinine level should be available. The risks of contrast- induced acute kidney injury are highest in patients with severe r enal impairment (estimated glomerular filtration rate [eGFR] 2 <30 /uni00A0 mL/min/1.73 /uni00A0 m), whereas in patients with normal renal 2 function (eGFR >60 /uni00A0 mL/min/1.73 /uni00A0 m) or even moderately impaired stable renal function (eGFR 45 /uni00A0 mL/min/1.73 /uni00A0 the risk is zero to minimal. Contrast should never be withheld if the benefits to the patient of making the diagnosis are felt to be justified by the referring surgeon and radiologist. But in patients with severe renal impairment the risks and benefits of contrast adminis tration need to be carefully assessed and, if contrast is given, the patient should be well hydrated and the lowest dose of an LOCM should be given. The evidence for the use of N -acetyl cysteine or sodium bicarbonate for renal protection is mixed, and their use is not recommended. patients taking metformin. Latest recommendations ar e that it appears safe to continue the metformin if the eGFR is above 2 for intravenous administration or above 30 /uni00A0 mL/min/1.73 /uni00A0 m 2 45 /uni00A0 mL/min/1.73m for intra-arterial injections. Any decision to stop metformin should be made with the radiologist and the physician managing the patient’s diabetes. Gadolinium-containing contrast agents are used in MRI examinations. Allergic reactions to these agents are very rare, occurring in less than 0.1% of administra tions. However, they can be nephrotoxic in patients with renal failure. In addition, they are associated with a risk of nephrogenic systemic fibrosis (NSF), an extremely rare but serious life-threatening condi - tion whereby connective tissue forms in the skin causing it to become coarse and hard. NSF may also a ff ect other organs, including joints, muscle, liver and heart. High-risk g adolinium- containing contrast agents are contraindicated in severe renal failure, in neonates and in the perioperative period of liver transplantation, and are not recommended in pregnancy . However, lower risk gadolinium preparations are available that may be used with caution. Liver-specific contrast agents for MRI, selectively taken up by hepatocytes, are increasingly used to characterise liver lesions and in cancer staging. - HAZARDS OF IMAGING Contrast media

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HAZARDS OF IONISING RADIATION

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The majority of ionising radiation comes from natural sources on Earth and cosmic rays, and this makes up the background radiation. However, medical exposure accounts for around 15% of the total received by humans. The e ﬀ ects of ionising radiation can be broadly divided into two groups. The first group comprises predictable, dose-dependent tissue e ﬀ ects and includes, for example, the development of cataracts in the lens of the eye. These e ﬀ ects are important for those chronically exposed to radiation, including those using image intensifiers regularly . The second group comprises the all-or-nothing e ﬀ ects such as the development of cancer (termed stochastic). These e ﬀ ects are not dose dependent, but increase in likelihood with increased radiation dose. The risk of radiation-induced cancer for plain films of the chest or extremities is very small, of the order of 1:1 /uni00A0 000 /uni00A0 000. However, that risk rises considerably for high-dose examina - tions such as CT of the abdomen or pelvis, where the estimated lifetime excess risk of cancer increases to the order of 1:1000. Use of CT has increased dramatically in the last 20 years, with 2 a 12-fold increase in the UK, and it has been estimated that up m) to 30% of these e xaminations may be unnecessary . Obviously , the risk of such examinations has to be balanced against the benefit to the patient in terms of increased diagnostic yield, and must also be viewed in the context that the lifetime risk of cancer for people generally is about 1:3. Nevertheless, the - increased risk is important since it is iatrogenic and applied to a large population. Therefore, techniques that do not use ionis - ing radiation, such as ultrasound and MRI, should be carefully - considered as alternatives, particularly in children and young people. In the UK, the Ionising Radiation (Medical Exposure) Regu lations (IR(ME)R) introduced in 2000, and amended in 2006, impose on the radiologist the duty to the patient to make sure that all studies involving radiation (plain radiographs, CT and nuclear medicine) are performed appropriately and to the highest standards. Inappropria te use of radiation is a criminal o ﬀ ence, so investigations involving radiation need careful consideration in order to prevent wasteful use of radiology . Summary box 8.2 Criteria for useful investigations There are special considerations for portable and fluoros copy units. The longer an operator keeps the fluoroscopy unit running, the higher the dose of radiation to all in the vicinity . Portable x-ray machines and fluoroscopic imaging equipment use much more radiation to achieve the same result. T and patients in the next bed, are at risk when portable equip ment is used. The result is also of lower quality , so portable x-ray machines should not be used unless absolutely necessary . When using the image intensifier, lead aprons, thyroid shields, lead glasses and radiation badges should always be worn. Preg nancy in the female patient or sta ﬀ must be excluded. Wilhelm Conrad Roentgen , 1845–1923, Professor of Physics, Würzburg (1888–1900), and then at Munich, Germany . He was awarded the Nobel Prize in Physics in 1901 for his work on x-rays. - Responsibilities of the radiologist and referrer /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF The UK’s Royal College of Radiologists produces an evidence-based guidance tool, called iRefer, which is widely available on line and shows radiation doses for common procedures (Table 8.1). -

A useful investigation is one in which the result – positive or negative – will inform clinical management and/or add con /f_i dence to the clinician's diagnosis. A signi /f_i cant number of radiological investigations do not ful /f_i l these aims and may add unnecessarily to irradiation of patients. To avoid the wasteful use of radiology, the important questions to be asked are as follows.

1. Has it been done already ? Repeating investigations that have already been done: such as at another hospital, in an outpatient department or in an emergency department. Every attempt should be made to obtain previous images and reports. Transfer of digital data through electronic links will assist in this respect. Although guidelines may not directly address this question, there are other initiatives that do
2. Is it needed ? Undertaking investigations when results are unlikely to affect patient management or over-investigating: because the anticipated positive /f_i nding is usually irrelevant – for example, degenerative spinal disease – or because a positive /f_i nding is unlikely. Some clinicians and patients tend to rely on investigations more than others for reassurance
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5. Has the problem been properly explained ? Failing to provide appropriate clinical information and questions that the imaging investigation should answer: de /f_i ciencies here may lead to the use of the wrong technique, or the report being poorly focused on the clinical problem. In some clinical situations /f_i rm guidelines have been established Radiologists have a legal responsibility to keep imaging as safe as possible The referrer has a duty to balance risk against bene /f_i t The referrer must provide adequate clinical details to allow justi /f_i cation of the examination Avoid using portable (mobile) x-ray machines whenever practical Take all precautions when using an image intensi /f_i er The gonads, eyes and thyroid are especially vulnerable to radiation and should be protected TABLE 8.1 Band classi /f_i cation of the typical doses of ionising radiation from common imaging procedures. Examples Lifetime Symbol Typical additional effective risk of cancer dose (mSv) induction /exam None 0 US; MRI 0 <1:20 /uni00A0 000 <1 CXR; XR limb, pelvis, lumbar spine; mammography 1:20 /uni00A0 000–1:4000 1–5 IVU; NM (e.g. bone); CT head and neck 5.1–10 CT KUB; NM 1:4000–1:2000 (e.g. cardiac)

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raphy; KUB, kidneys, ureters and bladder; MRI, magnetic resonance imaging; NM, nuclear medicine; PET, positron emission tomography; US, ultrasound; XR, x-ray. Source: https://www.rcr.ac.uk/sites/default/ /f_i les/documents/irefer_ introductoryiaea.pdf.

HAZARDS OF IONISING RADIATION

The majority of ionising radiation comes from natural sources on Earth and cosmic rays, and this makes up the background radiation. However, medical exposure accounts for around 15% of the total received by humans. The e ﬀ ects of ionising radiation can be broadly divided into two groups. The first group comprises predictable, dose-dependent tissue e ﬀ ects and includes, for example, the development of cataracts in the lens of the eye. These e ﬀ ects are important for those chronically exposed to radiation, including those using image intensifiers regularly . The second group comprises the all-or-nothing e ﬀ ects such as the development of cancer (termed stochastic). These e ﬀ ects are not dose dependent, but increase in likelihood with increased radiation dose. The risk of radiation-induced cancer for plain films of the chest or extremities is very small, of the order of 1:1 /uni00A0 000 /uni00A0 000. However, that risk rises considerably for high-dose examina - tions such as CT of the abdomen or pelvis, where the estimated lifetime excess risk of cancer increases to the order of 1:1000. Use of CT has increased dramatically in the last 20 years, with 2 a 12-fold increase in the UK, and it has been estimated that up m) to 30% of these e xaminations may be unnecessary . Obviously , the risk of such examinations has to be balanced against the benefit to the patient in terms of increased diagnostic yield, and must also be viewed in the context that the lifetime risk of cancer for people generally is about 1:3. Nevertheless, the - increased risk is important since it is iatrogenic and applied to a large population. Therefore, techniques that do not use ionis - ing radiation, such as ultrasound and MRI, should be carefully - considered as alternatives, particularly in children and young people. In the UK, the Ionising Radiation (Medical Exposure) Regu lations (IR(ME)R) introduced in 2000, and amended in 2006, impose on the radiologist the duty to the patient to make sure that all studies involving radiation (plain radiographs, CT and nuclear medicine) are performed appropriately and to the highest standards. Inappropria te use of radiation is a criminal o ﬀ ence, so investigations involving radiation need careful consideration in order to prevent wasteful use of radiology . Summary box 8.2 Criteria for useful investigations There are special considerations for portable and fluoros copy units. The longer an operator keeps the fluoroscopy unit running, the higher the dose of radiation to all in the vicinity . Portable x-ray machines and fluoroscopic imaging equipment use much more radiation to achieve the same result. T and patients in the next bed, are at risk when portable equip ment is used. The result is also of lower quality , so portable x-ray machines should not be used unless absolutely necessary . When using the image intensifier, lead aprons, thyroid shields, lead glasses and radiation badges should always be worn. Preg nancy in the female patient or sta ﬀ must be excluded. Wilhelm Conrad Roentgen , 1845–1923, Professor of Physics, Würzburg (1888–1900), and then at Munich, Germany . He was awarded the Nobel Prize in Physics in 1901 for his work on x-rays. - Responsibilities of the radiologist and referrer /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF The UK’s Royal College of Radiologists produces an evidence-based guidance tool, called iRefer, which is widely available on line and shows radiation doses for common procedures (Table 8.1). -

A useful investigation is one in which the result – positive or negative – will inform clinical management and/or add con /f_i dence to the clinician’s diagnosis. A signi /f_i cant number of radiological investigations do not ful /f_i l these aims and may add unnecessarily to irradiation of patients. To avoid the wasteful use of radiology, the important questions to be asked are as follows.

1. Has it been done already ? Repeating investigations that have already been done: such as at another hospital, in an outpatient department or in an emergency department. Every

attempt should be made to obtain previous images and reports. Transfer of digital data through electronic links will assist in this respect. Although guidelines may not directly address this question, there are other initiatives that do

2. Is it needed ? Undertaking investigations when results are unlikely to affect patient management or over-investigating: because the anticipated positive /f_i nding is usually irrelevant – for example, degenerative spinal disease – or because a positive /f_i nding is unlikely. Some clinicians and patients tend to rely on investigations more than others for reassurance
3. Is it needed now ? Investigating too early: for example, before the disease could have progressed or resolved, or before the results could in /f_l uence treatment. The need for investigation and treatment should be reviewed at a more appropriate time
4. Is this the best investigation ? Doing the wrong investigation: imaging techniques undergo rapid change. It is often helpful to discuss an investigation with a specialist in clinical radiology or nuclear medicine before it is requested
5. Has the problem been properly explained ? Failing to provide appropriate clinical information and questions that the imaging investigation should answer: de /f_i ciencies here may lead to the use of the wrong technique, or the report being poorly focused on the clinical problem. In some clinical situations /f_i rm guidelines have been established Radiologists have a legal responsibility to keep imaging as safe as possible The referrer has a duty to balance risk against bene /f_i t The referrer must provide adequate clinical details to allow justi /f_i cation of the examination Avoid using portable (mobile) x-ray machines whenever practical Take all precautions when using an image intensi /f_i er The gonads, eyes and thyroid are especially vulnerable to radiation and should be protected TABLE 8.1 Band classi /f_i cation of the typical doses of ionising radiation from common imaging procedures. Examples Lifetime Symbol Typical additional effective risk of cancer dose (mSv) induction /exam None 0 US; MRI 0 <1:20 /uni00A0 000 <1 CXR; XR limb, pelvis, lumbar spine; mammography 1:20 /uni00A0 000–1:4000 1–5 IVU; NM (e.g. bone); CT head and neck 5.1–10 CT KUB; NM 1:4000–1:2000 (e.g. cardiac)

> 1:2000 10 Extensive CT studies, some NM studies (e.g. some PET/CT) CT, computed tomography; CXR, chest x-ray; IVU, intravenous urog

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raphy; KUB, kidneys, ureters and bladder; MRI, magnetic resonance imaging; NM, nuclear medicine; PET, positron emission tomography; US, ultrasound; XR, x-ray. Source: https://www.rcr.ac.uk/sites/default/ /f_i les/documents/irefer_ introductoryiaea.pdf.

III IVb I

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Figure 8.42 (a) Surgical lobes of the liver (after Couinaud). IVC, inferior vena cava; LHV, left hepatic vein; LT, ligamentum teres; MHV, middle hepatic vein; RHV, right hepatic vein. (b) Segmental anatomy on computed tomography scan at the level of the hepatic veins. anatomy at the level of the portal veins. (d) Segmental anatomy below the level of the portal veins. Figure 8.43 Positron emission tomography shows /f_l uorodeoxyglu cose uptake in a carcinoma of the lung (short arrow) and mediastinal lymph nodes (long arrow).

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IMAGING IN COMMON SURGICAL CLINICAL SCENARIOS

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In this section the roles of di ff erent radiological modalities in common surgical scenarios are discussed, with a brief rationale behind their use and typical appearances of various patholog - ical processes. IMAGING IN COMMON SURGICAL CLINICAL SCENARIOS

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IMAGING IN ONCOLOGY

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Modern surgical treatment of cancer requires an understand - - ing of tumour staging systems, as in many instances the tumour stage will define appropriate management. The development of stage-dependent treatment protocols involving neoadjuvant chemotherapy and preoperative radiotherapy relies on the ability of imaging to determine stage accurately before surgical and pathological staging. The importance of accurate cancer staging is reflected in the central role of the radiologist in most MDT meetings . Once a diagnosis of cancer has been established, often by percutaneous or endoscopic biopsy , new imaging techniques can considerably improve the ability to define the extent of tumour, although the pathological specimen remains the ‘gold standard’. Many staging systems are based on the tumour– node–metastasis (TNM) classification. IMAGING IN ONCOLOGY

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INTERPRETING IMAGES

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- While the role of the imaging department is to provide - radiological reports for imaging examinations performed, it is nevertheless good clinical practice to be able to evaluate your patients' examinations, and a systematic approach is encouraged. The systematic approach to examining a radiograph varies according to the part of the body being imaged. For instance, - for a radiograph of an extremity , the alignment, the cortices and the medullary cavity of the individual bones, the joints and the soft tissues all need to be assessed on each view . A simple system for checking radiographs

Label Name of patient Site Date of examination Side (check marker) What part is the /f_i lm centred on? Does the /f_i lm cover the whole area required? Is there more than one view? Quality Is the penetration appropriate? Compare How have the appearances changed from previous images? Conclude Is the diagnosis clear? Is further imaging needed?

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Infection

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In the early stages of joint infection, the plain films may be normal, but they should still be performed to exclude bony erosions in case a painful joint is the first sign of an arthropa thy . Ultrasound examination is the easiest and most accurate method of assessing joint e ff usions, although, when an e ff usion is identified, it is not possible to discriminate between blood and pus. Aspiration guided by ultrasound is the best method of making this distinction. MRI may be required to assess early articular cartilage and bone inv olvement. Radiographs should also be used to examine patients with suspected osteomyelitis. Although they may not detect early infection, they will demonstrate or exclude bony destruction, calcification and sequestrum formation. CT may be needed to giv e a cross-sectional view , in order to assess the extent of bony sequestrum. MRI is perhaps the most sensitive method for detect - ing early disease and is the preferred technique to define the activity and extent of infection, as it shows not only the bony involvement but also the extent of oedema and soft-tis - sue involvement (Figure 8.26). Abscesses may be detected or excluded, and subperiosteal oedema is readily visible. MRI can be used as a staging procedure to plan treatment, including surgical intervention. Serial examinations can be used to follow the response to intravenous antibiotics and are very useful in the management of complex osteomyelitis. In cases of negative or equivocal MRI, nuclear medicine techniques such as bone scintigraphy can be very sensitive, and specialised studies using tracers such as gallium citrate or indium-labelled white cells increase specificity . Summary box 8.13 Imaging of potentially infected bone and joint /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF - /uni25CF

Figure 8.25 Coronal T1- (a) and axial T2-weighted fat-suppressed (b) images through the distal femur of the patient in Figure 8.24 illustrates the bony area involved, the soft-tissue extent of the

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Introduction

INTRODUCTION

Appropriate surgical management of the patient relies on correct diagnosis. While clinical symptoms and signs may provide a firm diagnosis in some cases, other conditions will require the use of supplementary investigations including imaging techniques. The number and scope of imaging tech niques available to the surgeon have dramatically increased within a generation, from a time when radiographs alone were the mainstay of investigation. The development of ultrasound and colour Doppler , computed tomography (CT) and magnetic resonance imaging (MRI) has enabled the surgeon to make increasingly confident diagnoses and has reduced the need for diagnostic surgical techniques such as explorative laparotomy . As a basic principle, the simplest, cheapest test should be chosen hoping that it will answer the clinical question. This necessitates knowledge of the potential complications and diagnostic limitations of the various methods. For example, in a patient pr esenting with the clinical features of biliary colic, an ultrasound examination alone may give enough informa tion to enable appropriate surgical management. In more com plex cases, it may be more e ffi cient to opt for a single, more expensive investigation, such as CT , rather than embarking on multiple simpler and cheaper investigations that may not yield the answer. The choice of technique is often dictated by equipment availability , expertise and cost, as well as the clinical presentation. However, it must be emphasised that, not infre quently , the most valuable investigation is prior imaging; this not only reduces the cost and the amount of radiation a patient receives but v ery often improves patient care. Christian Johann Doppler , 1803–1853, Professor of Experimental Physics, Vienna, Austria, enunciated the ‘Doppler principle’ in 1842.

The principles of different imaging techniques and • their advantages and disadvantages in different clinical scenarios The role of imaging in directing treatment in various • surgical scenarios

Introduction

Trauma remains a major cause of mortality and morbidity in - all age groups. Presented with a multiply injured patient, rapid and e ff ective investigation and treatment are required to maxi - mise the chances of survival and to reduce morbidity . Imaging - plays a major role in this assessment and in guiding treatment. As with the clinical assessment, imaging is carried out according to the principles of primary and secondary surveys, identifying major life-threa tening injuries of the airway , respiratory system

(c) Figure 8.26 (a) The plain /f_i lms of this 13-year-old are close to normal. On close inspection, there is a /f_i ne periosteal reaction on the /f_i bula. (b) The cor

onal T1-weighted magnetic resonance image shows little more, but (c) the coronal fast short tau inversion recovery (STIR) images and (d) axial T2 fast spin echo with fat suppression show the oedema in bone as white and the extensive periosteal /f_l uid with soft-tissue in /f_l ammation. The diagnosis is acute osteomyelitis.

consuming assessment of other injures. At no point should imaging delay the treatment of immediately life-threatening injuries. As in other settings, the quickest and least invasive examinations should be performed first. A radiologist present in the trauma room at the time of patient assessment is able to evaluate the radiographs rapidly , relay this information back to the team and guide further imaging, which may include further plain films, CT , ultrasound and MRI.

Inflammatory processes

Inflammatory processes

Appendicitis Historically , a straightforward clinical diagnosis of appendicitis obviated any need for imaging, but with the proven accuracy of available modalities imaging has become increasingly popular to reduce negative appendicectomy rates and to George Kenneth Mallory , 1900–1986, Professor of Pathology , Boston University , Boston, MA, USA. Soma Weiss , 1898–1942, Professor of Medicine, Harvard University Medical School, Boston, MA, USA. demonstrate a calcified appendicolith in the right iliac fossa, it is insu ffi ciently sensitive or specific to be reliable. In children, who typically have a fav ourable body habitus, ultrasound is the best test as it reduces radiation exposure. This also applies to females of childbearing age, again to reduce radiation exposure, but also because the symptoms may be mimicked by gynaecological pathology , such as ectopic pregnancy , haem - orrhagic ovarian cyst and tubo-ovarian abscess, all diagnoses that are best made with ultrasound. The definitive exclusion of appendicitis, however, hinges on the identification of a normal appendix, measuring less than 6 /uni00A0 mm in diameter . Retrocaecal appendicitis can readily escape detection with ultrasound, and thus CT is the next modality of choice; indeed, frequently it is the first requested in most adults (Figure 8.39). The diagnosis of appendicitis on CT requires the identification of a thick - ened appendix (>7 /uni00A0 mm), with periappendiceal inflammatory change as evidenced by stranding in the surrounding fat. Other signs that may be sought include free fluid, thickening of the caecal pole, possible localised small bowel ileus and right iliac - fossa lymphadenopath y . Both CT and ultrasound can also - identify collections if an inflamed appendix ruptures, and can be used to guide percutaneous drainage as a bridge to definitive surgery . -

Figure 8.39 Acute appendicitis. Contrast-enhanced computed tomography scan reconstructed in the coronal plane demonstrates a thickened appendix in the right iliac fossa (arrow) with in /f_l ammatory changes in the surrounding fat and reactive thickening of the caecal pole.

Inflammation of an obstructed diverticulum typically presents with left iliac fossa pain and pyrexia (Figure 8.40). While some authors have promoted the use of focused ultrasound for this indication, in general it is best diagnosed with a CT scan. The typical CT appearance is of pericolic inflammatory change around a diverticulum, most commonly in the sigmoid colon. Complications of diverticulitis include perforation, abscess formation, fistulation to adjacent structures and strictures in the bowel. CT is also the modality of choice to identify these; as with appendicitis, it can be used to guide percutaneous abscess drainage as a bridge to definitive surgery . Inflammatory bowel disease The diagnosis of inflammatory bowel disease is made histo logically . Radiologically , the diagnosis and monitoring of inflammatory bowel disease has changed significantly in recent years. Previously a barium study of the small bowel, either a follo w-through (where barium is ingested orally) or enteroclysis (where dilute barium is infused via a nasojejunal tube) was used as a screening tool if symptoms are vague. If the diagnosis of Crohn’s disease is established, barium studies can still be useful to demonstrate the extent of disease, particularly to demonstrate the length and number of strictures if surgery is planned. Increasingly , however, the role of barium studies has been superseded by cross-sectional imaging, particularly MRI enterography , which entails an abdominopelvic MRI scan Burrill Bernard Crohn , 1884–1983, gastroenterologist, Mount Sinai Hospital, New Y ork, NY , USA, described regional ileitis in 1932 along with Leon Ginzburg and Gordon Oppenheimer. John Benjamin Murphy , 1857–1916, Professor of Surgery , Northwestern University , Chicago, IL, USA, described his sign in 1903. He was the son of Irish immigrants fleeing the potato famine in Ireland, and was known as the ‘Stormy Petrel’ of American surgery , demonstrating the benefit of appendicectomy over conservative treatment among many things. distend the small bowel. The other obvious advantage of MRI is the lack of radiation, which is particularly relevant in young patients with Cr ohn’s disease, who often undergo multiple imaging studies over their lifetime; for this reason it is gaining in popularity for inflammatory bowel disease follow-up. An acute flare-up may also require imaging, and an ultra - sound is usually a good first test to look for dilated bowel loops and any abscess, though CT may ultimately be required as gas-filled bowel loops can obscure visualisation of an abscess on ultrasound. MRI is the imaging modality of choice to assess perianal fistulae and abscesses. Acute pancreatitis As with acute appendicitis, when the diagnosis is straight - - forward clinically there may be no need for imaging, though increasingly it is used to confirm the diagnosis, to assess the severity of the process and to look for complications. While ultrasound may show gallstones and can demonstrate an enlarged pancr eas with peripancreatic fluid and inflammatory changes, the optimal modality is CT . CT performed too early in the course of the attack, e.g. in the first 12 hours, can be equivocal and the optimal timing of imaging is 48–72 hours. In mild acute pancreatitis, CT may be normal or may show an enlarged oedematous gland, but in more severe attacks other findings which should be sought include peripancreatic fluid collections, v ascular complications such as arterial pseudoaneurysm formation or venous thrombosis and necrosis, either of the gland itself or of the surrounding fat. Necrosis typically develops 48–72 hours after the onset of symptoms and is manifest on CT as lack of enhancement of the necrotic areas. CT with intravenous contrast is therefore essential to look for necrosis, which is potentially catastrophic, particularly if it becomes infected. While CT is not always reliable to diagnose infected necrosis, it is suggested by bubbles of air in the necrotic segment. As with other intra-abdominal inflammatory processes, either ultrasound or more usually CT can be used to guide percutaneous drainage of inflammatory fluid collections. Acute cholecystitis/biliary colic/jaundice While acute cholecystitis is usually due to mechanical obstruc - tion of the cystic duct or gallbladder neck by a gallstone, acute acalculous cholecystitis can occur in critically ill patients from a number of causes. In any case ultrasound is the modality of c hoice should this diagnosis be suspected, and the classic diagnostic features are of gallbladder distension with wall thickening (>3 /uni00A0 mm). A gallstone obstructing the gallbladder neck or cystic duct may be visualised; alternatively , in acal - culous cholecystitis sludge may be seen layering in the gall - bladder lumen. Associated signs include pericholecystic fluid and hyperaemia on Doppler examination. Ultrasonographic Murphy’s sign refers to tenderness over the gallbladder when

Figure 8.40 Coronal computed tomography reformatted images showing a diverticular perforation. There is stranding around the sigmoid colon with an extraluminal track of gas (arrow). Because of surrounding in /f_l ammatory changes diverticular perforation usually leads to pericolic localised gas collections rather than generalised pneumoperitoneum.

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Ischaemia infarction

Ischaemia/infarction

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The value of immediate MRI in trauma is relatively limited and is largely confined to the imaging of spinal injuries (Figure 8.35) . Access to urgent MRI is not widely available, and there are major practical problems in imaging patients who require ven - tilation or monitoring. MRI is therefore only practical in stable patients. All monitoring equipment must be MRI compatible, and ventilation support should be undertaken by sta ff skilled and experienced in these techniques as applied to the MRI environment. MRI may be used to diagnose injuries of the spinal cor d and associated perispinal haematomas in patients with neurological signs or symptoms. MRI can supplement CT in spinal injuries by imaging soft-tissue injuries to the longitudi - nal and interspinous ligaments. MRI is mandatory in patients in whom there is facetal dislocation if surgical reduction is being considered, to minimise the risk of displacing soft-tissue or disc material into the spinal canal during r eduction proce - dures. Subtle fractures may be di ffi cult to identify , particularly if they are old, but an acute injury is normally identified b y the surrounding oedema. Bony abnormalities should be reviewed using CT as fracture lines are hard to identify with MRI and unstable injuries may be overlooked. In the less acute setting, MRI may also be used to assess di ff use axonal injuries, with an accuracy exceeding CT . Magnetic resonance imaging

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Mass lesions

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Mass lesions in muscle and soft tissue are examined by ultra - sound, which can be diagnostic in the majority of cases, thereby avoiding the need for further imaging. This is most often the case when a lesion is purely cystic and, as most soft-tissue masses are cysts, ultrasound is a very e ff ective screening test.). There are occasions w hen no mass lesion is found at the site of

(b)

concern, and then reassurance can be o ff ered. If the ultrasound examination is normal, this e ff ectively excludes soft-tissue neoplasia. A reasonable protocol is to perform ultrasound on all palpable 'lesions' to exclude cysts, and on patients without any identifiable mass, and to proceed to MRI only when there is a solid or partly solid element to an unidentifiable lesion. Tumour vascularity is best assessed by Doppler ultrasound. It can be studied by intravenous gadolinium DTPA-enhanced MRI; however, this is a more expensive and invasive technique, providing no more information than Doppler ultrasound. Summary box 8.12 Imaging of soft-tissue lesions /uni25CF /uni25CF /uni25CF /uni25CF

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Metabolic bone disease

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Plain radiographs should be the first images of patients with metabolic bone disease. They may detect the subperiosteal erosions in hyperparathyroidism or, more commonly , the osteopenia in osteoporosis, but they cannot be used to quantify osteoporosis. The apparent density of the bone on the film is linked to the penetration of the rays, among other variables, as well as to the bone density . If a quantitative method is needed, (DEXA) is the most accurate and practical. However, fractures will cause erroneously high readings, and they tend to occur in the vertebrae used for DEXA measurements. Quantitative CT is an alternative technique, although this is less readily avail able. Ultrasound transmission measurement in the extremities has its advocates, as it arguably measures factors that better represent the strength of bone rather than its density . Its limita e that it cannot be used to study the vertebrae or hip, tions ar and these are the sites where osteoporotic fractures occur most frequently . MRI may be useful in detecting fractures and is an essential prerequisite to percutaneous vertebroplasty .

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The demonstration of metastatic disease will usually signifi cantly a ff ect surgical management. Modern cross-sectional imaging has greatly improved the detection of metastases, but occult lesions will be overlooked in between 10% and 30% of patients. CT is the most sensitive tec hnique for the detection of lung deposits, although the decision to perform CT will depend on the site of the primary tumour, its likelihood of intra Claude Couinaud , 1922–2008, French surgeon and anatomist, described the segmental anatomy of the liver in his seminal book chirurgicales. pulmonary spread and the e ff ect on staging and subsequent therapy of the demonstration of intrapulmonary deposits. Ultrasound and CT are most frequently used to detect liver metastases. Contrast-enhanced CT can detect most lesions cm, although accuracy rates vary with the greater than 1 /uni00A0 technique used and range from 70% to 90%. Recent studies suggest that MRI may be more accurate than CT in demon - strating metastatic disease. Preoperative identification of the - segment of the liver involved can be determined by translation of the segmental surgical anatomy , as defined by Couinaud, to the cross-sectional CT images (Figure 8.42). The technique of PET/CT with FDG, an analogue of glu - cose, is becoming a powerful tool in oncological imaging. This functional and anatomical imaging technique reflects tumour metabolism and allows the detection of otherwise occult metas - tases. The most common indications for PET/CT have been staging of lymphoma, lung cancer, particularly non-small cell lung cancer , and preoperative assessment of potentially resect - - ab le liver metastases, such as colorectal carcinoma metastases (Figure 8.43). Intraoperative ultrasound is an additional method of staging that provides superb high-resolution imaging of sub - centimetre liver nodules that may not be palpable at surgery . This is often used immediately prior to resection of liver - metastases. Le Foie: Études anatomiques et

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Nodes

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- Accurate assessment of nodal involvement remains a chal - lenge for imaging. Most imaging techniques rely purely on size criteria to demonstrate lymph node involvement, with no possibility of identifying micrometastases in normal-sized nodes. A size criterion of 8–10 /uni00A0 mm is often adopted, but it is not usually possible to distinguish benign reactive nodes from infiltrated nodes. This is a particular problem in patients with intrathoracic neoplasms, in whom enlarged benign reactive mediastinal nodes are common. The echo characteristics of nodes at endoscopic ultrasound have been used in many centres to increase the accuracy of nodal staging, and nodal sampling is possible via either mediastinoscopy or transoesoph ageal biopsy under endoscopic ultrasound control. PET/CT is of increasing use in detecting nodal metastases from a wide range of malignancies, with the capacity to co-register the area of increased FDG uptake with a precise anatomical location. No vel MRI contrast agents may help in the identification of non-enlarged tumour-infiltrated nodes.

Figure 8.41 (a) Endoscopic ultrasound in gastric cancer. The hypoechoic tumour (arrows) is in /f_i ltrating the layered structure of the gastric wall and extending out beyond the serosa. (b) Computed tomography scan demonstrates thickening and enhancement of the gastric wall in the same area (arrows). The stomach is distended with water to provide low-density contrast.

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Perforation

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The erect chest x-ray (CXR) is the ideal first test for hollow organ perforation and as little as 10–20 /uni00A0 mL of free air can be detected under the diaphragm (Figures 8.37 and 8.38). About 10 minutes should be left between sitting the patient upright and taking the film to allow time for air to rise; the free air must be sought under the right hemidiaphragm to prevent misinterpretation of the gastric air bubble; and the re viewer must be able to recognise Chilaiditi’s syndrome, the harmless and asymptomatic interposition of large bowel between the liver and diaphragm. Caution must also be exercised in interpreting any free air in the context of recent abdominal surgery , as postoperative air can persist for up to 5–7 days in the peritoneal cavity . If the erect CXR is equivocal or a possible walled-o ff per - foration is suspected, a CT is the optimal modality , which may show tiny quantities of free air but may also show the cause, e.g. peptic ulcer, diverticulitis or a neoplastic lesion. As with suspected obstruction, oral or rectal contrast is unnecessary if perf oration is suspected as making the diagnosis should prompt appropriate management even if the precise site of perfora tion is not identified. Also, it cannot be overstressed that if there is any possibility of a leak from the gastrointestinal tract (GIT) barium is absolutely contraindicated as it can induce a serious and potentially fatal peritonitis. Perforation

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Plain radiographs

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Conventional radiography allows rapid assessment of the major injuries and can be carried out in the trauma room while the patient is clinically assessed and treated. Despite the time constraints, the number of sta ff involved and the restricted mobility of the patient, high-quality images can be routinely obtained with due care and attention. Increasingly plain films are being replaced by whole-body CT . In many centres CT scanners are immediately available in the emergency depart ment and indeed in some departments patients are assessed and treated on the scanning table. There is no routine set of radiographs to be obtained, and the decision is based on the mechanism of injury , the stability of the patient's condition and w hether the patient is intubated. The most commonly performed initial radiographs are a chest radiograph, a single anteroposterior view of the pelvis and a cervical spine series. The supine chest radiograph should encompass an area from the lung apices to the costophrenic recesses and include the ribs laterally . Chest radiographs give valuable information in both blunt and penetrating trauma. Evaluation of the radio- graph should be undertaken in a systematic manner to mini mise the chances of missing an injury . In the first instance, the should be assessed, followed by assessment of the central air - ways. Following this, the lungs should be evaluated for abnormal focal ar eas of opacification, which may represent aspiration, haemorrhage, haematoma or oedema, as well as more di ff use opacifica tion reflecting a pleural collection. Alternatively , rel - ative focal or unilateral lucency may reflect a pneumothorax in the supine position. Evaluation of the mediastinum should include its position, which may be altered by tension pneumo - thoraces or large collections, as well as its contour, an alter - ation of w hich may reflect a mediastinal haematoma due to aortic or spinal injury . Finally , the skeleton and the soft tissue should be carefully examined for rib, vertebral, scapular and limb fractures, as well as evidence of surgical emphysema and paraspinal haematomas (Figure 8.27). Pelvic radiographs are also commonly performed to screen for, and assess, fractures of the bony pelvis. The image should include the iliac crests in their totality and extend inferiorly to below the lesser trochanters. When assessing the film, the align - - ment of the sacroiliac joints and the symphysis pubis should be carefully examined, as some fractures, especially those of the sacral arcades, can be very subtle on the pelvic radiograph. The presence of pubic fractur es raises the possibility of ure - thral injury and should alert clinicians to exercise caution with bladder catheterisation (Figure 8.28). The utility of cervical spine x-rays depends on the con - sciousness level of the patient and the presence of distracting injuries. In fully conscious patients with an isolated neck injury , clinical assessment can be used to guide the need for x-rays. In patients with distracting injuries and/or altered consciousness, including intubated patients, CT is preferr ed (Figure 8.29). Further radiographs of the thoracic and lumbar spine - and the peripheral skeleton may be required, depending on the clinical setting. As with all skeletal radiographs, two

Figure 8.27 Supine chest radiograph of a patient involved in a road traf /f_i c accident. The patient is intubated. There are multiple left-sided rib fractures (arrows) and extensive surgical emphysema. Depression of the left hemidiaphragm and mediastinal shift to the right suggest that there is a tension pneumothorax present. Figure 8.28 Retrograde urethrogram in a patient who sustained extensive pelvic fractures following a fall. The pelvic injuries have been stabilised using an external /f_i xation device. The urethrogram identi /f_i es extensive injury to the urethra with extravasation of contrast (arrow).

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(b) Figure 8.29 Lateral view of the cervical spine (a) fails to demonstrate the cervicothoracic junction. In addition, there appears to be a break in the posterior arch of C1 (arrow). Computed tomography of the cervical spine (b) demonstrates a fracture of the anterior arch as well as the posterior ar ch of C1 (arrow).

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Plain radiographs

Conventional radiography allows rapid assessment of the major injuries and can be carried out in the trauma room while the patient is clinically assessed and treated. Despite the time constraints, the number of sta ff involved and the restricted mobility of the patient, high-quality images can be routinely obtained with due care and attention. Increasingly plain films are being replaced by whole-body CT . In many centres CT scanners are immediately available in the emergency depart ment and indeed in some departments patients are assessed and treated on the scanning table. There is no routine set of radiographs to be obtained, and the decision is based on the mechanism of injury , the stability of the patient’s condition and w hether the patient is intubated. The most commonly performed initial radiographs are a chest radiograph, a single anteroposterior view of the pelvis and a cervical spine series. The supine chest radiograph should encompass an area from the lung apices to the costophrenic recesses and include the ribs laterally . Chest radiographs give valuable information in both blunt and penetrating trauma. Evaluation of the radio- graph should be undertaken in a systematic manner to mini mise the chances of missing an injury . In the first instance, the should be assessed, followed by assessment of the central air - ways. Following this, the lungs should be evaluated for abnormal focal ar eas of opacification, which may represent aspiration, haemorrhage, haematoma or oedema, as well as more di ff use opacifica tion reflecting a pleural collection. Alternatively , rel - ative focal or unilateral lucency may reflect a pneumothorax in the supine position. Evaluation of the mediastinum should include its position, which may be altered by tension pneumo - thoraces or large collections, as well as its contour, an alter - ation of w hich may reflect a mediastinal haematoma due to aortic or spinal injury . Finally , the skeleton and the soft tissue should be carefully examined for rib, vertebral, scapular and limb fractures, as well as evidence of surgical emphysema and paraspinal haematomas (Figure 8.27). Pelvic radiographs are also commonly performed to screen for, and assess, fractures of the bony pelvis. The image should include the iliac crests in their totality and extend inferiorly to below the lesser trochanters. When assessing the film, the align - - ment of the sacroiliac joints and the symphysis pubis should be carefully examined, as some fractures, especially those of the sacral arcades, can be very subtle on the pelvic radiograph. The presence of pubic fractur es raises the possibility of ure - thral injury and should alert clinicians to exercise caution with bladder catheterisation (Figure 8.28). The utility of cervical spine x-rays depends on the con - sciousness level of the patient and the presence of distracting injuries. In fully conscious patients with an isolated neck injury , clinical assessment can be used to guide the need for x-rays. In patients with distracting injuries and/or altered consciousness, including intubated patients, CT is preferr ed (Figure 8.29). Further radiographs of the thoracic and lumbar spine - and the peripheral skeleton may be required, depending on the clinical setting. As with all skeletal radiographs, two

Figure 8.27 Supine chest radiograph of a patient involved in a road traf /f_i c accident. The patient is intubated. There are multiple left-sided rib fractures (arrows) and extensive surgical emphysema. Depression of the left hemidiaphragm and mediastinal shift to the right suggest that there is a tension pneumothorax present. Figure 8.28 Retrograde urethrogram in a patient who sustained extensive pelvic fractures following a fall. The pelvic injuries have been stabilised using an external /f_i xation device. The urethrogram identi /f_i es extensive injury to the urethra with extravasation of contrast (arrow).

perpendicular views are required for adequate assessment. However, with the increasing use of CT in assessment of the torso the need for plain films is diminishing. Radiographs of the skull or facial bones have no role in the immediate assessment of the multitrauma individual, except for immediate localisation of a penetrating object.

(b) Figure 8.29 Lateral view of the cervical spine (a) fails to demonstrate the cervicothoracic junction. In addition, there appears to be a break in the posterior arch of C1 (arrow). Computed tomography of the cervical spine (b) demonstrates a fracture of the anterior arch as well as the posterior ar ch of C1 (arrow).

REQUESTING IMAGING

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Best practice depends on close collaboration between the radiologist and the referrer and must take into account local expertise and access to facilities. When requesting imaging, consider what it is that you want to know from the investigation. - Give a provisional diagnosis or state the clinical problem. If there is uncertainty over the best method to answer the clinical problem, then discussion with a radiologist is always worth - while, informally or within the context of a clinic–radiological meeting or a multidisciplinary team (MDT) meeting. As well as the basic demographic information stored on the radiolog y information system, it is important to provide relevant past medical history , e.g. diabetes, epilepsy , renal fail - ure, allergies and anticoagulation, all of which can a ff ect which contrast agent can be given safely , and the date of the last men - ses in women of childbearing potential. REQUESTING IMAGING

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SURGERY Introduction

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Imaging is an integral part of musculoskeletal diagnosis. Image-guided, minimally invasive techniques also play a major role in treatment. In broad terms, radiographs are the best method of looking for bony lesions or injuries, MRI shows bone marrow disease, muscle, tendon and soft-tissue disorders and ultrasound has better resolution than MRI for small struc tures, with the added advantage of showing dynamic changes. CT enables visualisation of the fine detail of bony structures, clarifying abnormalities seen on plain radiographs. hniques There are occasions when a combination of tec will be important, and due consideration should be given to reducing the ionising radiation burden to the patient, using ultrasound and MRI as primary investigations whenever opriate. appr Summary box 8.8 Imaging in musculoskeletal conditions /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF /uni25CF

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Skeletal trauma

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Musculoskeletal trauma is best imaged by an initial plain radiograph. All skeletal radiographs should be taken from two di ff erent angles, usually at right angles to each other. This is important in trauma because a fracture or dislocation may not be visible on a single view (Figure 8.18). Occasionally , specific locations such as the scaphoid, more than two views are routinely performed. If this fails to make a clear diagnosis, or if there is suspicion of soft-tissue injuries, then cross-sectional ted. studies are indica Increasingly in the assessment of spinal trauma, CT is replacing radiographs as the first-line investigation for two main reasons: the first is that the sensitivity of CT is superior, , enabling treatment to com the second is that it is quicker mence sooner. Axial CT images alone may fail to diagnose some frac tures, so three-dimensional reformatting is important to pre vent errors. Sections should be thin, but care must be taken Nikola Tesla , 1856–1943, American physicist and electrical engineer who worked for the Westinghouse Electric and Manufacturing Company . A tesla is the SI unit of magnetic flux density . - Summary box 8.9 Trauma imaging /uni25CF /uni25CF /uni25CF not to cover too wide an area, as the radiation burden may be excessive, particularly with multislice CT .

Figure 8.18 Anteroposterior radiograph of the wrist (a) in a patient following a fall does not show an acute bony injury. It is only on the second view (b) that a fracture of the dorsal cortex of the distal radius is visualised (arrow). Initial imaging is either radiography or CT At least two views are needed for radiographs Use CT for spine, intra-articular or occult fractures

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In most published studies, cross-sectional imaging techniques (CT , ultrasound, MRI) are more accurate in staging advanced (T3, T4) than early (T1, T2) diseases, and the staging of early disease remains a challenge. In gut tumours, endoscopic ultra - sound is more accurate than CT or MRI in the local staging of early disease (T1, T2) by virtue of its ability to demonstrate the layered structure of the bowel wall and the depth of tumour penetra tion (Figure 8.41). Developments in MRI may also improve the staging accuracy of early disease. MRI is extremely valuable in bone and soft-tissue tumour staging and in intracranial and spinal disease. - Tumour

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Ultrasound has an evolving role in the assessment of acutely traumatised patients. The main current roles of ultra sound include the assessment of intraperitoneal fluid and trauma [FAST]), the evaluation of pneumothoraces in supine patients and in guiding intervention. FAST ultrasound is a limited examination directed to look f or intraperitoneal fluid or pericardial injury as a marker of underlying injury . T his avoids the invasiveness of diagnostic peritoneal lavage. In the presence of free intraperitoneal fluid and an unstable patient, the ultrasound allows the trauma sur - geon to explore the abdomen as a cause of blood loss. In the presence of fluid and a haemodynamically stable individual, further assessment by way of CT can be performed. Howe ver, it is important to realise that ultrasound has limitations in the identification of free fluid. This includes obscuration of fluid by bowel gas or extensive surgical emphysema. More organ - ised haematoma may be more di ffi cult to visualise. It must also be emphasised that the principal role of ultrasound is not to identify the primary solid organ injury , although this may be visualised. Occasionally , a second ultrasound scan may show free fluid in the presence of an initially nega tive FAST scan. The detection of a pneumothorax on a supine radiograph can be very di ffi cult. Ultrasound examination may be used to identify a radiographically occult pneumothorax. With a high-resolution linear probe, the pleura can be visualised as an ec hogenic stripe, and its motion with respiration can also be assessed. In the presence of a pneumothorax, the sliding motion of the pleura is lost. Ultrasound may also be used to detect a haemothorax or haemopericardium. Finally , ultrasound may be of value in guiding the place - ment of an intravascular line by direct visualisation of the ves - sels. This can be especially advantageous in shocked patients. Ultrasound

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Vascular interventional radiology

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With the development and refinement of CT angiography - techniques, the diagnostic role of formal angiography has become limited. CT angiography is the first-line investigation for aortic trauma and for penetrating and non-penetrating peripheral vascular trauma. Endovascular techniques play an important role in the treatment of acute solid organ injuries, and the interventional radiologist should be consulted early in the decision-making

Figure 8.32 Coronal computed tomography image of the body shows a grade V splenic injury (‘shattered spleen’; arrow) with vascular injury at the hilum and free /f_l uid around the spleen and liver (arrowhead). Figure 8.33 Coronal computed tomography demonstrating free /f_l uid around the liver. The upper pole of the

right kidney and whole left kidney demonstrate no contrast uptake in keeping with acute vascular injury (arrows). In addition there is a distraction injury with lateral dislo

cation of the T11–T12 intervertebral junction (curved arrow). Figure 8.34 Sagittal reformats of computed tomography of the calcaneus in a patient following a fall illustrate a comminuted calcaneal fracture with intra- articular extension into the posterior facet of the subtalar joint (arrow).

available embolic agents such as soluble gelatin sponge and microcoils, selective embolisation and reduction of blood flow to the injured segment can be achieved without causing infarc tion. Selective embolisation techniques are also suitable for the treatment of patients with pelvic fractures with ongoing blood loss and volume issues. With penetrating and non-penetrating extremity trauma, balloon occlusion and embolisation may be emplo yed to control haemorrhage, while the application of stent grafts can aid in re-establishing the circulation to the a ff ected extremity .

(a) (b) Figure 8.35 Sagittal T1-weighted (a) and T2-weighted (b) magnetic resonance imaging of the spine demonstrate a burst fracture of L2 causing neural compression (arrows).

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