

Introduction

Recent technological advances have produced a bewildering array of complex imaging techniques and procedures. The basic principle of imaging, however, remains the anatomical demonstration of a particular region and related abnormalities, the principal imaging modalities being:

- **plain X-rays:** utilizes a collimated X-ray beam to image the chest, abdomen, skeletal structures, etc.;
- **fluoroscopy:** a continuous X-ray beam produces a moving image to monitor examinations such as barium meals, barium enemas, etc.;
- **ultrasound (US):** employs high-frequency sound waves to visualize structures in the abdomen, pelvis, neck and peripheral soft tissues;
- **computed tomography (CT):** obtains cross-sectional computerized densities and images from an X-ray beam/detector system;
- **magnetic resonance imaging (MRI):** exploits the magnetic properties of hydrogen atoms in the body to produce images;
- **nuclear medicine (NM):** acquires functional as well as anatomical details by gamma radiation detection from injected radioisotopes.

Contrast media

Contrast agents are substances that assist visualization of some structures during the above techniques, working on the basic principle of X-ray absorption, thereby preventing their transmission through the patient. The most commonly used are barium sulphate to outline the gastrointestinal tract, and organic iodine preparations; the latter widely used intravenously in CT for vascular and organ enhancement. Contrast agents can also be introduced into specific sites, for example:

- *arteriography:* the arterial system;
- *venography:* the venous system;
- *myelography:* spinal theca;

- *cholangiography:* the biliary system;
- *hysterosalpingography:* uterus;
- *arthrography:* joints;
- *sialography:* salivary glands.

The possibility of an allergic reaction exists with iodinated contrast media, an increased risk noted in those with a history of allergy, bronchospasm and cardiac disease, as well as in the elderly, neonates, diabetics or patients with multiple myeloma.

- *Minor reactions:* nausea, vomiting, urticarial rash, headache.
- *Intermediate reactions:* hypotension, bronchospasm.
- *Major reactions:* convulsions, pulmonary oedema, cardiac arrhythmias, cardiac arrest.

Drug therapy should be readily available to treat reactions, for example:

- urticaria: chlorphenamine or other antihistamines;
- pulmonary oedema: furosemide i.v.;
- convulsions: diazepam i.v.;
- bronchospasm: hydrocortisone i.v. and bronchodilators such as salbutamol;
- anaphylactic reactions: adrenaline s.c. or i.v.

Radiation protection

All individuals receive natural background radiation but diagnostic tests now account for the largest source of exposure and every effort at reduction must be made. Although ionizing radiation is deemed to be potentially hazardous, the risks should be weighed in the context of benefits to the patient.

- Doses should be kept to a minimum and a radiological investigation performed only if management is going to be affected. Consideration should be given to the radiation dose to the patient for each specific investigation. CT, barium and radionuclide studies are high-dose examinations, whereas plain films of the extremities and chest X-rays are typically low dose.

- The fetus is particularly sensitive, especially in the first trimester with possible induction of carcinogenesis or fetal malformation. A menstrual history obtained in a woman of reproductive age, and if necessary a pregnancy test, will prevent accidental fetal exposure to radiation.
- Clear requests to the radiology department, with relevant clinical details, aids in the selection of the most appropriate views or investigations.
- Discussion of complex cases with a radiologist may help in choosing the most relevant study or examination.
- Unnecessary examinations should be avoided, for example repeat chest X-rays for resolution of pneumonic consolidation at less than weekly intervals, or preoperative chest X-rays in young patients.
- Ultrasound and MRI, because of the lack of ionizing radiation, are the preferred imaging modalities where clinically indicated.

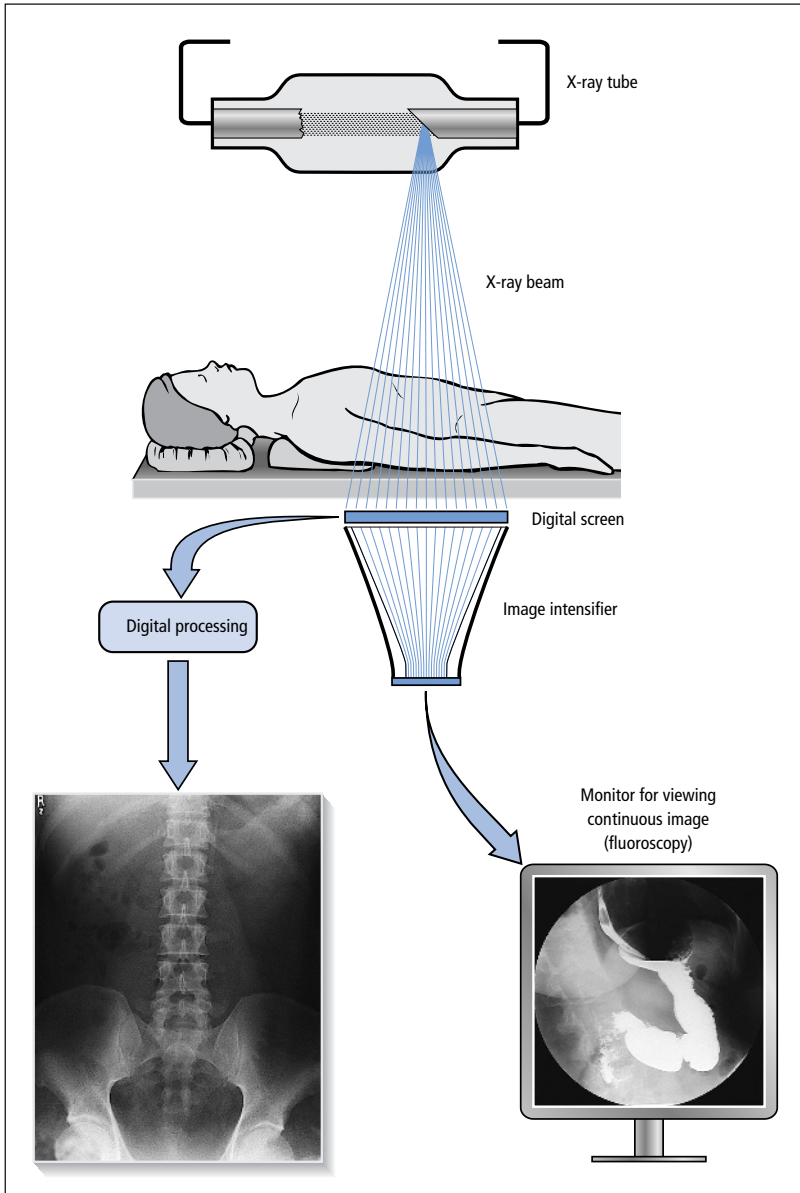


Figure 1.1 Basic principles of plain films and fluoroscopy.



Figure 1.2 Digital plain film and fluoroscopy equipment.

Plain films and fluoroscopy

Conventional radiography

X-rays are part of the electromagnetic spectrum, emitted as a result of bombardment of a tungsten anode by free electrons from a cathode. Hard copy plain films are produced by their passage through the patient and exposing a radiographic film.

Bone absorbs most radiation, causing least film exposure, thus the developed film appears white. Air absorbs least radiation, causing maximum film exposure, so the film appears black. Between these two extremes a large differential tissue absorption results in a grey-scale image. The majority of plain films are now performed with digital radiography and conventional plain films are infrequently used.

Digital radiography

In digital radiography, the basic principles are the same but a digital screen replaces the X-ray film. The tissue absorption characteristics are computer analysed and the image is visualized on a monitor. CT, MRI and ultrasound are already available in digital format; with the rapid introduction of digital plain-film radiography, radiological departments are now filmless (picture archival and communication system, PACS). The principal advantages of digital radiography are:

- significant reduction in radiation exposure;
- digital enhancement ensures all images are of an adequate quality;
- transfer of images out of the radiology department to other sites;

- elimination of storage problems associated with conventional films;
- no hard copy films;
- rapid retrieval of previous images and reports for comparison;
- ease of availability of examinations to clinicians.

Plain film images are particularly useful for:

- chest;
- abdomen;
- skeletal system: trauma, spine, joints, degenerative, metabolic and metastatic disease.

Fluoroscopy/screening

Fluoroscopy is the term used when a continuous low-power X-ray beam is passed through the patient to produce a dynamic image that can be viewed on a monitor. Many different procedures, such as barium studies of the gastrointestinal tract, arteriography and interventional procedures, are monitored and carried out with the aid of fluoroscopy.

Ultrasound

Ultrasound employs high-frequency sound waves, produced by a piezo-electric crystal in a transducer. The waves travel through the body, and are reflected back variably, depending on the different types of tissue encountered. The same transducer, as well as transmitting ultrasound, receives the reflected sound and converts the signal into an electric current; this is subsequently processed into a grey-scale picture. A moving image is obtained as the transducer is advanced across the body (real-time ultrasound). Sections can be obtained in any plane and

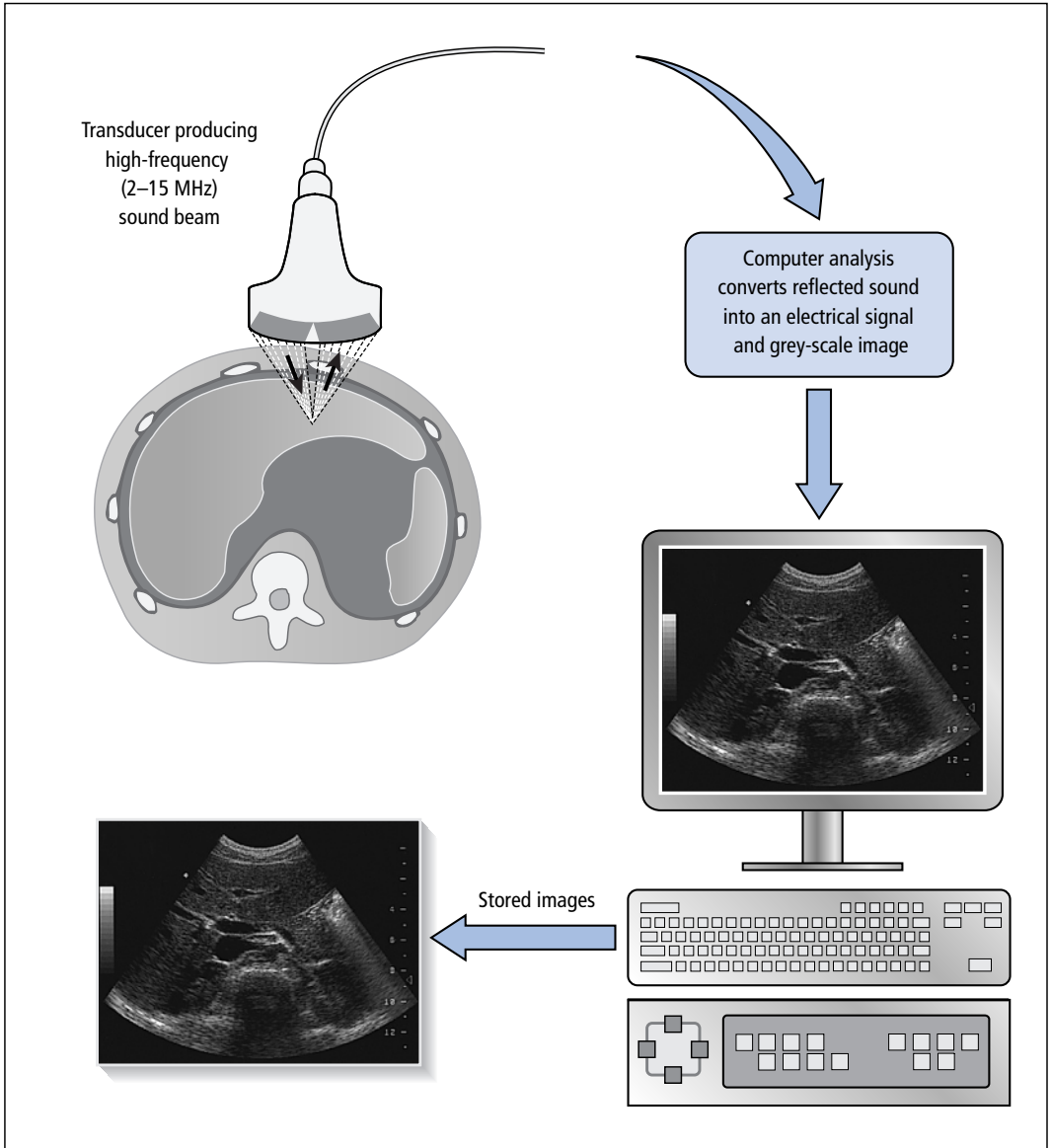


Figure 1.3 Basic principles of ultrasound.

viewed on a monitor. Bone and air are poor conductors of sound, thus there may be inadequate visualization, whereas fluid has excellent transmission properties.

Doppler ultrasound

Doppler ultrasound is a technique to examine moving structures in the body. Blood flow velocities are

measured using the principle of a shift in reflected sound frequency produced from moving structures. It is utilized for:

- assessment of cardiac chambers and heart valves;
- arterial flow studies, especially carotids and peripheral vascular disease;
- venous flow studies for detection of deep vein thrombosis.



Figure 1.4 Ultrasound machine with differing frequency probes ranging from 5–20 MHz. Specialist ones include transvaginal, transrectal and musculoskeletal probes.

Uses

- Brain: Imaging the neonatal brain.
- Thorax: Confirms pleural effusions and pleural masses.
- Abdomen: Visualizes liver, gallbladder, pancreas, kidneys, etc.
- Pelvis: Useful for monitoring pregnancy, uterus and ovaries.
- Peripheral: Assesses thyroid, testes and soft-tissue lesions.

Advantages

- Relatively low cost of equipment.
- Non-ionizing and safe.
- Scanning can be performed in any plane.
- Can be repeated frequently, for example pregnancy follow-up.
- Detection of blood flow, cardiac and fetal movement.
- Portable equipment can be taken to the bedside for ill patients.
- Aids biopsy and drainage procedures.

Disadvantages

- Operator dependent.
- Inability of sound to cross an interface with either gas or bone causes unsatisfactory visualization of underlying structures.
- Scattering of sound through fat produces poor images in obesity.

Computed tomography

CT involves passage of a collimated X-ray beam through the patient to obtain images of thin transverse sections of the head and body. A sensitive detection system with photomultiplier tubes is employed, with the X-ray tube rotating around the patient during each cycle. An image is obtained by computer processing of the digital readings from the photomultiplier tubes and analysis of the absorption pattern of each tissue. Absorption values are expressed on a scale of +1,000 units for bone, the maximum absorption of the X-ray beam, to -1,000 units for air, the least absorbent.

Each image represents a section through the body, the thickness being varied from 1 to 10 mm. Tissues lying above or below this slice are not imaged and a series of slices is taken to cover a particular region. Rapid sequences can be obtained, with the thorax and abdomen imaged in a few seconds.

The CT image consists of a matrix of picture elements (pixels), the slice thickness giving the volume component (voxel). Each voxel represents the attenuation value of the X-ray beam at that particular point in the body.

Oral contrast is used to outline the gastrointestinal tract, and intravenous contrast to delineate the vascular system and to study organ enhancement in various pathological conditions.

Uses

- Any region of the body can be scanned: brain, neck, abdomen, pelvis and limbs.
- Staging primary tumours such as colon and lung for secondary spread, to determine operability or a baseline for chemotherapy.
- Radiotherapy planning.
- Exact anatomical detail when ultrasound is not successful.
- Vascular anatomy such as coronary arteries.

Advantages

- Good contrast resolution.
- Precise anatomical detail.

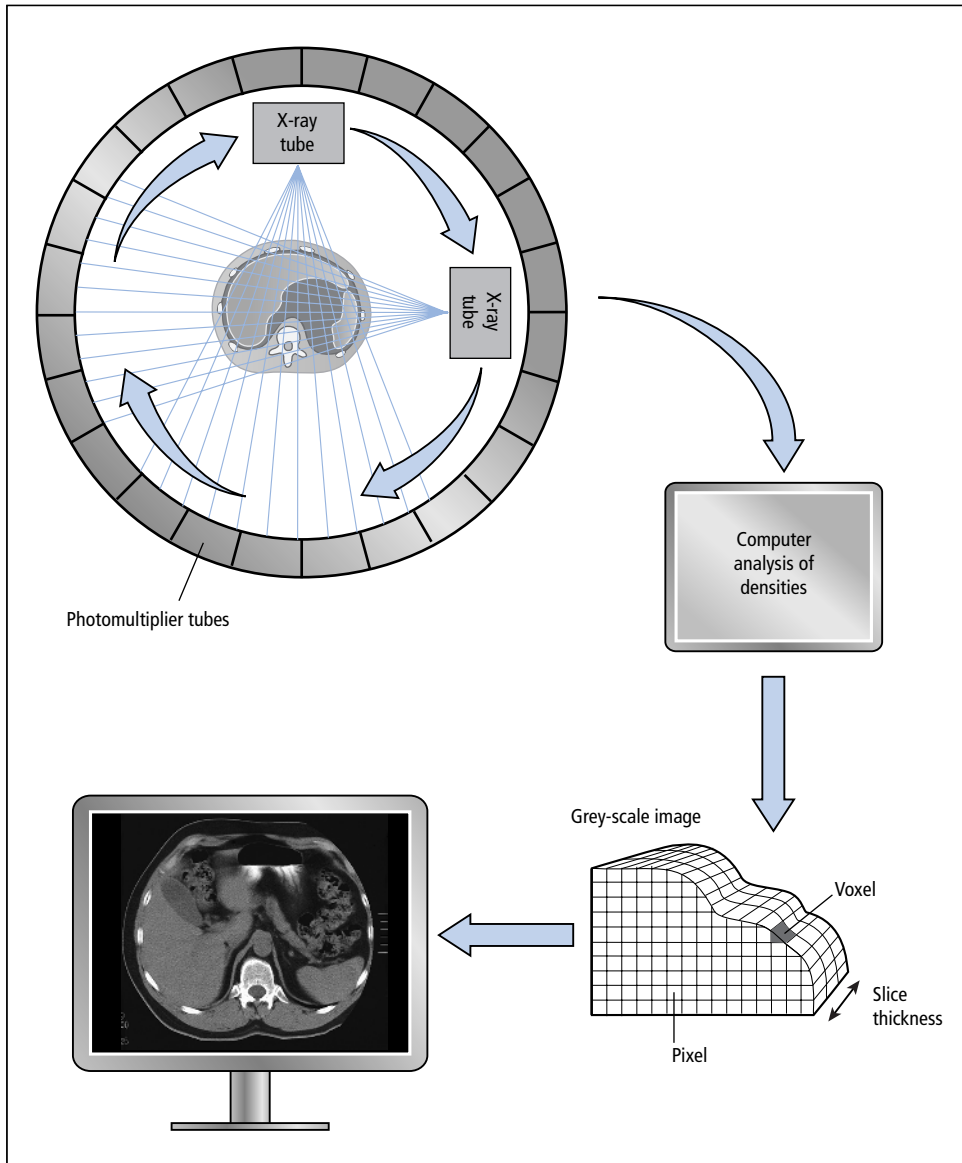


Figure 1.5 Basic principles of CT.

- Rapid examination technique, so valuable for ill patients.
- Good diagnostic images are obtained in obese patients as fat separates the abdominal organs, unlike ultrasound.
- Scanning mostly restricted to the transverse plane, although reconstructed images can be obtained in other planes.

Disadvantages

- High dose of ionizing radiation for each examination.
- High cost of equipment and scan.
- Bone artefacts in brain scanning, especially the posterior fossa, degrade images.

Magnetic resonance imaging

MRI produces images of the body by utilizing the magnetic properties of certain nuclei, principally those of



Figure 1.6 CT scanner.

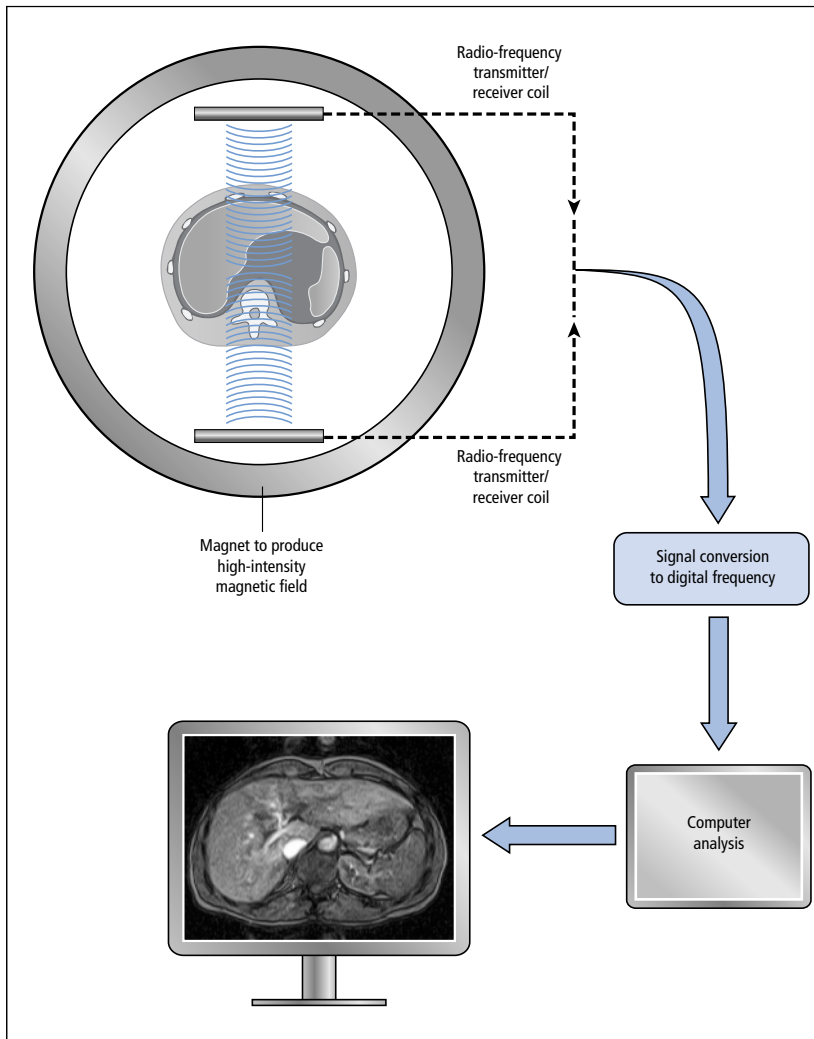


Figure 1.7 Basic principles of MRI.



Figure 1.8 MRI scanner.

hydrogen in water molecules. The patient is placed in the scanner tunnel and subjected to a high-intensity magnetic field. This forces the hydrogen atom nuclei to align with the magnetic field. A pulse of radio-frequency applied to these nuclei then displaces them from their position; when the pulse ceases, they return to their original state, releasing energy (in the form of a radio-frequency signal). Computer analysis processes this energy into a digital signal, with conversion to a grey-scale image. Hence, the basic principle of MRI is a study of the response of magnetized tissue to a pulse of radio-frequency, whereby pathological tissue returns different signals compared to normal.

Uses

- Central nervous system (CNS): technique of choice for brain and spinal imaging.
- Musculoskeletal: accurate imaging of joints, tendons, ligaments and muscular abnormalities.
- Cardiac: imaging with gating techniques related to the cardiac cycle enables the diagnosis of many cardiac conditions.
- Thorax: assessment of vascular structures in the mediastinum.
- Abdomen: abdominal organs are well visualized, surrounded by high signal from surrounding fat.
- Pelvis: staging of prostate, bladder and pelvic neoplasms.

Advantages

- Can image in any plane – axial, sagittal or coronal.
- Non-ionizing and hence believed to be safe to use.
- No bony artefacts due to lack of signal from bone.
- Excellent anatomical detail, especially of soft tissues.

- Visualizes blood vessels without contrast: magnetic resonance angiography (MRA).
- Intravenous contrast utilized much less frequently than CT.

Disadvantages

- High operating costs.
- Poor images of lung fields.
- Inability to show calcification with accuracy.
- Fresh blood in recent haemorrhage not as well visualized as by CT.
- MRI more difficult to tolerate with examination times longer than CT.
- Contraindicated in patients with pacemakers, metallic foreign bodies in the eye and arterial aneurysmal clips (may be forced out of position by the strong magnetic field).

Nuclear medicine

Radionuclide imaging is a valuable diagnostic tool, the principal modality that examines abnormal physiology of the body in preference to anatomical detail. Technetium-99m is the commonest isotope used, and by tagging with certain substances, a particular region of interest can be targeted.

Positron emission tomography (PET)

PET uses positron-emitting isotopes, many short-lived and cyclotron produced. These agents include

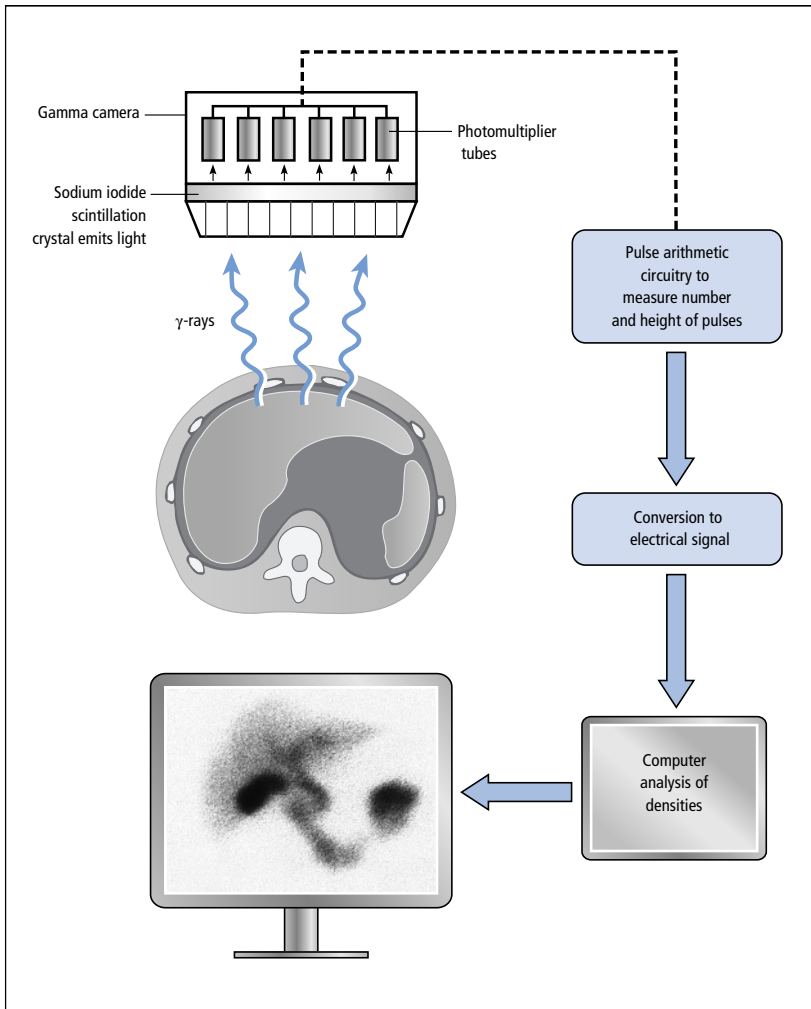


Figure 1.9 Basic principles of isotope scanning.



Figure 1.10 Nuclear medicine scanner.

Table 1.1 Typical applications of isotopes.

Anatomical area	Agent	Application
Respiratory tract	Tc99m microspheres Krypton, DTPA	Perfusion and ventilation scanning for diagnosis of pulmonary embolus
Cardiovascular	Thallium-201 Tc99m MIBI	For infarct imaging as it accumulates in normal myocardium showing a defect corresponding to infarcts
Gastrointestinal	Na pertechnetate and Tc99m-labelled WBCs	Studies to detect Meckel's diverticulum and inflammatory bowel conditions
Liver and spleen	Tc-labelled sulphur colloid	Reticuloendothelial uptake to image focal abnormalities
Biliary system	Tc99m HIDA	Useful in cholecystitis and obstruction, as isotope uptake in liver is excreted in bile
Urinary tract	DMSA MAG3	Studies of renal functional and anatomical abnormalities
Skeletal	Tc-labelled phosphonates	Uptake at sites of increased bone turnover, e.g. tumours and arthritis
Thyroid	Iodine-131 or Tc99m	Assessing focal nodules
Parathyroid	Sestamibi protein labelled with Technetium 99	May visualize adenomas

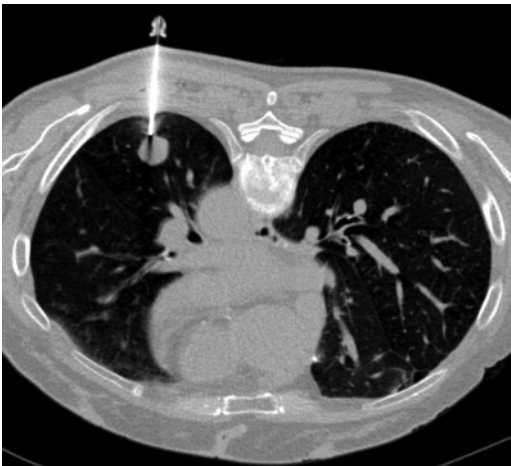


Figure 1.11 A biopsy needle has been inserted under CT control into a lung nodule for histology samples.

radioactive oxygen, carbon and nitrogen but the commonest in use is fluorodeoxyglucose (FDG), a glucose analogue, indicating tissue metabolic activity in the detection of tumours or secondary deposits. It is often combined with a CT to give anatomical as well as functional information. Accurate studies of blood flow and metabolism are also possible using these tracers.



Figure 1.12 Insertion of a chest drain (arrows) under CT control for a pneumothorax.

Interventional radiology

Respiratory tract

Lung biopsy

A needle is inserted directly into the lung or pleural mass and tissue taken for microbiological or histological analysis. The procedure may be performed under fluoroscopy or CT.

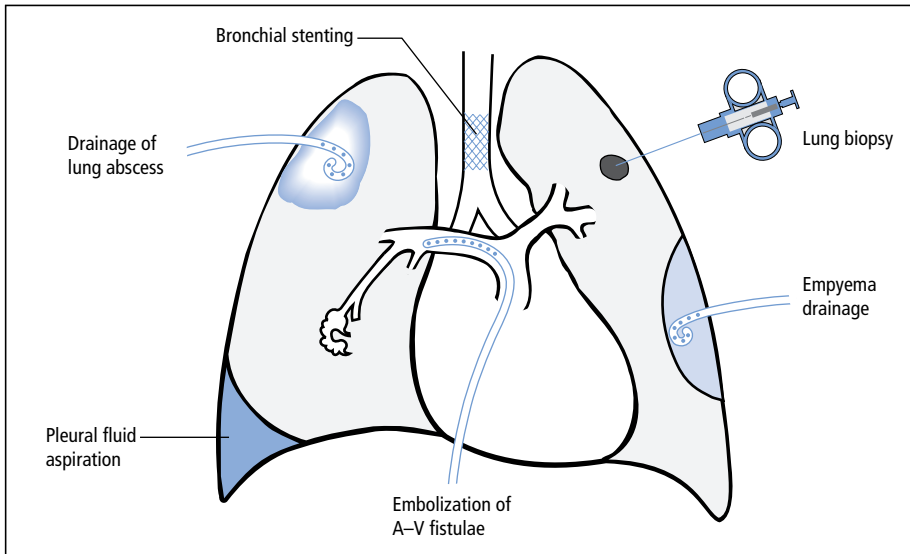


Figure 1.13 Respiratory tract interventional procedures.

Pleural fluid aspiration

Ultrasound is effective in diagnosing pleural fluid. Even small quantities can be visualized and aspirated for analysis.

Empyema drainage

Purulent fluid in the pleural cavity, usually due to infection from adjacent structures, can be drained directly by catheter insertion.

Bronchial wall stenting

In malignant narrowing of the bronchus, insertion of an expandable metal stent.

Embolization

Bronchial artery embolization in treatment of life-threatening haemoptysis, and embolization of pulmonary arterio-venous malformations.

Cardiovascular system

Angioplasty

Stenoses in the aorta, iliacs, femorals, peripheral vessels, carotids, coronary vessels, renals and virtually any other artery can be dilated by means of balloon inflation. Narrowed arterial segments and occlusions can also be



Figure 1.14 Aortic stent inserted via the femoral arteries for an aortic aneurysm.

treated by insertion of metallic stents. The superior vena cava can be stented to relieve malignant obstruction.

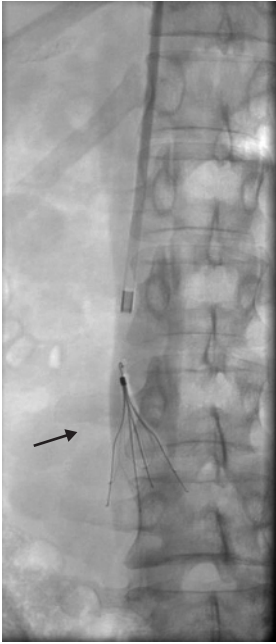


Figure 1.15 IVC filter insertion via the jugular vein (arrow).

Thrombolysis

Recent arterial thrombus can be lysed by positioning a catheter in the thrombus and infusing streptokinase or tissue plasminogen activator (TPA). Contraindications to this procedure include bleeding diatheses and recent cerebral infarction.

Embolization

The deliberate occlusion of arteries or veins for therapeutic purposes. Steel coils, detachable balloons or various other occluding agents are injected directly into the feeding vessels. Indications include arterial bleeding, arteriovenous fistulae and angiomatous malformations.

Vena cava filter insertion

A filter is introduced percutaneously through either the femoral or internal jugular vein and positioned in the inferior vena cava, just below the renal veins, thus preventing further embolization from the thrombus originating in pelvic or lower limb veins.

Aortic stenting (EVAR)

Used for the treatment of abdominal aortic aneurysms with insertion of the stent via the common femoral arteries.

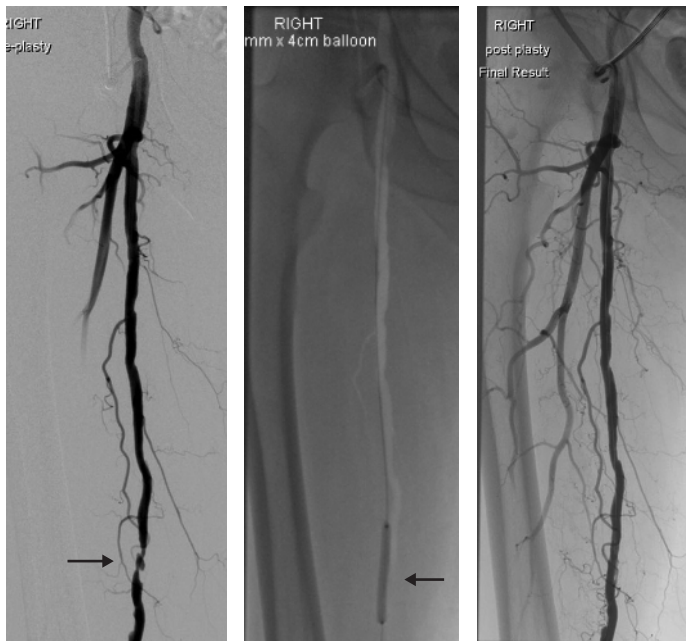


Figure 1.16 Arteriogram showing a femoral stenosis (arrow), subsequent balloon inflation in the stenosis (arrow), and following angioplasty showing a significant improvement in the stenosis.

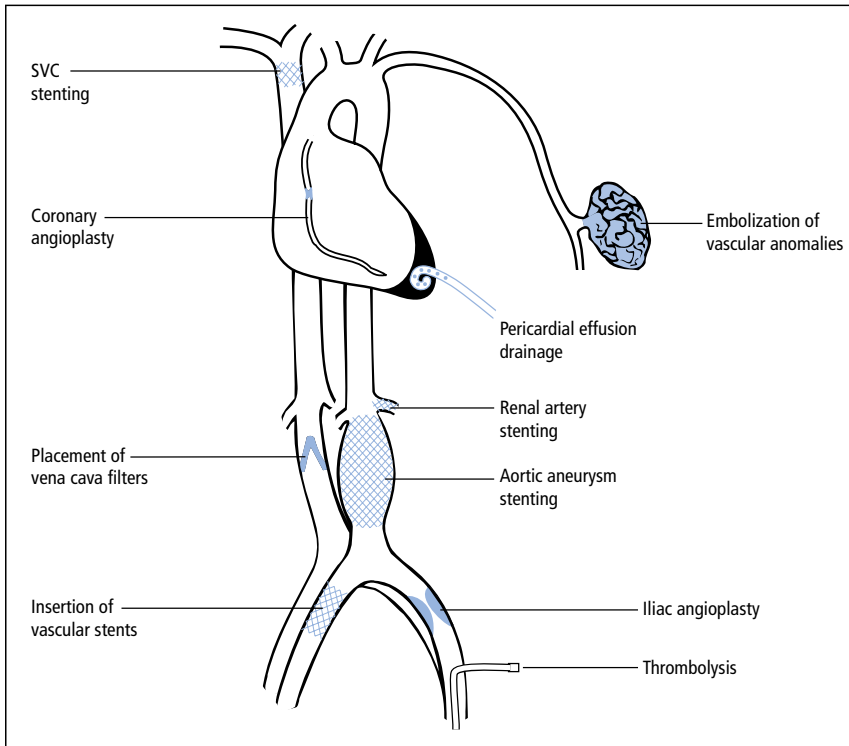


Figure 1.17 Cardiovascular system interventional procedures.

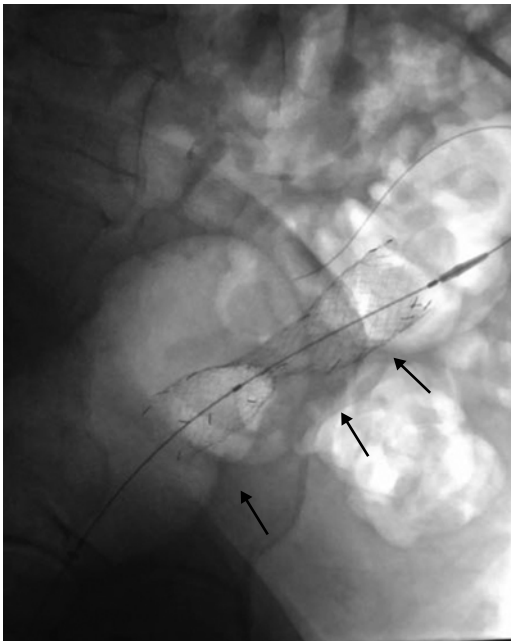


Figure 1.18 Colonic stent insertion (arrows) after a guidewire has been manoeuvred through the stricture and a stent deployed.



Figure 1.19 Percutaneous insertion of a gastrostomy (arrows). A nasogastric tube is in position.

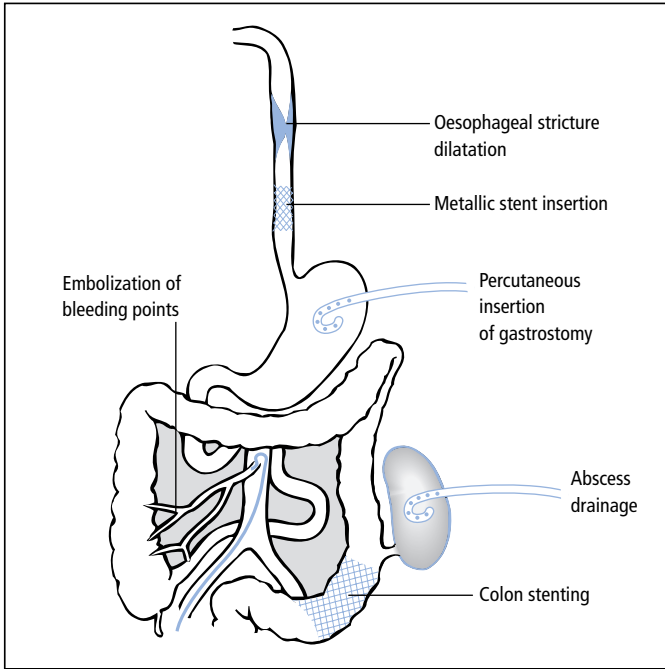


Figure 1.20 Gastrointestinal tract interventional procedures.

Gastrointestinal tract

Oesophageal dilatation

A larger diameter balloon is used for dilatation of benign structures, postoperative anastomotic strictures (e.g. gastroenterostomy), achalasia and palliation of malignant strictures.

Oesophageal stent

A metallic self-expanding stent is inserted for palliation of malignant oesophageal strictures.

Colonic stent

Metal expandable stents can be inserted for palliation of malignant strictures.

Percutaneous gastrostomy

After gastric distension with air, a catheter is inserted directly through the anterior abdominal wall into the stomach.

Embolization

Angiography may localize the bleeding point in severe gastrointestinal haemorrhage. Control of

haemorrhage may be possible by infusion of vasopressin or embolization.

Abscess drainage

Percutaneous drainage of subphrenic and pancreatic collections.



Figure 1.21 Cholangiogram showing complete biliary obstruction with marked dilatation of the intrahepatic bile ducts.

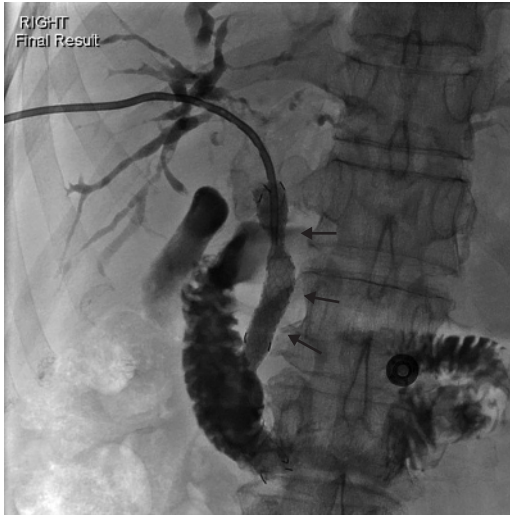


Figure 1.22 Biliary obstruction relieved by the insertion of a metal stent in the common bile duct (arrows).

Biliary tract

External biliary drainage

In biliary obstruction, a catheter is inserted percutaneously through the liver into the bile ducts.

Internal biliary drainage with endoprosthesis

A plastic or metal stent is positioned within the biliary stricture and free internal drainage achieved without the need for any external catheters. The procedure is preferably carried out by endoscopic retrograde cholangiopancreatography (ERCP), but if this fails, the stent can be inserted using a percutaneous approach.

Liver biopsy

Safer to perform with ultrasound control. Focal lesions can be biopsied for a histological diagnosis.

Biliary duct dilatation

Balloon dilatation of a benign biliary stricture.

Other

Liver/subphrenic abscess drainage and biliary stone removal.

Urinary tract

Renal angioplasty

Balloon dilatation of renal artery stenosis or insertion of metallic stents to alleviate the stenosis (treatment of hypertension or to preserve renal function).

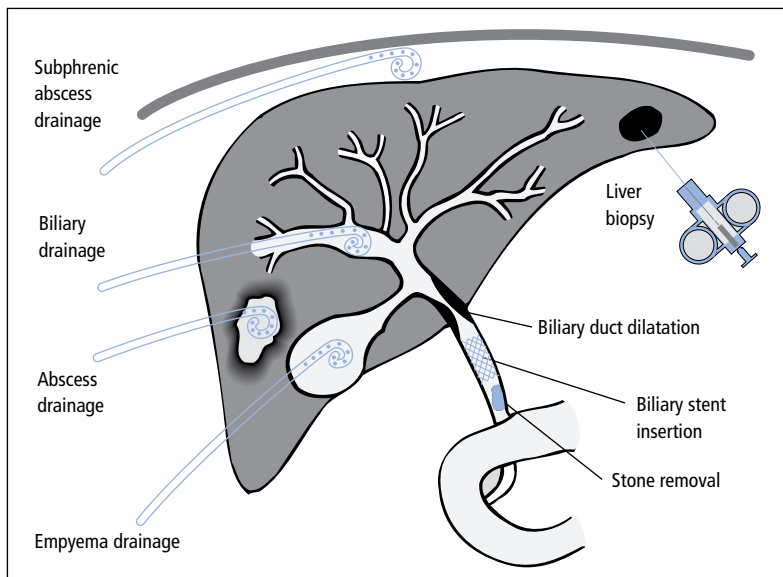


Figure 1.23 Biliary tract interventional procedures.

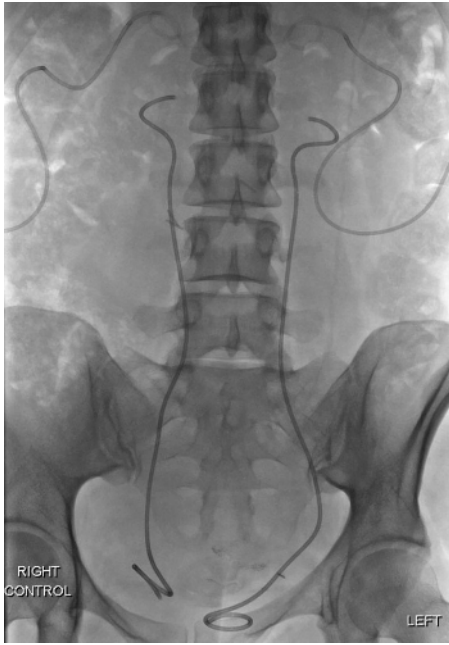


Figure 1.24 Percutaneous insertion of bilateral ureteric stents.

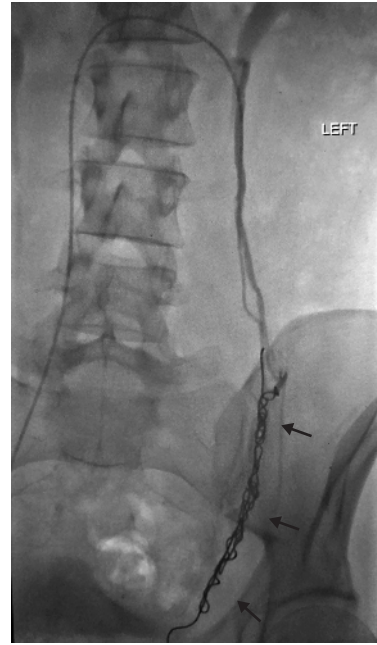


Figure 1.25 Venogram showing a catheter inserted via the right femoral and embolization coils deployed (arrows) for a left varicocele.

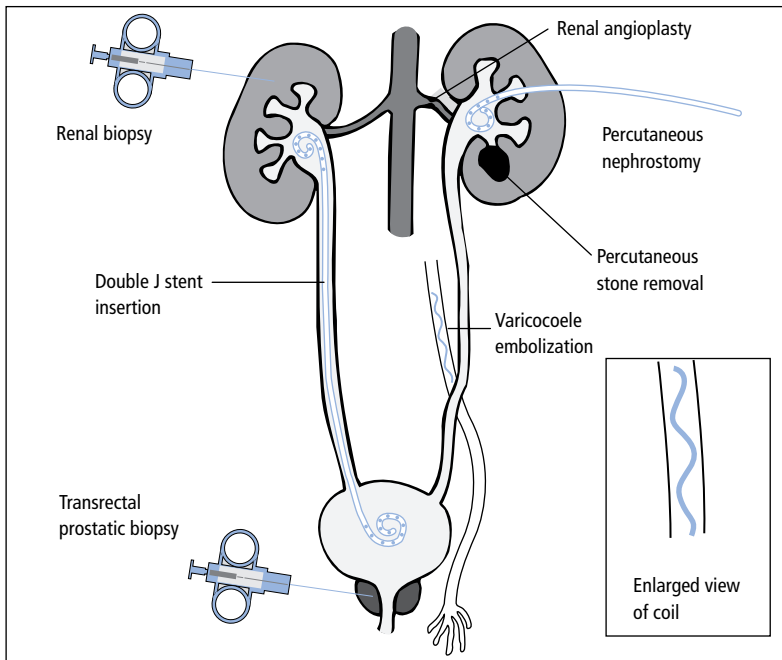


Figure 1.26 Interventional procedures of the urinary tract.

Percutaneous nephrostomy

To establish free drainage of urine when the kidney is obstructed, by insertion of a catheter into the pelvicalyceal system.

Ureteric stent

A special catheter positioned, so one end lies in the renal pelvis and the other in the bladder, for the relief of obstruction. Introduction is either from the lower ureter after cystoscopy by an urologist or from above percutaneously under radiological control.

Percutaneous stone removal

Removal of a renal calculus, through a percutaneous track, from the posterior abdominal wall directly into the kidney.

Embolization

Useful in the treatment of bleeding A-V renal fistulae and to occlude the testicular vein in a varicocoele.

