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Кафедра лучевой диагностики, лучевой терапии с курсом ФПКиП

Н. М. ЕРМОЛИЦКИЙ

ЛУЧЕВАЯ ДИАГНОСТИКА И ЛУЧЕВАЯ ТЕРАПИЯ

Допущено Министерством образования Республики Беларусь в качестве учебного пособия для иностранных студентов учреждений высшего образования, обучающихся по специальности «Лечебное дело»

В двух частях

Часть 1
Основы лучевой диагностики

RADIOLOGY

Teaching guide

In two parts

Part 1
Basic diagnostic radiology

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Учебное пособие на английском языке подготовлено в соответствии с типовой программой по специальности «Лечебное дело». Включены темы, изучаемые в V семестре. Содержит необходимые для усвоения разделы дисциплины: принципы и методы лучевой диагностики; основы защиты от ионизирующих излучений; радиология опорно-двигательной системы, грудной клетки, сердечно-сосудистой и нервной систем, представлены наиболее частые случаи.

Материалы адаптированы к программе лучевой диагностики и лучевой терапии с учетом объема часов преподавания, также использована аутентичная английская терминология к описанию специфики предмета.

Пособие предназначено для иностранных студентов 3 курса медицинских вузов, может быть полезным для иностранных студентов старших курсов при изучении терапевтических и хирургических дисциплин, в том числе для клинических ординаторов радиологии.

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CONTENTS

I. OVERVIEW AND PRINCIPLES OF RADIOLOGY IMAGING

Introduction

Radiology is an essential component of current medical practice, having assumed a central role in the evaluation and follow-up of many clinical problems, from the head to the toes. Becoming familiar with and knowledgeable about the indications and capabilities of various diagnostic and therapeutic procedures that are driven by imaging, across a wide range of clinical subspecialties and imaging modalities, it is important for those who use radiology for any diagnostic and therapeutic purpose.

Of high importance in today's managed care environment, diagnostic ima-ging can also be used for the early identification of potential medical problems, to help prevent their occurrence. Radiologists and other physicians interpret the resulting images to diagnose various medical illnesses or injuries so that a patient treatment and therapy can be specifically planned and implemented. Diagnostic imaging is also used to guide surgical planning and it is often used to follow surgery and/or monitor the outcomes of therapeutic procedures.

From the initial discovery of X-rays and their application to medical ima-ging by Wilhelm Röntgen, imaging has been an increasingly vital part of medical practice. Modern doctor needs a deep understanding of different modalities and their application in the diagnosis and management of a wide range of medical conditions. While in many situations images are reported by expert radiologists, the ability to understand and interpret radiological images is essential and a vast majority of medical schools will require students to demonstrate fundamental skills in this area. More importantly, diagnostic and therapeutic imaging opens a window to the internal structure and function of the human body and links the fundamental sciences of anatomy, physiology, and pathology to the patient as a whole presenting with symptoms and signs of the disease. The clues gleaned from a careful history and thorough examination lead us to select the most appropriate investigations to expedite a diagnosis, allowing us to inform the patient about their condition and commence an appropriate treatment. It is the distinction between a normal and an abnormal structure and function, which is at the core of radiological diagnosis, that provides an illustrative basis for learning and a truly patient-orientated understanding of medical disorders.

The newest frontier in diagnostic imaging, molecular imaging, makes it possible to identify certain molecules within cell structures. The development of further imaging techniques such as ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI) followed in the second half of the twentieth century have led to medical imaging occupying a central place in the management of patients with a very wide range of conditions.

Three modes of image production

There are three basic means by which radiologic images are produced: transmission of energy, reflection of energy, and emission of energy. Physicians have understood this, and they also know that the three methods are complementary, each providing information at a different level.

Transmission imaging

Radiograph is produced by the transmission of energy. A beam of high-energy photons is passed through the body, some of which are attenuated or blocked when they strike subatomic particles. The principal transmission moda-lities include plain radiography (such as chest radiographs and abdominal radiographs), fluoroscopy, and computed tomography.

Fluoroscopy represents a kind of "movie", or a moving picture, in which a continuous detection and a display of the pattern of a photon transmission enables the visualization of dynamic processes in real time. CT gathers transmission data from multiple perspectives and employs a mathematical algorithm (the Fourier transform) to reconstruct an image of the slice of the tissue through which the x-ray beams passed.

Reflection imaging

The radiologic modality that exemplifies reflection imaging is ultrasound. As we shall see, ultrasound creates images not according to the density diffe-rences between various tissues, but by their acoustic differences. A very low-density structure such as fat, which appears black on a radiograph, may be very "echogenic" acoustically, and hence appear bright on a sonogram.

Emission imaging

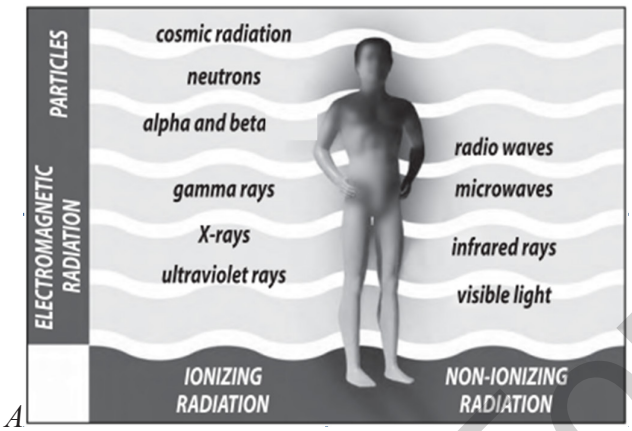
The emission modalities include MRI and nuclear medicine. MRI creates images by distinguishing between the nuclear magnetic properties of various tissues. MRI also utilizes no ionizing radiation, generating images using a magnetic field and radio waves.

The other emission modality, nuclear medicine (NM), creates images by introducing radioisotopes into the human body and then detecting their emission of gamma rays (like x-rays, except from a different source). In contrast to MRI, nuclear medicine involves ionizing radiation.

Different types of ionizing radiation

The gamma (γ) ray corresponds to the emission of a short wavelength and variable energy photons (Figure 1.1). This radiation translates the loss of excessive energy in the nucleus and its transformation into a more stable state, as opposed to the production of X-rays, obtained after excitation and ionization of electrons. X-rays

and gamma rays are ideal medical diagnosis tools. As they are very penetrating, they can go through large thicknesses of the matter and travel for hundreds of meters in the air. Dense materials such as lead, very thick concrete or deep water are able to stop them or, at least, strongly attenuate them.



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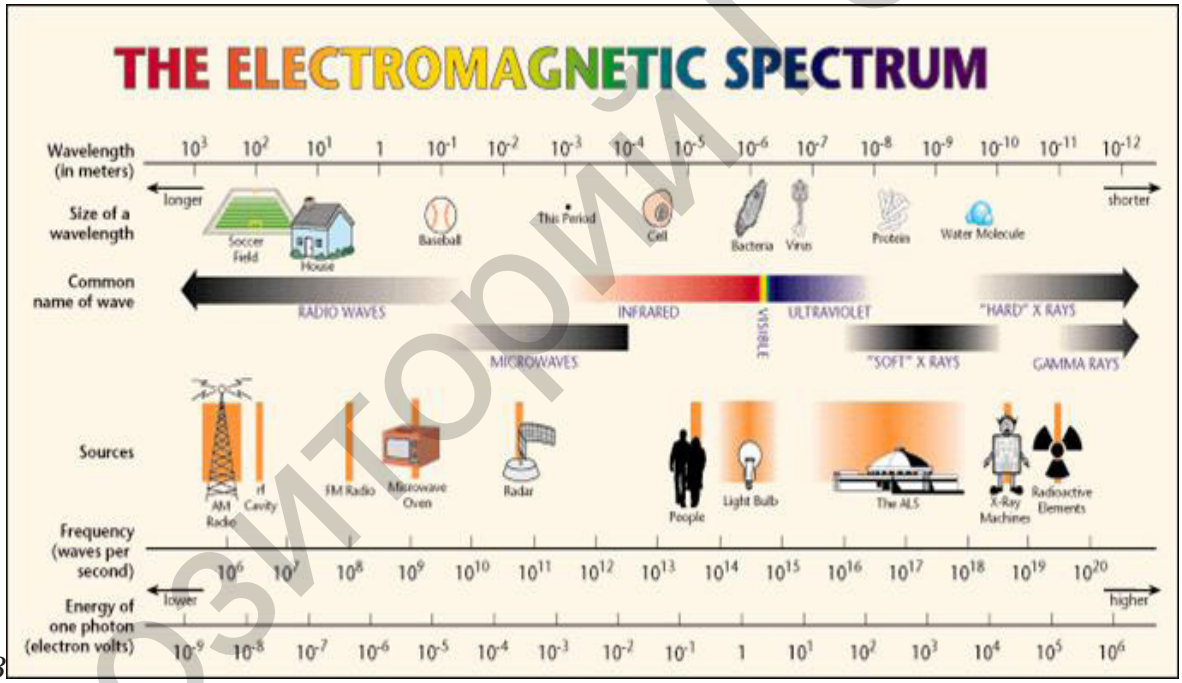


B

Figure 1.1 — (A) Different types of radiations to which man is daily exposed. (B) — Electromagnetic spectrum extending over several orders of magnitude listing values of wavelengths, frequency, and identifying values in some of the more common regions of the spectrum. Ionizing radiation has sufficient energy to penetrate in to the human tissue

An X-ray is an electromagnetic wave of the same type as light waves, but with a higher energy level, thus capable to some extent of travelling through the matter. The technique is based on the matter's capacity to attenuate an external beam of X-rays depending on whether it is solid, liquid or gaseous. Therefore, organs will allow radiation to pass through them according to their density, thickness and con-

stitution; the intensity of the rays is measured on a photogra-phic film or using a specific detector. Initial applications distributed on organs and tissues presenting a different coefficient of absorption.

X-rays, or roentgen rays, are a form of electromagnetic radiation or energy of extremely short wavelength. X-rays in the diagnostic range are near the end of the spectrum of short wavelengths. The shorter the wavelength of an electromagnetic radiation form, the greater its energy and, as a rule, the greater its ability to penetrate into various materials.

Production of X-Rays

Electromagnetic radiation can be produced in a variety of ways. One method makes use of the acceleration or deceleration of electrons. For example, a radio transmitter is merely a source of high-frequency alternating current that causes electrons in an antenna wire to which it is connected to oscillate (accelerate and decelerate), thereby producing radio waves (photons) at the transmitter frequency. X-rays used in diagnostic radiology require a vacuum and the presence of a high potential difference between a cathode and an anode. Moving these electrons toward the anode at an energy level sufficient to produce x-rays requires a high potential — up to 125,000 V (125 kV). When the accelerated electrons strike the tungsten anode, x-rays are produced.

In an x-ray tube, electrons boiled off from a hot filament of cathode are accelerated toward a tungsten anode by a high voltage on the order of 100 kilovolts (kV) (Figure 1.2).

X-ray tube

Producing x-rays requires a source of electrons, a means to rapidly accelerate hem, and a means to rapidly decelerate them. These factors are built into the x-ray apparatus.

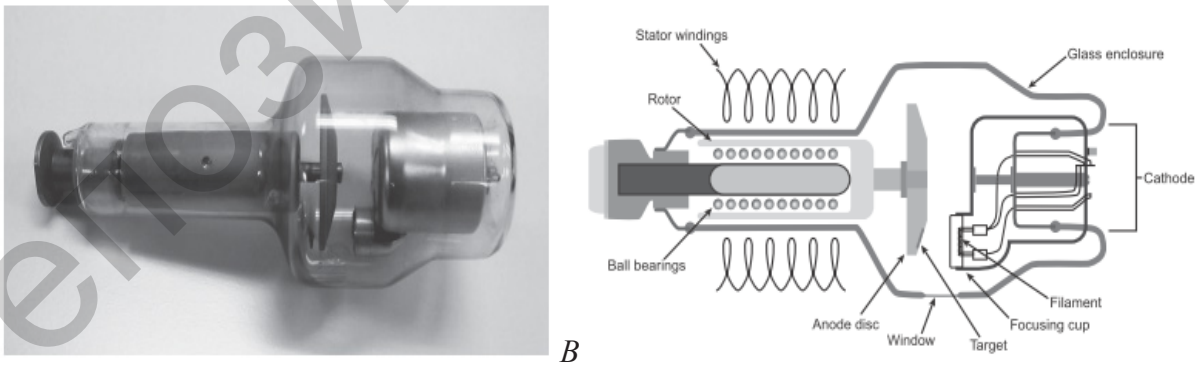


Figure 1.2 — A rotating anode x-ray tube within a housing assembly. (A) Photograph of a complete x-ray tube. (B) Diagram of a complete x-ray tube, showing alignment of the filament to the anode

Just before hitting the anode, the electrons will have a source of light such as a candle is used rather than an extended light source such as a fluorescent tube (Figure 1.2).

Unfortunately, the smaller the focal spot, the more likely the anode will melt. The power (energy per second) dumped into the anode is equal to the product of the kilovoltage and milliamperage; i.e., at 100 kV and 500 mA, 50,000 watts (W) of heat energy is deposited into an area of the order of a few square millimeters. The three principal components of an x-ray machine are the x-ray tube, generator, and control console.

Production of images

Image production by x-rays results from attenuation of those x-rays by the material through which they pass. Attenuation is a process by which x-rays are removed from a beam through absorption and to scatter. In general, the greater the material's density — that is, the number of grams per a cubic centimeter — the greater its ability to absorb or scatter x-rays. Absorption is also influenced by the atomic number of the structure. The denser the structure, the greater the attenuation, which results in less blackening of the "film" (fewer x-rays strike the "film"). Less-dense structures attenuate the beam to a lesser degree and result in more blackening of the "film" (more x-rays strike the "film", Figure 1.3).

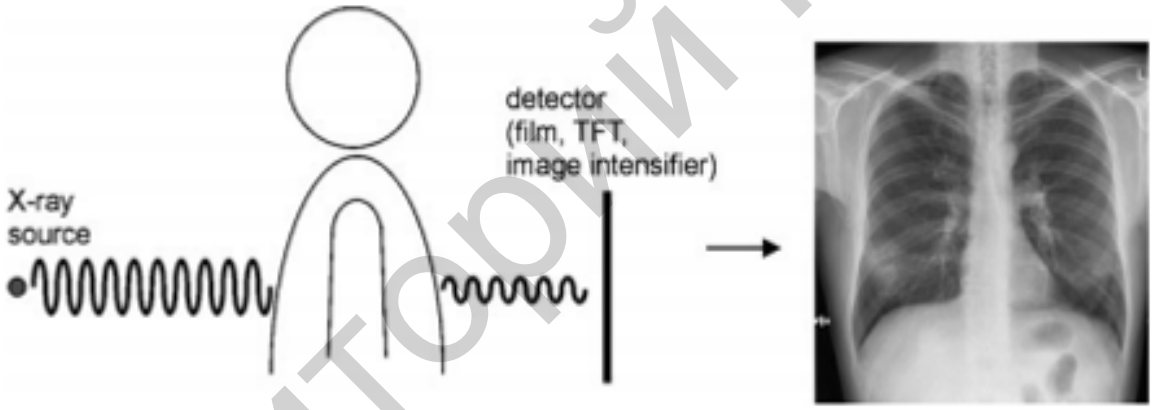


Figure 1.3 — X-rays penetrate into the human body and produce an image that shows tissue-specific absorption along a path from the X-ray source to a detector

A small percentage of the incident radiation beam exits the patient and strikes a detector. An image receptor is required to convert the radiation into an image after it has passed through the area of interest.

An x-ray tube in the fluoroscope emits an x-ray beam that passes through the patient and falls upon an image intensifier. An image intensifier is an electronic vacuum tube that converts an incident x-ray image into a light image of a small size and high brightness. The image intensifier converts the x-ray radiation into visible light images and amplifies them. These images are then displayed on a monitor and can be viewed or recorded. A modern digital radiographic apparatus consists of a digital flat panel detector, using computer algorithms it reconstructs the data into images.

Radiographic density

It is important to differentiate between two types of densities that you will hear mentioned when discussing radiographs with radiologists or other colleagues: physical density and radiographic density. Physical density is the type of density just described. Radiographic density refers to the degree of blackness of a film. Radiographic contrast is the difference in radiographic densities on a film. The radiographic density of a substance is related to its physical density. The effect on a film or other recording media occurs paradoxically: structures of high physical density produce less radiodensity and vice versa. Structures that produce more blackening on the film are referred to as being radiolucent; those that produce less blackening are called radiopaque or radiodense. There are five main types of radiographic densities; in increasing order of physical density, these are gas (air), fat, soft tissue (water), bone (calcium) and metal (Figure 1.4). Radiographically, these appear as black, gray-black, gray, light gray and white, respectively.

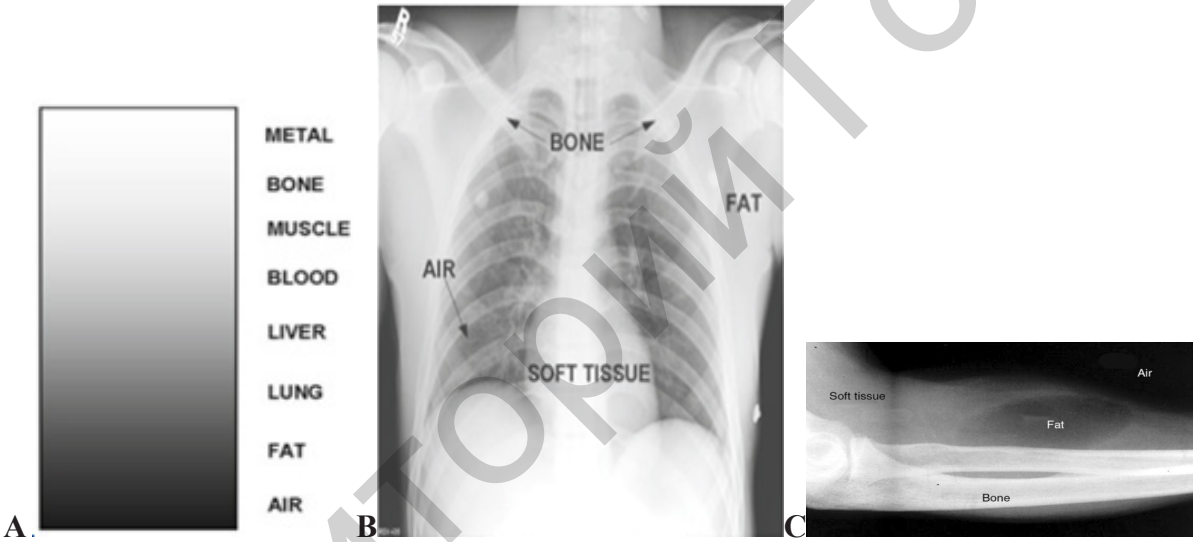


Figure 1.4 — (A) Diagram of radiographic densities on NEGATIVE image. (B) Note how the four basic densities are visible on a negative frontal chest radiograph and (C) four basic densities are visible on a negative radiograph of the region forearm

Both density and thickness tissues, are factors to take into account in assessing the degree of opacification noted on a radiograph (Figure 1.3). Radiographs were initially referred to as "skiagraphs", from the Greek for "shadow pictures", because they represent recordings of the shadows cast by anatomic structures as photons pass through the body.

Recording media (detector)

X-ray film

The most common type of recording medium used is an x-ray film. An X-ray film is still used in many parts of the world. However, state-of-the-art radiology departments have replaced an x-ray film with electronic recording media.

An X-ray film consists of a plastic sheet coated with a thin emulsion that contains silver bromide and a small amount of silver iodide. This emulsion is sensitive to light and radiation. A protective coating covers the emulsion. When the film is exposed to light or to ionizing radiation and then developed, chemical changes take place within the emulsion, resulting in the deposition of metallic silver, which is black. The amount of blackening on the film depends entirely on the amount of radiation reaching it and therefore on the amount attenuated or removed from the beam by the subject.

Fluoroscopic screen (for fluoroscopy)

A fluoroscopic screen is coated with a substance (phosphor) that gives off visible light (or fluoresces) when it is irradiated. The brightness of the light is proportional to the intensity of the x-ray beam striking the plate and depends on the amount of radiation removed from the beam by the object being irradiated. Today, the fluoroscopic screen is combined with an electronic device that converts the visible light into an electron stream that amplifies the image (makes it brighter) by converting the electron pattern back into visible light.

This system allows a radiologist to see the image clearly without requiring dark adaptation of the eyes, as was necessary in non-image-enhanced fluoroscopy. The technology of image intensification was originally developed around 1950 for a military use at night. Intensifying screens, variants of fluoroscopic screens, were used in most film cassettes to reduce the amount of radiation needed to produce an acceptable exposure.

The classic imaging receptor is a film/screen combination into cassette. The x-ray beam strikes a fluorescent screen (into cassette), which produces light that exposes the film, and then the film is developed.

Digital image plate

Modern day fluoroscopy units have digital flat panel detectors. Digital fluoroscopy can be performed with an image intensifier but in fluoroscopy more and more digital flat panel detectors are also used. Photon counting systems have the advantage of low electronic noise and the possibility of measuring the energy of each detected X-ray photon.

Photon-counting detectors are relatively small and for full-field coverage the detector is used in an imaging mode. Digital radiography and digital fluoroscopy techniques offer substantial improvement of image quality compared with analogue technique-like film-screen radiography.

Historical Data

In 1895, Dutch physicist Wilhelm Conrad Roentgen developed the equipment that could generate an unknown radiation, unknown because indefinable and original, which he called X. Wilhelm Roentgen succeeded in creating the first image of

an X-rayed hand and demonstrated the fact that human tissues behave differently depending on their density.

This first radiography of Mrs. Roentgen's hand, dating to 1896, became famous and opened the way for a new discipline of medicine, diagnostic and therapeutic radiology (Figure 1.5 B).

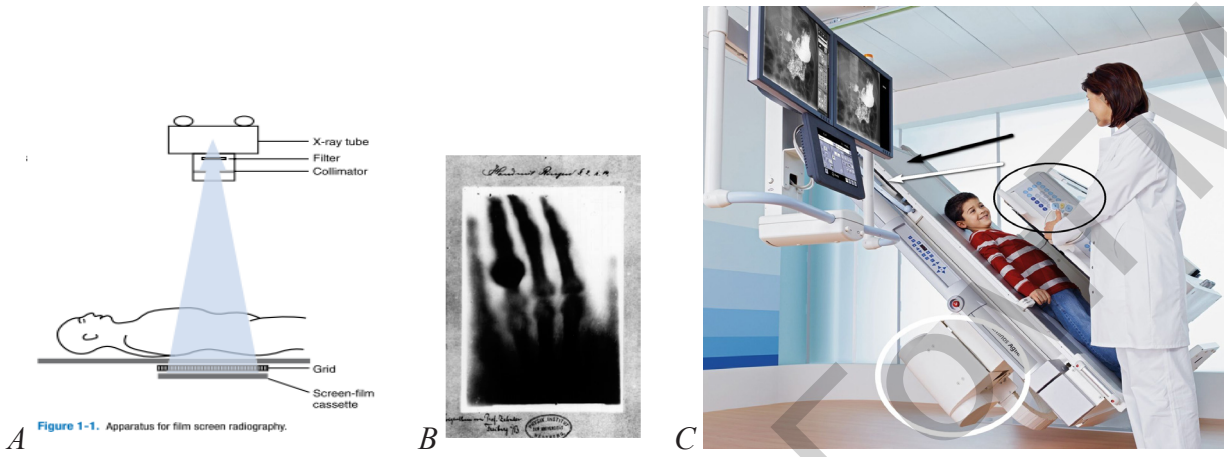


Figure 1.5 — (A) Schematic representation of plain film radiography. (B) The first X-ray (radiograph of Mrs Roentgen's hand, taken in 1896). (C) A standard radiology room equipped for both conventional radiography and fluoroscopy. The patient lies on the table (black arrow), which has the capacity to tilt up or down. Images can be obtained using the tube on the fluoroscopic carriage (black oval), which can be moved over the patient by the operator and then manipulated more or less freely to follow the barium column. Static images can be obtained using the overhead x-ray tube (white oval). The x-ray tube can be moved into the place over an x-ray cassette, which would be located under the patient (white arrow)

The recognition of the value and advantages of this technology made it possible to create special radiology services within five years.

An introduction to imaging modalities

Plain film (x-ray, projection, conventional) radiography

Plain radiographs are often called "plain X-rays" — but you cannot see the X-rays, only the images created by them. Radiographs can be produced using a variety of imaging methods. The image or picture is basically a shadow of the parts of the patient that absorb or block the X-rays.

The x-rays are directed in a limited beam towards the patient (Figure 1.5 A). The radiograph itself is a two-dimensional representation of the three-dimensional structures of the patient's body. These structures are visible because of the differences in attenuation of the x-ray beam. Attenuation refers to the process by which x-rays are removed.

The radiographic image **is a** "**photographic negative**" of the object — the "shadows" are white regions (where the X-rays were blocked by the object). The image is black in the regions that did not stop the X-rays, and they passed through to expose the film or sensor.

Plain radiographs ("plain films") are usually taken by a trained registered radiologic technologist. The resulting films or images are then interpreted by the radiologist to make a diagnosis or suggest further tests.

Principle radiography: the rays pass through the area under investigation, and depending on the tissues, a variable amount is absorbed — this is known as differential attenuation. The exact amount of whiteness depends on how much calcium or other heavy metal is present. The bone containing calcium — absorbs almost all of the rays and so shows up as white, fat absorbs much less, and air absorbs none so it appears black. The rays can then be imaged either using film, to get a conventional x-ray, or can be detected using a special equipment to get digital radiographs. The routine x-ray is a shadow picture. Plain radiograph may be conceptualized as a snapshot: it provides a static view of anatomic structure obtained in a fraction of a second.

Conventional radiographs (plain films) are produced using ionizing radiation generated by x-ray machines and viewed on a monitor or light box. Such x-ray machines are relatively inexpensive and widely available, and they can be made portable. The images are limited as to the sensitivity of findings they are capable of displaying.

Advantages:

— Inexpensive.

— Usually quick to perform.

— Painless, noninvasive.

— Good diagnostic tool for many pathologies.

Disadvantages:

— Soft tissue, lung, bone resolution much reduced compared with CT/magnetic resonance imaging (MRI).

— Provides a two-dimensional (2D), single image only.

— Radiation exposure.

Indications — are broad:

Chest X-ray

— Respiratory — infection, septic screen, pneumothorax, chest trauma, inhaled foreign body, pleural effusion, suspected malignancy.

— Cardiac — clinical heart failure, clinical cardiomegaly, heart murmurs.

Abdominal X-ray

— Abdomen — bowel obstruction, perforated viscus (erect CXR more sensitive), ingested foreign body, abdominal pain in the emergency setting.

— Pelvic — pelvic fracture, neck of femur fracture.

Soft tissue X-ray neck

— Inhaled foreign body.

— Retropharyngeal abscess.

Bone X-ray

— Limbs — trauma, fractures, skeletal survey, acutely swollen joint, osteomyelitis, septic arthritis, bone pain, tumour/metastasis.

— Skulls — skeletal survey, myeloma, dental imaging.

— Spine — trauma, scoliosis.

Conventional X-ray remains an important diagnostic tool in medicine and remains the most commonly used imaging modality. Plain films are commonly the chest X-ray (CXR), abdominal X-ray (AXR), and orthopaedic bone/joint X-rays. An XR is relatively inexpensive, time effective, and does not require any special preparation of the patient. A patient that has just been subject to a radiological examination is not radioactive, even if X-rays are a form of radioactivity. Outside the field, the effect of the radiation disappears. There is a degree of ioni-sing radiation associated with X-ray exposure and this radiation dose varies with a body part; a lumbar spine XR entails a far higher radiation dose than a wrist XR for example owing to radiation of pelvic organs. However, generally X-ray doses are far lower than those associated with computed tomography. Progress in these last years has effectively aimed at reducing both the time taken to acquire the image and the dose necessary for this acquisition, while still maintaining, even improving quality.

Fluoroscopy

Fluoroscopy enables real-time radiographic visualization of moving anato-mic structures. A continuous x-ray beam passes through the patient and falls onto a fluorescing screen (Figure 1.6). The faint light pattern emitted by the fluorescing screen is amplified electronically by an image intensifier, and the image is displayed on a television monitor and recorded digitally as a single image or series of images for real-time viewing (i.e., a movie). Video and static fluoroscopic images are routinely stored in digital format. Fluoroscopy is a technique for obtaining “live” X-ray images of a living patient.

Fluoroscopy (or “fluoro”) is a modality in which ionizing radiation (x-rays) is used in performing real-time visualization of the body in a way that allows for evaluation of the motion of body parts, real-time positioning changes of bones and joints, and the location and path of externally administered barium or iodine contrast agents through the gastrointestinal and genitourinary tracts and blood vessels. Images can be viewed as they are acquired on video screens and captured as either a series of static images or moving (vi-deo) images.

If, instead of using the light from a fluorescent screen to blacken a film, one viewed the fluorescent screen directly with the naked eye, then one would be performing fluoroscopy as it was done in the early days of medical x-ray use. Unfortunately, the image made in this fashion was very dim, even at a high exposure rate to the patient, so modern fluoroscopy uses an image intensifier that amplifies the light from a fluorescent screen. A typical fluoroscopic imaging system is shown in Figure 1.6 (B, C).

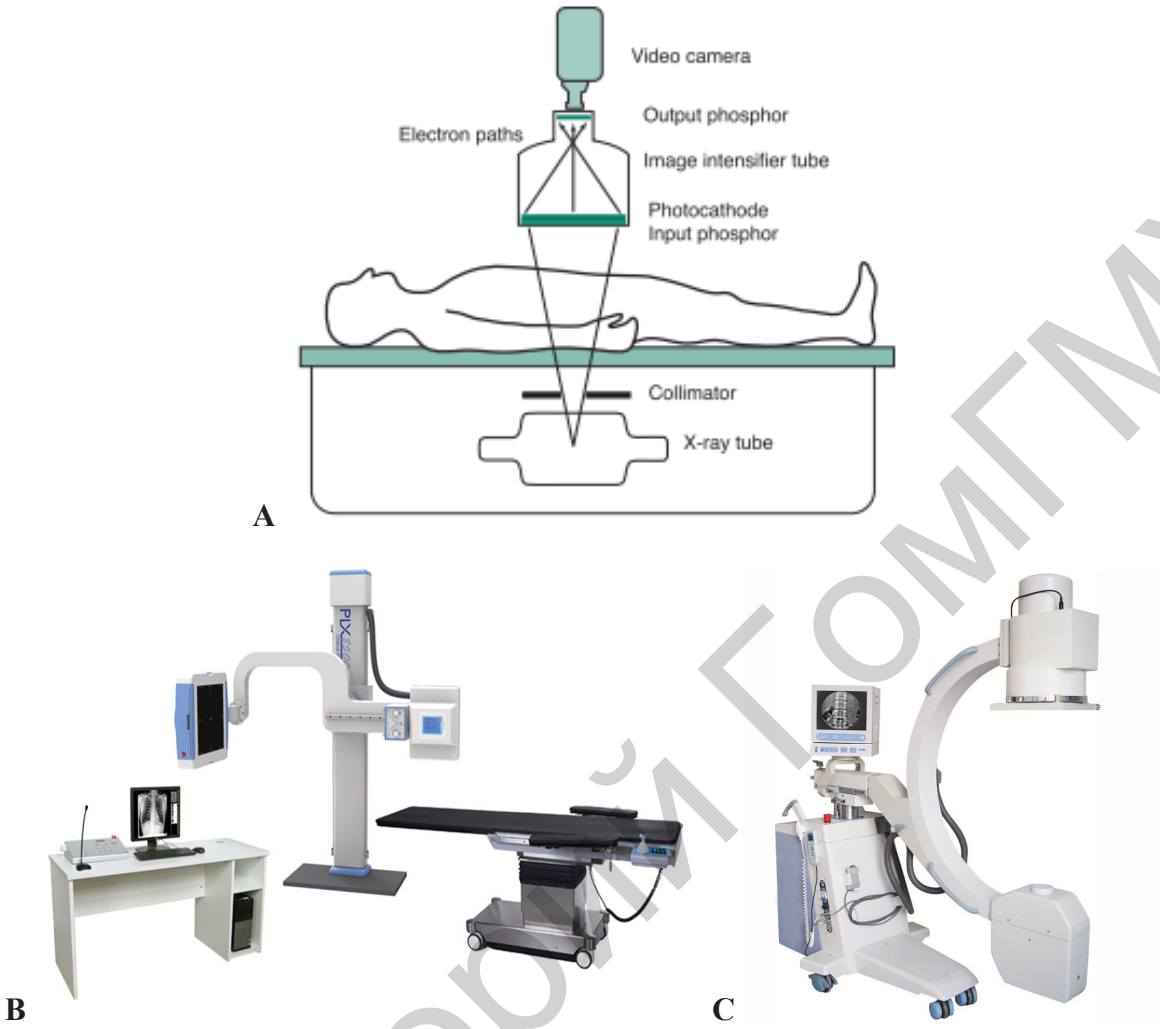


Figure 1.6 — (A) This is a diagram of a fluoroscopic unit illustrates the components of the system. The real-time fluoroscopic images are viewed on a television monitor and may be re-corded on the videotape. Radiographs are obtained by a digital image capture or by placing a film cassette between the patient and the image intensifier and exposing the image receptor with a brief pulse of radiation. (B) Radiography–fluoroscopy unit with flat-panel detector. (C) Mobile C-arm fluoroscopy unit

Advantages:

— Allow a "live" assessment.

— Relatively inexpensive, readily available.

— Relatively noninvasive.

Disadvantages:

— Exposure to ionising radiation, which may be significant, e.g. barium enema.

— Poor soft tissue resolution.

— Endoscopy techniques are more accurate in bowel mucosal assessment and allow tissue biopsies.

Fluoroscopy units can be made mobile, although they are still relatively large and heavy. They carry the same warnings regarding exposure to radiation as any other modality using ionizing radiation.

Radiation doses in fluoroscopy can be substantially higher than those used in conventional radiography because so many images are acquired for every minute of the fluoroscopy time. Therefore the dose is reduced by using the shortest possible fluoroscopy time to obtain diagnostic images.

The fluoroscopic image generally has less contrast and less resolution of fine detail than a radiographic image; however, it is clearly convenient to view the image in real time — particularly when observing the flow of radiopaque contrast agents ingested or injected into the body. During fluoroscopic examinations, the x-ray tube is typically operated below 100 kV and below a 3 mA tube current. Even so, entrance exposure rates (at the point where the x-ray beam enters the patient) are about 2 to 5 R/min, depending on patient thickness; hence, fluoroscopic examinations generally result in significantly higher patient exposures than do radiographic examinations.

The fluoroscopic image is usually viewed via a closed circuit television chain. Images may be recorded in a number of ways:

— X-ray "spot" films performed during screening.

— Light image from output fluorescent screen recorded by photospot or cine camera.

— Electronic image from television camera recorded in digital format on magnetic tape, magnetic disc or optical disc.

Conventional tomography

Conventional (linear) tomography provides radiographic images of slices of a living patient. This is done by simultaneously moving both an x-ray tube and an x-ray detector around a pivot point centered in the patient in the plane of the anatomic structures to be studied (Figure 1.7).

Structures above and below the focal plane are blurred by the motion of the tube and detector. Objects within the focal plane are visualized with an improved detail as a result of the blurring of the overlying and underlying structures. With wide availability of cross-sectional imaging, the use of conventional tomography is currently quite limited.

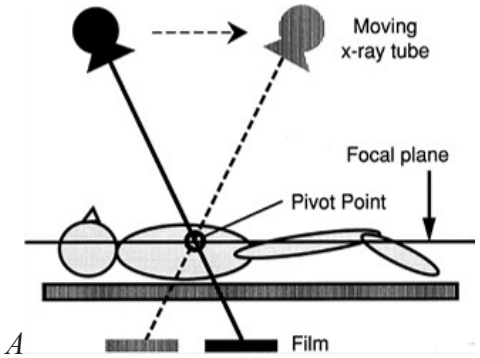


Figure 1.7 — (A) Scheme of linear (conventional, X-ray) tomography. In this technique, the x-ray tube and film simultaneously move about a pivot point at the level of the desired focal plane. Anatomic structures within the focal plane remain in a sharp focus, whereas the structures above and below the focal plane are blurred by the motion of the tube and film

Advantages:

— The objectivity — tomogram is the document.

— Inexpensive.

Disadvantages:

— High patient dose with multiple cuts.

— Long exposure times (exposure time determined by time it takes to move the tube for 3–6 seconds).

— Motion artifacts with long exposure times are more common.

Mammography

Mammography is a specific type of imaging that uses a low-energy x-ray system for the examination of breasts with high resolution of structures. Example indications: palpable breast mass, screening for breast cancer.

Mammography:

— Performed on dedicated x-ray units designed to image the whole breast.

— Mammography x-ray tube with very fine focal spot, low kVp, special anode materials [Molybdenum (Mo) ± Rhodium (Rh), Tungsten (W)].

— Rotating C-arm for different projections, compression device with compression paddles.

— Image capture stage with cassette holder and integrated grid (SFM), or digital flat plate detector and automatic exposure control (AEC) device. Film serves as image display and storage device.

— Narrow dynamic range up to 100, limited by film grain, quantum noise and processing chemistry.

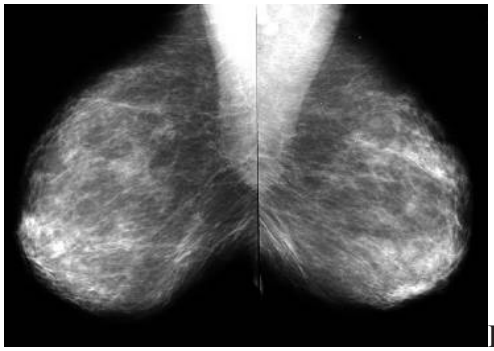
— Interpreted on high light output dedicated mammography viewer or modern light box.

Benefits: very high spatial resolution [15–20 line pairs (lp)/mm], widely available, proven effective.

Disadvantages: only one physical copy; susceptible to QA errors, image degradation, damage, loss.

The standard mammographic examination consists of two views: cranio-caudal and lateral oblique. A range of further views may be used to delineate an abnormality seen on the two standard views. These include spot compression, magnification, and craniocaudal views angulated medially or laterally (Figure 1.8).

Mammography is the first investigation of choice for a breast lump in women over 30 years of age, though US is increasingly used in younger women. Diagnostic mammography may also be performed for other reasons such as nipple discharge, or to search for a primary breast tumour where metastases are found elsewhere. Screening mammography is performed to search for early cancers in asymptomatic women.



A B

C

D

Figure 1.8 — (A–B) Two mammograms, cranio-caudal projections. Right mammary gland; (B) left mammary gland (age-normal variant). (C to D) Photographs of the variant modern mammographic equipment

X-ray mammography is performed utilizing a radiographic film, screen and digital combination.

Digital mammography: decouples image acquisition from display, storage and distribution.

The machine consists simply of an X-ray tube connected to a breast support which houses the imaging detector on a C-shaped arm, with a moveable compression paddle between the two (Figure 1.9).

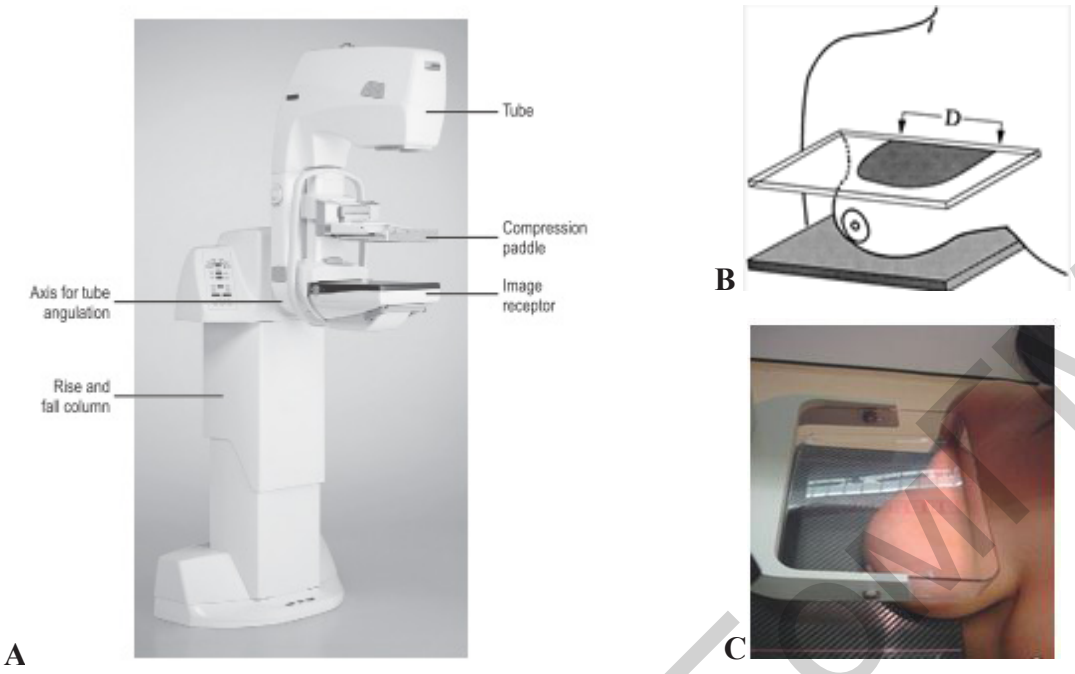


Figure 1.9 — (A) Mammography unit. (B,C) Compression device for craniocaudal image. Compression in pounds per square inch (psi). The actual pressure applied to the breast is the force applied (in pounds) divided by the area over which the force is spread, giving psi. If the breast is assumed to be a hemisphere, then psi equals half the area of a circle whose diameter (D) is that of the part of the breast touched by the compression paddle, divided into the number of pounds applied. This diagram depicts the surface in contact with the compression paddle and film holder. The larger the surface in contact, the lower the pressure in psi

Functional requirements

— High-voltage generator. The generator must supply a near DC high voltage with ripple less than 5 %.

— Kilovoltage (kVp) output. Most modern mammography machines have automatic selection for kVp in order to optimise contrast. The generator provides a constant potential and the high voltage applied to the tube must be from 22 to 35 kVp in increments of 1 kVp.

— Focal spot size. The focal spot should be as small as possible to ensure adequate resolution, for example 0.3 mm for general mammography and 0,1 mm (small focus) for magnification views.

The high-frequency generators offer more precise control of kilovolt (peak) (kVp), milliamperes (mA), and exposure time. The linearity and reproducibility of radiographic exposures using high-frequency generators are uniformly excellent. The greatest benefit of these generators may be the efficient waveform output that produces a higher effective energy x-ray beam per set kVp and mA.

Viewing images

It is recommended that craniocaudal (CC) images are viewed “back-to-back” with the posterior aspects of the breasts touching (Figure 1.9 B). Mediolateral

obliques are viewed with the pectoral aspects touching. These strategies facilitate vital comparison of similar areas of each breast for each projection.

Digital radiography

X-ray technologies were revolutionized by the advent of digital imaging. Digital radiography (computed radiography) replaces the screen/film system of conventional radiographic techniques by processing image data in a digital (computer) rather than analog form. The essential parts of a digital radiography system are the image plate and the image reader. Any conventional x-ray system can be used for the x-ray generation.

Digital images often look sharper and cleaner than the analog version. Many of the fluoroscopic x-ray procedures have benefited greatly from the addition of digital technology. Modern day fluoroscopy units have digital flat panel detectors which has resulted in significant improvements in sensitivity, temporal resolution, and contrast resolution (Figure 1.10). Spatial resolution of modern digital detectors is equivalent to their analog counterparts. Modalities modern digital radiography includes digitizing conventional film, computed radiography and direct radiography.

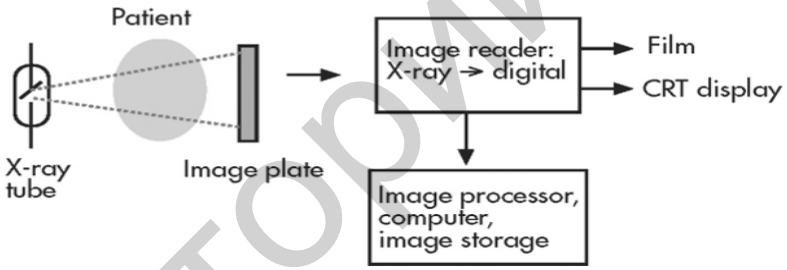


Figure 1.10 — Diagram of the digital radiography system

Advantages:

— Digital images do not deteriorate physically or degrade chemically over time.

— They allow a true reproduction of quality from copy to copy and from ge-neration to generation.

— Digital images are flexible, allowing a variety of manipulation such as magnification, cropping, edge enhancement, compression, etc.

— Digital detectors allow implementation of a fully digital picture archiving and communication system (PACS) in which images are stored digitally and available any time.

— The images can be distributed electronically by web-based technology with no risk of losing clarity.

— Increased dose efficiency and wide dynamic range of digital detectors with possible reduction of radiation exposure to the patient.

Using picture archiving and communication systems (PACS), images are acquired, stored, and retrieved electronically, making images available any time and anywhere. The advantages of this technology include high detection efficiency and rapid image display. These systems have an excellent image quality and allow a significant reduction in an effective dose compared with conventional film-screen based systems.

Digital subtraction angiography

Digital subtraction angiography (DSA) remains the gold standard in the examination of the cerebral vasculature for many abnormalities. However, the less invasive alternatives are now adequate for many situations, and so its use is now confined to specialist applications such as prior to endovascular or neurosurgical treatment. It is advantageous to use a biplanar C-arm mounted fluoroscopic system rather than a single-plane system, to enable a reduction in examination time and the amount of radiological contrast medium administered (Figure 1.11). Biplanar is preferred for diagnostic use, and is considered essential for interventional use. 3D rotational angiography is useful to depict intracranial aneurysms, providing the facility to rotate the resultant angiographic image to display the vessels under examination to their best advantage.

Figure 1.11 — Example of the digital C-arm mounted angiographic system

Imaging can be acquired on film radiographs (which are processed similarly to routine radiographs) or more commonly with digital subtraction angiography. In DSA, images are processed with the help of a computer. The initial image has no contrast and is called the mask. The X-ray images are then obtained in rapid sequence while contrast is injected. The computer then digitally “subtracts” the mask from the subsequent images leaving only the contrast, thereby yielding fine detail imaging of the vasculature (Figure 1.12).

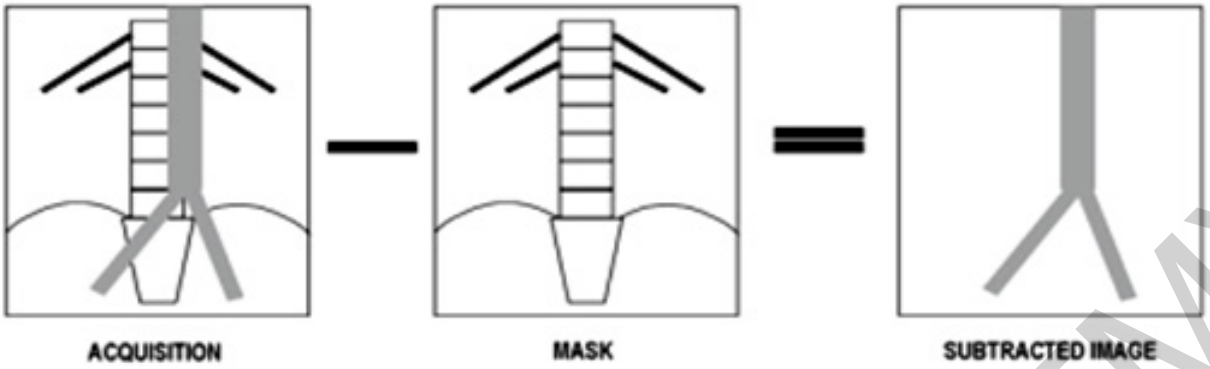
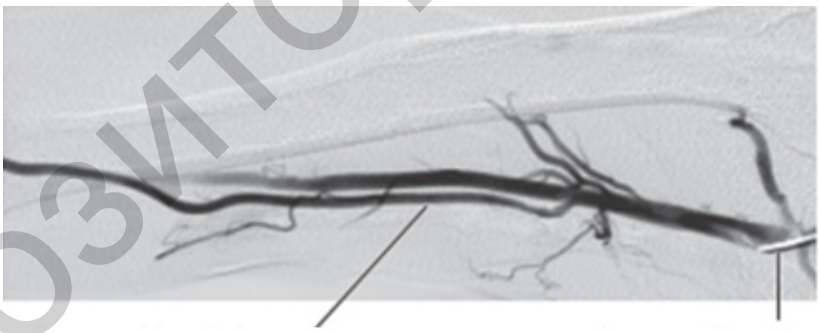


Figure 1.12 — Scheme of the digital subtraction angiography (DSA). DSA contrast is injected in the patient's aorta and images are acquired. Just before the contrast is injected, the computer acquired a mask, as seen in the center. As the contrast images are acquired, the computer subtracts the mask from the images leaving the only portion which has changed between the two, the intra-arterial contrast

Arteriograms are used to diagnose the changes in the vasculature associated with atherosclerosis, vasculitis, and injury, either iatrogenic or traumatic. The femoral artery is a commonly used entry point and is accessed at the level of the femoral head where its position is relatively superfi cial; therefore, hemostasis can be achieved with ease as the artery can be compressed against the femoral head once the procedure is completed. Different catheters are used to access the branch arteries requiring imaging. Once the catheter is in the appropriate vessel, iodinated contrast is injected at a controlled rate and volume via an injector.



High origin of the radial artery Catheter in axillary artery

Figure 1.13 — Digital subtraction positive arteriogram of region of the thigh

If an area of stenosis or narrowing is identified, it can be treated using ercutaneous transluminal angioplasty (PTA), with or without the use of a metallic stent. If blood flow cessation is required in an area of bleeding (e.g., after trauma) or as preoperative embolization, a catheter can be advanced to the vessel requiring embolization and different materials can be delivered into the artery to stop flow (Figure 1.13).

Cross-sectional imaging techniques

CT, MR, and US are the techniques that produce cross-sectional images of the body. All three interrogate a three-dimensional volume or slice of the patient`s tissue to produce a two-dimensional image. The resulting image is made up of a matrix of picture elements (pixels), each of which represents a volume element (voxel) of the patient`s tissue.

To produce an anatomic image, shades of gray are assigned to ranges of the pixel values. The middle gray shade is assigned to the pixel values centered on a selected window level. The pixels with values greater than the upper limit of the window width are displayed white, and the pixels with values less than the lower limit of the window width are displayed black. To analyze optimally all of the anatomic information of any particular slice, the image is viewed at different window-width and window-level settings, which are optimized for bone, air-filled lung, soft tissue, and so forth.

The digital images obtained by CT, MR, and US examination are ideal for storage and access. Among the features that can be used are interactive alterations in window width and window level, magnification, fusing of images from different modalities, reformatting serial images in different anatomic planes, creation of three-dimensional reconstructions, and marking key images that summarize major findings.

Computed tomography

Computer (assisted) tomography (CAT-scanning), X-ray computed tomography, also computed tomography (CT) or computed axial tomography (CAT) is the process where a computer can fabricate a model of the densities of an object or a person by rotating the source of x-rays around the object and looking at the shadows (Figure 1.14). CT-scanning, another name for tomography (from the Greek to meaning “to slice”), has improved the quality of results of X-ray examinations.

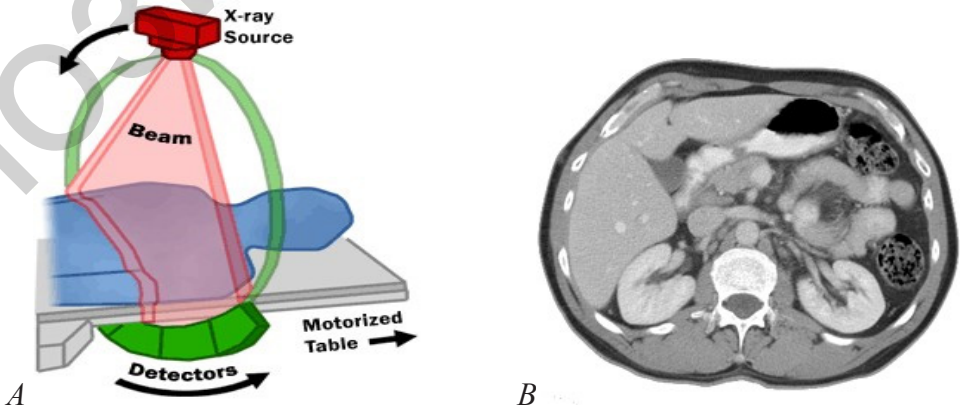


Figure 1.14 — (A) Diagrams of the standard computed tomography system. (B) Axial tomogram of abdomen displayed using “soft tissue windows” to evaluate the upper abdominal structures. Gas is black; bone and contrast medium of aorta and stomach are white; muscle and hepar are light grey; and fat is dark grey

Principle: computed tomography uses x-rays, but the x-ray tube rotates around the patient as the table moves, creating a vast number of images. The principle behind the computed tomography image is differential absorption of x-rays by various tissues. The only difference is that the images are produced by a computer rather than directly on a film. The x-rays are processed by a computer to form axial, coronal, or sagittal images. These may be adjusted by the radiologist to show a detail of the soft tissue; bone; or, in the thorax. Modern scanners allow this volume of the data to be reformatted in various planes or even as volumetric 3D representations of structures.

Once an image is produced, however, further processing is possible to optimize desired image characteristics, such as the contrast between soft tissue structures. This accounts for the difference between the so-called soft tissue windows, bone windows, and lung windows on a chest CT examination. Through postimaging processing, it is also possible to "reconstruct" the data acquired in one plane (in CT, generally the axial plane, Figure 1.15) in other planes (e.g., the coronal or sagittal planes).

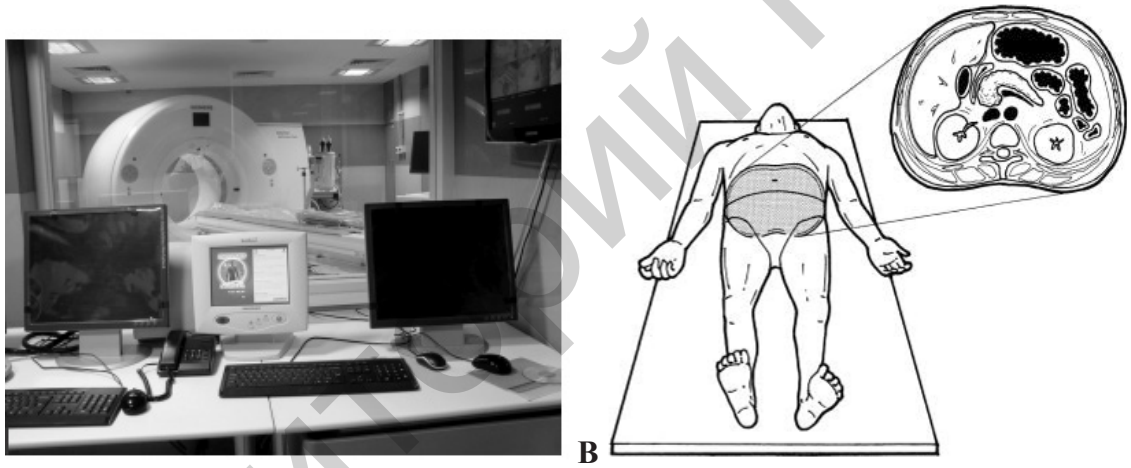


Figure 1.15 — (A) Photograph of the variant CT unit (in two rooms). (B) Orientation of computed tomography axial image

Computed tomography utilizes rapidly spinning arrays of x-ray sources and detectors and sophisticated computer processing to increase the sensitivity of findings visible to display them in any geometric plane. CT scanners have become the foundation of cross-sectional imaging. They are moderately expensive and also use ionizing radiation to produce their images.

CT has the ability to detect minute differences in the densities of tissues and portray them in varying shades of gray. These CT densities are measured in Hounsfield units, after Godfrey Hounsfield, the father of CT. Distilled water at a standard pressure is given a value of 0 and air is given a value of –1,000. Bone densities are very high, up to +1,000; soft tissue values falling in between. One of the major benefits of CT scanning over conventional radiography is its ability to expand the gray scale,

which enables differentiation of many more than the five basic densities available on conventional radiographs.

Once the digital information has been acquired, the software equipping these tools gives the radiologist the option of navigating from one organ to another, and of isolating a particular element in order to be able to focus on the element of interest. Then, the entire data, including the images, can be sent to a colleague for confirmation or additional expertise with a simple click of the mouse.

CT and MR usually present images as transverse (axial) slices of the body. If, as you stand and look at the patient from the foot of the bed, you think of these images as slices lifted out of the body, you will have the orientation correct.

Advantages:

— CT produces images that are far more detailed than a chest x-ray.

— CT is especially useful because it can simultaneously show many different types of tissue, including the lungs, heart, bones, soft tissues.

— Because of the inherent high-contrast resolution of CT, differences bet-ween tissues that differ in physical density by less than 1 % can be distinguished.

— High sensitivity and specificity in particular for assessment of the lungs, mediastinum, bones, abdomen/pelvis structures, the brain.

— Data from a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task. This is referred to as multiplanar reformatted imaging.

— Provides 2D cross-sectional images of the body, which are rapidly acquired with the potential to reformat in multiple planes; 3D reformatting is also possible.

Disadvantages:

— CT scanners are expensive.

— Moderate to high dose of radiation. Compared with plain x-rays, CT uses about 10 to 100 times more radiation.

— May require intravenous (IV) iodinated contrast use – risk of contrast reaction (allergy, anaphylaxis) and nephrotoxicity in those at risk.

Example indications:

— Head — trauma, brain imaging (ischaemic/haemorrhagic strokes, calcifications, haemorrhage, malignancy).

— Chest — detailed imaging of the lungs to detect abnormalities not seen on CXR, used in diagnosis and surveillance of malignancy, pulmonary embolism, emphysema, fibrosis.

— Abdomen and pelvis — diagnosis, staging, and surveillance of malignancies, bowel obstruction, pancreatitis, renal calculi (CT kidneys ureters and bladder (CT KUB) and CT IV urogram (CT IVU).

— CT angiography and venography — for example, suspected limb or mesenteric vascular occlusion, sagittal sinus thrombosis.

— Orthopaedic — complex fractures.

— CT-guided biopsy, surgery, and radiosurgery.

Diagnostic ultrasound

Ultrasonography is generally considered to be **a very safe imaging modality** that has no known major side effects when used at medically diagnostic levels. In ultrasonography (US, sonography), a probe is applied to the patient's skin, and a high frequency (1 to 20 MHz) beam of sound waves is focused on the area of interest (Figure 1.16). The sound waves propagate through different tissues at different velocities, with denser tissues allowing the sound waves to move faster. A detector measures the time it takes for the wave to reflect and return to the probe. Ultrasounds are waves that are imperceptible to the human ear, but which retain such properties as reverberation (echo) or matter absorption (attenuation). By taking advantage of these two characteristics and the properties of tissue subject to ultrasound, it has been possible to develop a tool capable of measuring and analysing the nature of its reflection according to the tissue through which it has travelled and off which it has bounced. Measurement of the time required for the wave to be detected also permits the distance travelled to be calculated.

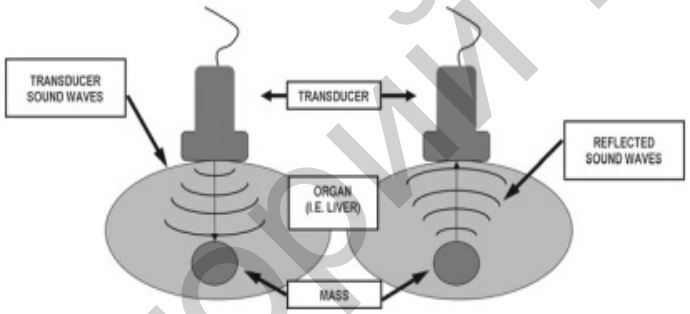


Figure 1.16 — Principle of ultrasound. The transducer sends a short burst of high frequency sound into the tissue. Some part of the sound is reflected back by the tissues and the reflected signal is "read" by the transducer and an image is created

Principle:

— The use of high-frequency sound waves to produce real-time images, provides a simple and painless way to examine structures.

— A transducer sends out sound waves, which reflect off body structures.

— A computer receives these reflected waves and uses to create a picture.

How it is done:

— A clear, water-based conducting gel is applied to the skin over the area being examined to help with the transmission of the sound waves.

— A hand held transducer is then moved over the area being examined.

— Transducer sends high frequency sound waves into the body.

— The waves are reflected back by various tissues they go through.

— The reflected waves, with a help of a computer, form an image on the screen.

— Color coding of the various reflected echoes gives color images.

Example indications:

— Pregnancy evaluation.

— Echocardiography.

Tissue density is determined by the reflection time and an image is produced on the screen for the ultrasongrapher to see in real time (Figure 1.17).

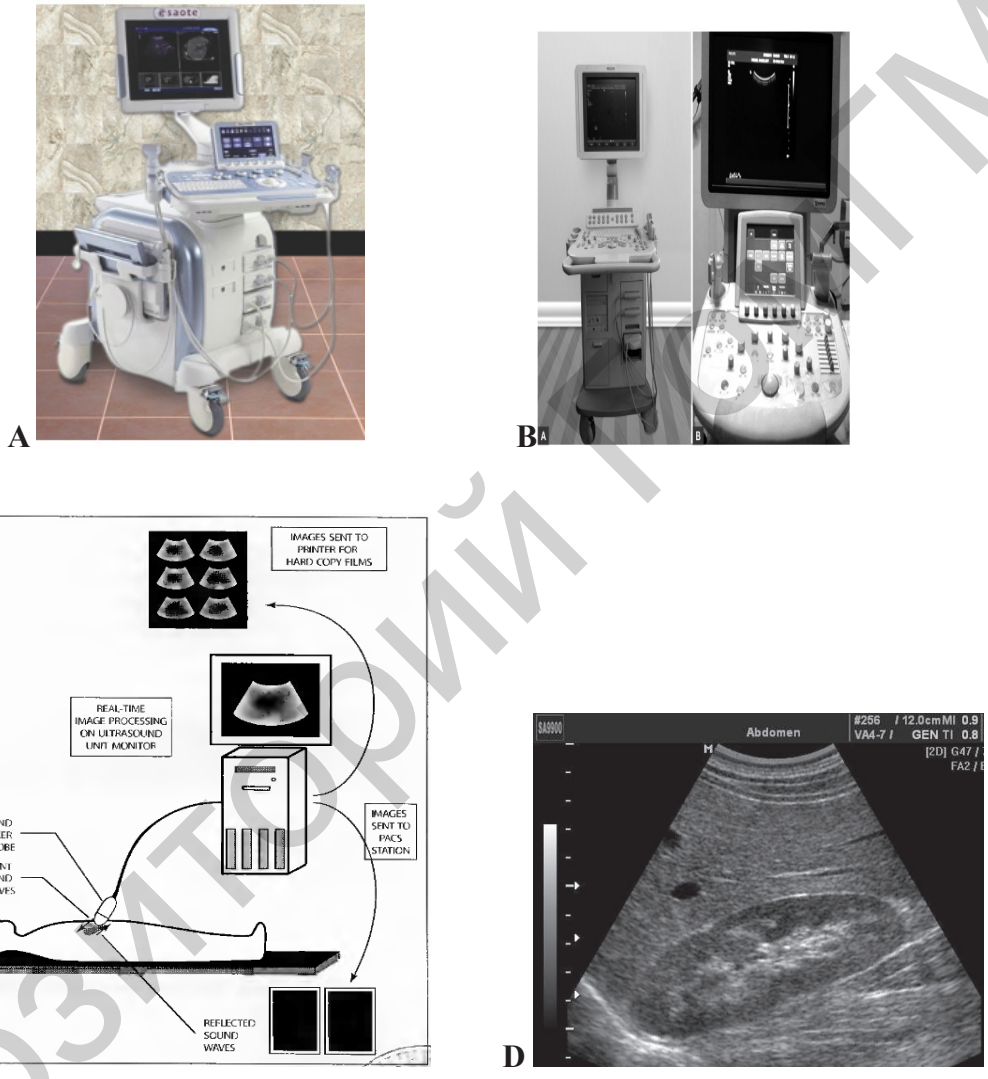


Figure 1.17 — (A and B) Modern ultrasound scanning unit with LCD screens. (C) Diagram of the standard ultrasound system. (D) Normal sonogram of hepar and right kidney in longitudinal view (B-mode, parasaggital plane)

Normal soft tissue appears as medium echogenicity. Fat is usually more echogenic than the soft tissue. Simple fluid, such as bile, has low echogenicity, appears dark, and often has “through-transmission” or brightness beyond it. Complex fluid, such as blood or pus, may have strands or separations within it, and generally has lower through-transmission than simple fluid. Calcification usually appears as high echogenicity with posterior “shadowing”, or a “dark band” beyond it. Air does not

transmit sound waves well and does not permit imaging beyond it, as the sound waves do not reflect back to the transducer. Therefore, bowel gas and lung tissue are a hindrance to ultrasound imaging. Ultrasonography produces images using the acoustic properties of the tissue and does not employ ionizing radiation. It is thus safe for use in children and in women of childbearing age and during pregnancy. It is particularly useful in analyzing soft tissues and blood flow. Ultrasonography units are less expensive, are in widespread use, and have been produced as small as hand-held devices.

Ultrasonography is widely used in medical imaging. It is usually the study of the first choice in imaging the female pelvis and in pediatric patients, in imaging of the fetus and placenta during pregnancy, in differentiating cystic versus solid lesions in patients of all ages, in noninvasive vascular and in real-time, image-guided fluid aspiration and biopsy.

Advantages:

— Real-time assessment and interpretation of results.

— Non-invasive test (some US is performed using endocavity probes, e.g. transrectal, transvaginal, transoesophageal).

— Requires no preparation.

— No pain.

— Useful for imaging the soft tissue and muscles, extremities, testes, breast, and eye, plus abdomen, pelvis, chest, and vascular colour Doppler applications.

— Provides accurate anatomic information, including dimensions.

— No radiation risk.

— Avoiding the potential allergic and toxic complications of contrast media.

— Can be used on individuals with poor kidney function in whom contrast cannot be given.

— No complications.

— Can be done at bedside.

— Relatively economical exam.

Limitation:

— Operator dependant.

— Gas as in GI tract and lungs prevent the sound waves from passing through; therefore not useful in portions of abdomen and lungs.

Disadvantages:

— Images are degraded by gas and fat, and this restricts US use in the abdomen/pelvis in some patients.

Example indications:

— Abdomen — trauma, malignancy, abdominal aortic aneurysm surveillance, gallstones, suspected hydronephrosis.

— Chest – assessment of pleural spaces.

— Musculoskeletal — assessment of muscles, ligaments, and tendons.

— Scrotal — assessment of testicles, epididymis, and scrotum.

— Obstetrics – growth scans, placental sighting, anomaly scans.

— Gynaecology — transabdominal and transvaginal imaging of ovaries, uterus, and Fallopian tubes.

— Baby hips.

— Breast, eye assessment.

— Vascular applications — suspected upper/lower limb deep vein thrombosis, carotid/peripheral vascular assessment.

The ultrasound transducer

A transducer (probe, array) is any device that converts one form of energy to another (Figure 1.18). In ultrasound the transducer converts electric energy to mechanical energy, and vice versa. In diagnostic ultrasound systems the transducer serves two functions: (1) converting the electric energy provided by the transmitter to the acoustic pulses directed into the patient and (2) serving as the receiver of reflected echoes, converting weak pressure changes into electric signals for processing.

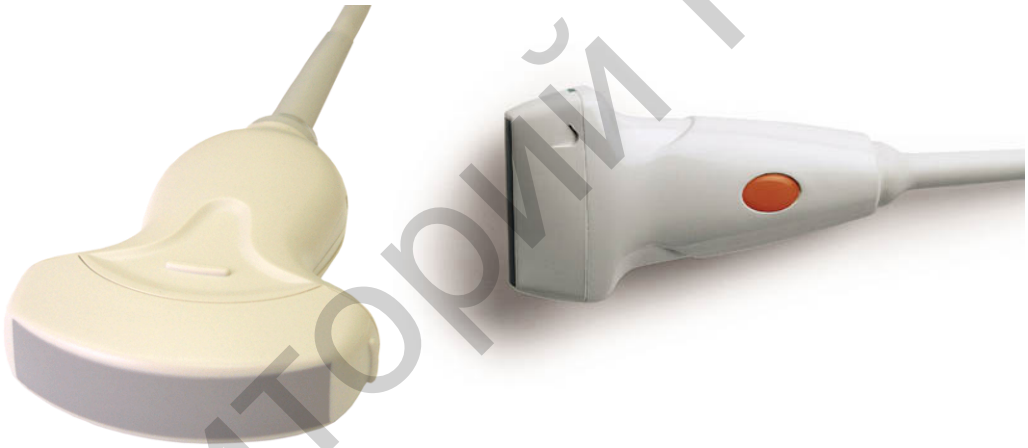


Figure 1.18 — Photo of variants of the ultrasound transducers

Ultrasound transducers use piezoelectricity, a principle discovered by Pierre and Jacques Curie in 1880. Piezoelectric materials have the unique ability to respond to the action of an electric field by changing shape. They also have the property of generating electric potentials when compressed. Changing the polarity of a voltage applied to the transducer changes the thickness of the transducer, which expands and contracts as the polarity changes. This results in the generation of mechanical pressure waves that can be transmitted into the body.

The source of ultrasound for diagnostic imaging is the piezoelectric ultrasound transducer. The key component of this assembly is a disc of a special ceramic material made up of orderly aligned molecules that have the property of being electrical dipoles. A thin layer of electrically conducting metal has been plated onto both sides of the disc, so that an electrical field (in the order of 150 volts) can be set up across the disc, which is often termed the “crystal”.

In response to an electrical field the molecular dipoles realign, and the disc consequently changes its thickness. When a high-frequency alternating voltage is applied, the disc oscillates and these oscillations become particularly forceful and uniform at a particular frequency, the resonance frequency. When the voltage is turned off, the crystal continues to oscillate at its resonance frequency, which is determined by the thickness of the disc. The "backing material" in the transducer assembly quickly damps this "after ringing". It is essential that the ultrasound impulse lengths are extremely short (in the order of 1μsec), because the axial ("depth") resolution decreases for increasing spatial pulse length.

The transducer is covered by a thin "matching layer" of a material with an acoustic impedance in between that of the ceramic disc and that of the skin. When the transducer is held against the skin the acoustic impedance is further improved by a watery gel spread in advance over the skin.

The piezoelectric transducer functions also in the reverse direction as receiver of ultrasound echoes. The receiving period is much longer (some hundred μsec) than the transmission period to give time for capture of echoes stemming from deeply located structures. When the receiving ("listening") transducer is hit by incoming ultrasound waves the disc becomes slightly deformed and electrical potentials in the order of 2 μvolts are set up across the disc. These electrical signals are the ones used to construct the image.

Transducer designs

Transducers are characterized by their frequency, size (effective aperture in the case of arrays), and degree of focusing. Typically, the range of frequency for diagnostic ultrasound imaging is 1 to 15 MHz. The degree of focusing is either short (1 to 4 cm), medium (4 to 8 cm), or long (6 to 12 cm). Focusing is achieved internally by the crystal shape, externally by an acoustic lens, electronically by selective pulsing of individual elements of an array, or by a combination of these three methods. The length of the zone available for focusing (Fresnel zone) is governed by the effective transducer aperture and its operating frequency. Ultrasound gel acoustically couples the ultrasound transducer to the body, where the ultrasound waves can then spread.

Such transducer arrays may be formed in a variety of configurations. Typically, these are linear, curved, phased, or annular arrays (Figure 1.19). For example, a linear array optimised for superficial work will tend to have a narrower width in the elevation plane for more precise beam control in the near field. A linear array suitable for investigation of deep vein thrombosis will have to have good performance from 1,5 to 5 cm depth; the width of the elements in the elevation plane is greater allowing better control of focusing here through a larger aperture but with reduced precision in the near field. Much depends on the standard of investigation required, but for optimum performance, a range of transducers is required.

Current technology uses a transducer composed of multiple elements, usually produced by precise slicing of a piece of piezoelectric material into numerous small units, each with its own electrodes.

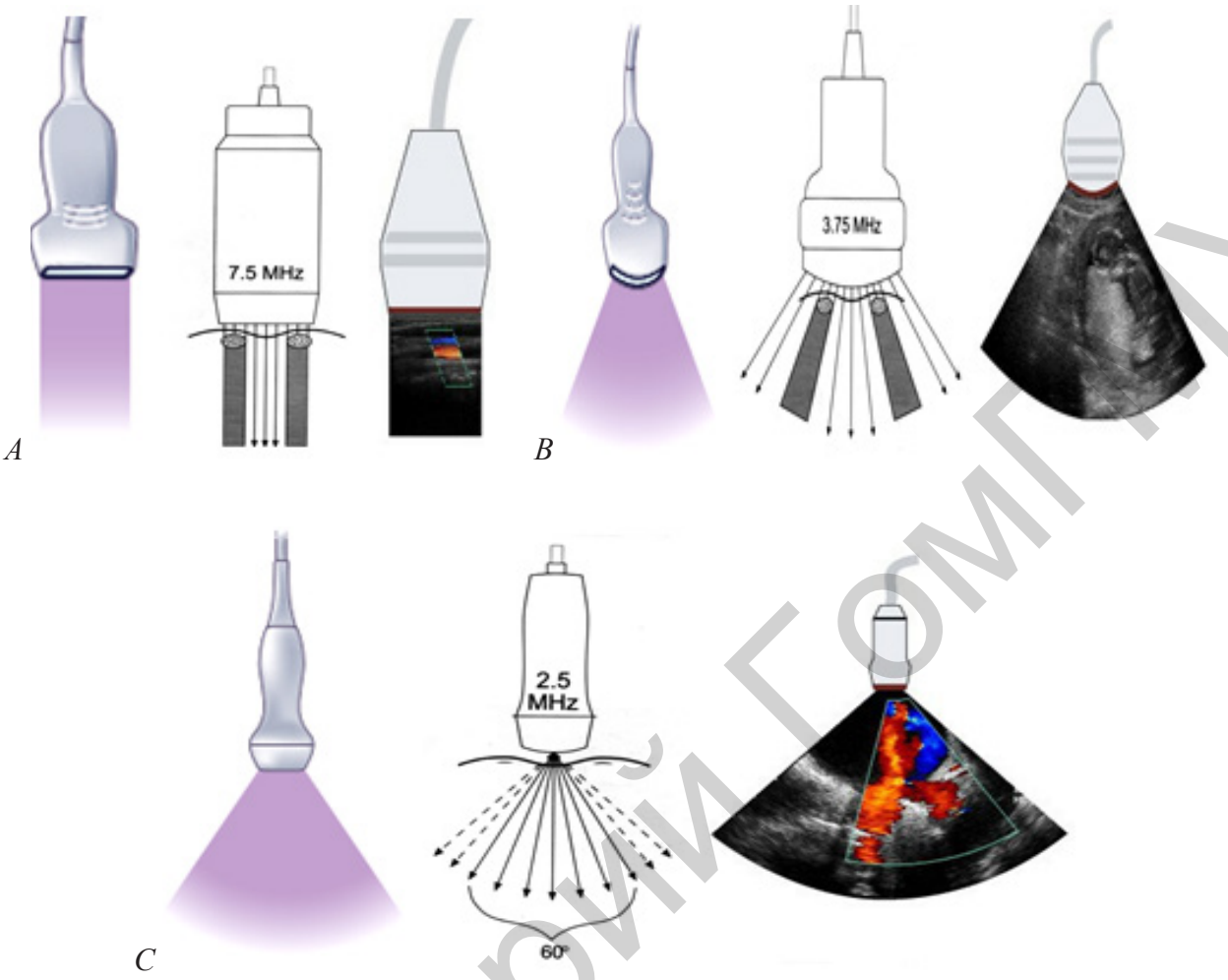


Figure 1.19 — Common types of array transducer shape and image format. (A) Linear array. (B) Curved linear array. (C) Sector phased array

Cranial scanning can generally be performed using a curved array but sometimes, when the fontanelle is small and access limited, the preference is for a small footprint vector transducer to enable better intracranial views through the anterior fontanelle. For ocular scanning a small footprint, high frequency probe is required.

The commonest ultrasound examination is the abdominal scan, so once again a good range of transducers is needed. Curved arrays are undoubtedly best and should be in a frequency range suitable for newborns to adolescents, i.e. 7,5 to 3,5 MHz. A minimum of two probes is required.

When choosing a transducer, the main considerations are:

— Transducer type, e.g. curvilinear/phased/linear array, endocavity.

— The frequency range.

— The size of the array: for example small linear array for paediatric and perioperative work additional features, for example matrix arrays for dynamic focusing in the slice thickness/elevation plane (Figure 1.20).

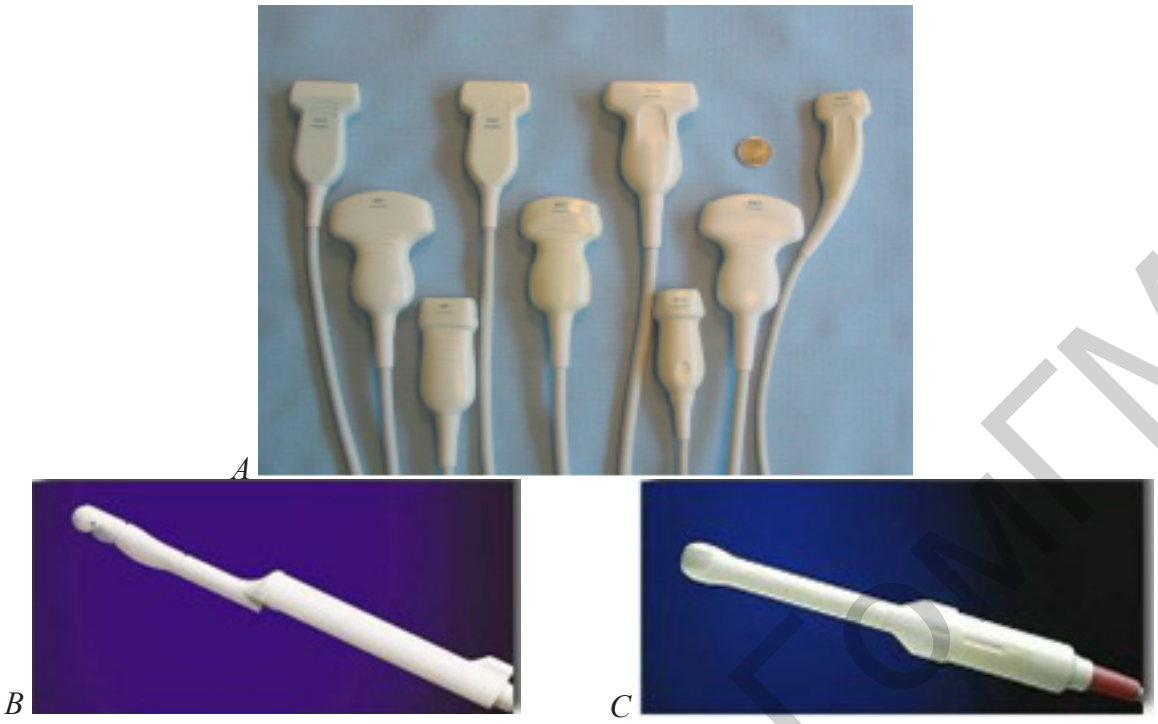


Figure 1.20 — Photos of transducers commonest ultrasound examination. (A) There are a wide range of transducers available for most scanners. Transducers used for vascular imaging: in the top row are a range of linear arrays with different frequency ranges and apertures for a range of paediatric and adult peripheral vascular applications. The middle row has three different curvilinear arrays with frequency ranges from 1 to 8 MHz. The two phased arrays have different transducer face formats, one for deep abdominal vascular applications and the other for transcranial Doppler imaging. There is some overlap between transducers but by having a range of transducers, optimal imaging can be achieved for the full range of applications. (B – C) An array of transducer sizes and frequencies may be used in a general ultrasound department. Advanced, biplane endocavitary, transrectal probe from 4,0 to 8,0 MHz. Transducer design ranges from very small to the larger curved array probes. Transducer designs in multiple shapes and sizes are used for specific US examinations

Three-dimensional ultrasound

Dedicated 3-D scanners used for fetal, gynecologic, and cardiac scanning may employ hardware-based image registration, high-density 2-D arrays, or software registration of scan planes as a tissue volume is acquired. 3-D imaging permits volume data to be viewed in multiple imaging planes and allows accurate measurement of lesion volume.

Doppler sonography

Conventional B-mode ultrasound imaging uses pulse-echo transmission, detection, and display techniques. Brief pulses of ultrasound energy emitted by the transducer are reflected from acoustic interfaces within the body. Precise timing allows determination of the depth from which the echo originates. When pulsed

wave ultrasound is reflected from an interface, the backscattered (reflected) signal contains amplitude, phase, and frequency information.

This information permits inference of the position, nature, and motion of the interface reflecting the pulse. B-mode ultrasound imaging uses only the amplitude information in the backscattered signal to generate the image, with differences in the strength of reflectors displayed in the image in varying shades of gray. Rapidly moving targets, such as red cells in the bloodstream, produce echoes of low amplitude that are not usually displayed, resulting in a relatively anechoic pattern within the lumens of large vessels.

Doppler effect

The Doppler effect is the apparent change in frequency of sound or light waves emitted by a source as it moves away from or toward an observer (Figure 1.21). Sound that reflects off a moving object undergoes a change in frequency. Objects moving toward the transducer reflect sound at a higher frequency than that of the incident pulse, and objects moving away reflect sound at a lower frequency. The difference between the transmitted and the received frequency is called the Doppler frequency shift.

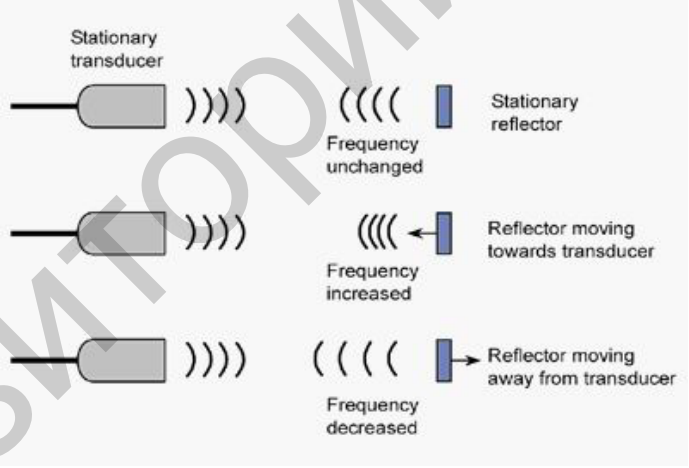


Figure 1. 21 — The Doppler effect refers to a change in frequency of a sound wave when the source or the listener is moving relative to the other

If the red blood cell (RBC) moves along the line of the ultrasound beam (parallel to flow), the Doppler shift is directly proportional to the velocity of the RBC. If the RBC moves away from the transducer in the plane of the beam, the fall in frequency is directly proportional to the velocity and direction of RBC movement (Figure 1.22–1.23).

The frequency of the echo will be higher than the transmitted frequency if the reflector is moving toward the transducer, and lower if the reflector is moving away.

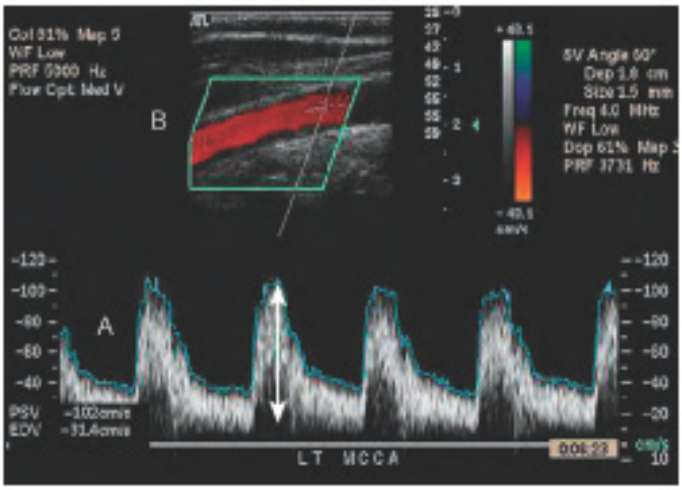


Figure 1.22 — Doppler display.
(A) Doppler frequency spectrum waveform shows changes in flow velocity and direction by vertical deflections of the waveform above and below the base-line. The width of the spectral waveform (spectral broadening) is determined by the range of frequencies present at any instant in time (arrow). A brightness (gray) scale is used to indicate the amplitude of each frequency component.
(B) Color Doppler imaging. Amplitude data from stationary targets provide the basis for the B-mode image. Signal phase provides information about the presence and direction of motion, and changes in frequency relate to the velocity of the target. Backscattered signals from red blood cells are displayed in color as a function of their motion toward or away from the transducer, and the degree of the saturation of the color is used to indicate the frequency shift from moving red cells

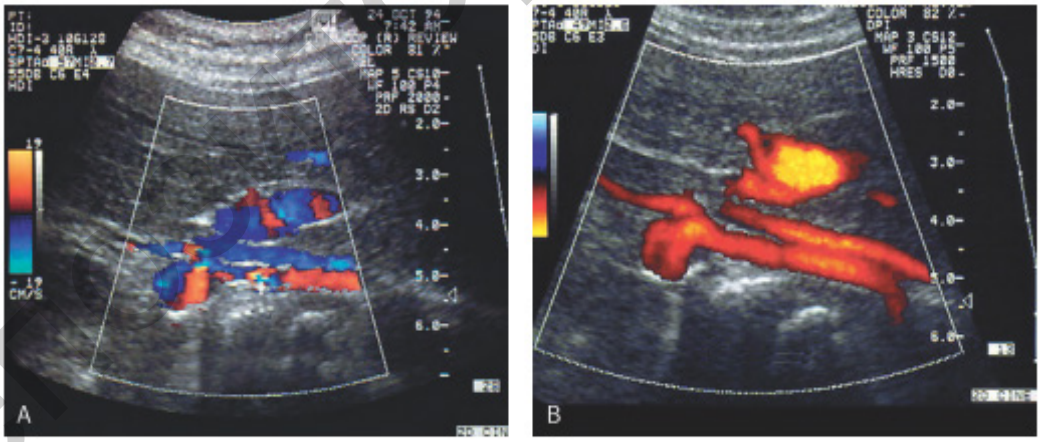


Figure 1.23 — Color flow and power mode Doppler.
A, Color flow Doppler imaging uses a color map to display information based on the detection of frequency shifts from moving targets. Noise in this form of display appears across the entire frequency spectrum and limits sensitivity.
B, Power mode Doppler uses a color map to show the distribution of the power or amplitude of the Doppler signal. Flow direction and velocity information are not provided in power mode Doppler display, but noise is reduced, allowing higher gain settings and improved sensitivity for flow detection

Modes of sonography

Several different modes of diagnostic ultrasound are used in medical imaging. The main ones are:

— **A-mode**: A-mode (amplitude mode) is the simplest type of ultrasound. A single transducer scans a line through the body with the echoes plotted on the screen as a function of depth. Therapeutic ultrasound aimed at a specific tumor or calculus is also A-mode, to allow for pinpoint accurate focus of the destructive wave energy. A-scan is a one-dimensional technique. The echoes received are displayed on a screen as vertical reflections. This technique is rarely used today except for measurements.

— **B-mode**: More often. In B-mode (brightness mode) ultrasound, a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on the screen. B-scan is a technique in which the echo amplitude is depicted as dots of different brightness (gray scale). It is mostly used as a two-dimensional B-scan to form a two-dimensional ultrasound image by multiple ultrasound beams, arranged successively in one plane. The images are built up by mechanically or electronically regulated scanning in a fraction of a second.

— **M-mode**: In M-mode (motion mode, also sometimes referred to as TM-scan) ultrasound, pulses are emitted in quick succession – each time, either an A-mode or B-mode image is taken. Over time, this is analogous to recording a video in ultrasound. As the organ boundaries that produce reflections move relative to the probe, this can be used to determine the velocity of the specific organ structures. M-scan is a way to display motion, e.g. of parts of the heart. The echoes produced by a stationary ultrasound beam are recorded over time, continuously.

— **Doppler modes**. This mode makes use of the Doppler effect in measu-ring and visualizing a blood flow, moving tissues. Doppler techniques use the Doppler effect as a further source of information: if the ultrasound waves are reflected by an interface moving towards the transducer or away from it, the reflected frequency will be higher or lower respectively than the transmitted frequency. The difference between the emitted and received frequencies is proportional to the speed of the moving reflector. This phenomenon is called the Doppler effect, and the difference is called the Doppler frequency or Doppler shift. The Doppler shift depends on the ultrasonic frequency, the velocity of the reflector, and the angle between the ultrasound beam and the blood stream.

• **Continuous Doppler**: Doppler information is sampled along a line through the body, and all velocities detected at each time point are presented (on a time line). There is no information about the distance of the reflector(s), but only about the velocity, at which the reflector (the blood stream) moves.

• **Pulsed wave (PW) Doppler**: Doppler information is sampled from just a small sample volume (defined in 2D image), and presented on a timeline (Figure 1.15). In this way, the movement of the reflectors in a particular distance (gate, selected by the operator) can be displayed and analyzed (spectral Doppler), or displayed in the B-scan image (duplex techniques).

• **Color-Doppler** and power-Doppler techniques are used as duplex techniques integrated in the B-scan image. The echoes arising from stationary reflectors (tissue) are displayed as bright spots (gray-scale technique).The echoes from moving reflectors are analyzed by the Doppler technique separately, but displayed in the same image "color-coded". The different colors indicate the direction of the blood flow (color-Doppler, CD). It has become common practice to represent flow towards the transducer as red and flow away as blue.

• **Power Doppler** technique (synonyms: color Doppler energy or, not as suitable, "ultrasound angiography") is based on the total integrated power of the Doppler signal. This Doppler technique is more sensitive for the detection of small vessels (that are too small to be resolved in the 2D image and that otherwise could not be studied) and slow flow to be angle-independent, but it does not give information about the direction of the flow.

• **Duplex**: a common name for the simultaneous presentation of 2D and (usually) PW Doppler information. Using modern ultrasound machines color Doppler is almost always used as well hence, the alternative name **Triplex**. This Doppler shift falls in the audible range and is often presented audibly using stereo speakers: this produces a very distinctive, although synthetic, pulsating sound. Spectral content presents in Figures 1.24–1.25.

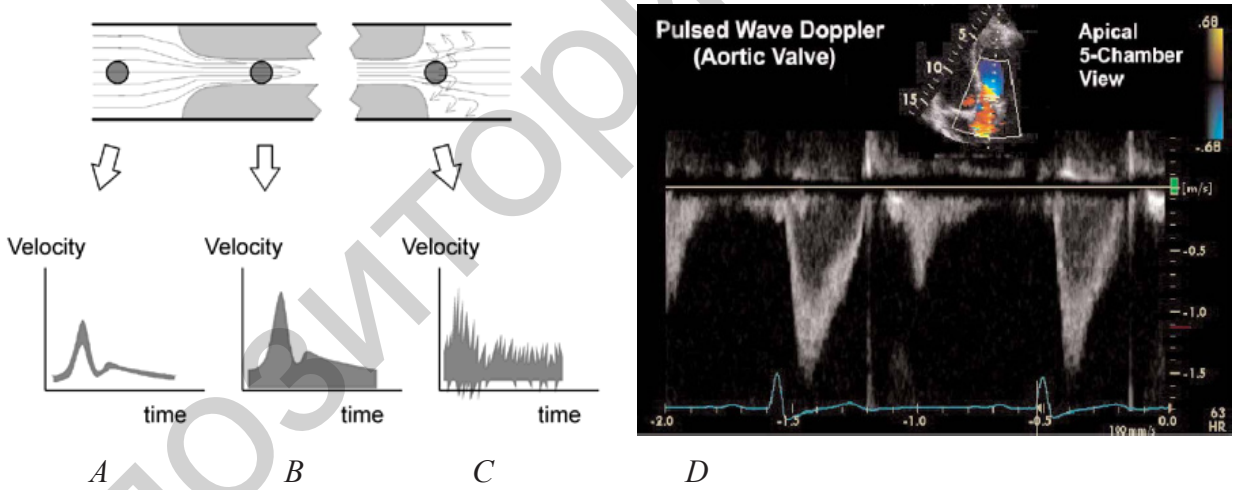


Figure 1.24 — (A to D) Images of different flow profiles. Spectral tracing shows (A-C) variants stenotic of an arterial blood flow on the diagrams (black circle is control volume, point registration of velocity) and (D) of the aortic valve normal blood flow (triplex US complex image, B-color sector sonogram of heart at top)

The distribution of the shades of grey in each time slot indicates the range of flow velocities present in the vessel at that time. If there is a plug flow, this distribution is very narrow, whereas parabolic flow gives rise to a wider range of frequencies. The spectral broadening is produced by a stenosing lesion.

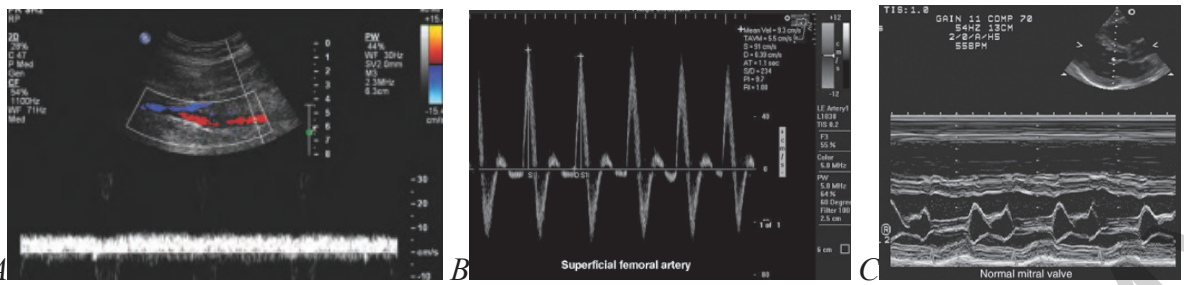


Figure 1.25 — (A) Spectral distribution in a venous flow, triplex image, B-color Doppler sector sonogram of thigh at the top image. Normal venous Doppler waveforms. Spectral Doppler analysis from the femoral vein demonstrates normal venous spectral signal. The slower flow in this vein gives rise to a wide range of velocities during each time interval. (B) Spectral distribution in a plug flow. Pulsed Doppler display for a femoral artery with calculations displayed. A very narrow band of velocities is present throughout the cardiac cycle in this artery. In this case peak systolic and end diastolic velocities are displayed on the real-time image. (C) Duplex US of heart images complex. The insert of B-mode scan (above right of the sector image) of heart shows the orientation of the M-mode image of moved structures normal mitral valve

Finally, with the use of Doppler imaging in US, which detects flow velocity and direction, one can image blood vessels so the technique has become well-known in monitoring pregnancy, but it was also developed in other fields ranging from cardiology to oncology, as the aorta for suspected aneurysm, and the deep leg veins or portal vein for thrombosis.

Common uses of ultrasound include evaluating the gall bladder for suspected cholecystitis, the pancreas for pancreatitis, and the right lower quadrant of the abdomen in suspected appendicitis. Other indications include evaluation of the liver, pancreas or kidneys for masses or evidence of obstruction. Ultrasound is also very helpful in the evaluation of pelvic pain in women and in suspected ectopic pregnancy, ovarian torsion, or pelvic masses. This technique is useful in cardiology, and of course, in obstetrics and endocrinology.

Contrast agents were originally developed and used to obtain a stronger signal from a blood flow. The so-called microbubbles, more or less stabilized encapsulated gas bubbles, somewhat smaller than erythrocytes, are used for this purpose. The use of these contrast agents considerably improves the visibility of small vessels with a slow flow. However, the real advantage is the possibility to get a more detailed information about the static and especially the dynamic vascularity of tissues and tumors. Special software programs and efficient equipment are necessary to use this interesting technique, including, for example, contrast harmonic imaging. With this technique the nonlinear interaction of the microbubbles with ultrasound power is used, to improve the Doppler signals. This new technology improves the quality of

ultrasound in a way similar to that seen with the tissue harmonic imaging technique used for the B-mode.

An image definition has been very clearly improved, and color, as well as animated sequences, have made their appearance. Several contrast agents, composed of air micro-bubbles trapped in biodegradable substances, have been developed. As ultrasounds are completely reflected by air, these products allow images to be taken of cavities in the same way that contrast agents are used in radiology. The resolution of traditional devices seems low, but the information obtained is sufficient for most analysis, avoiding investment in a more powerful device. The latest, top-of-the-range tools offer a resolution lower than a tenth of a millimeter and are used more particularly in the eye and the skin analysis.

Displaying the image, understanding the composition of the image

Images from the sonographic scanner can be displayed, captured, and broadcast through a computer using a frame grabber to capture and digitize the analog video signal. The captured signal can then be post-processed on the computer itself (Figure 1.26).

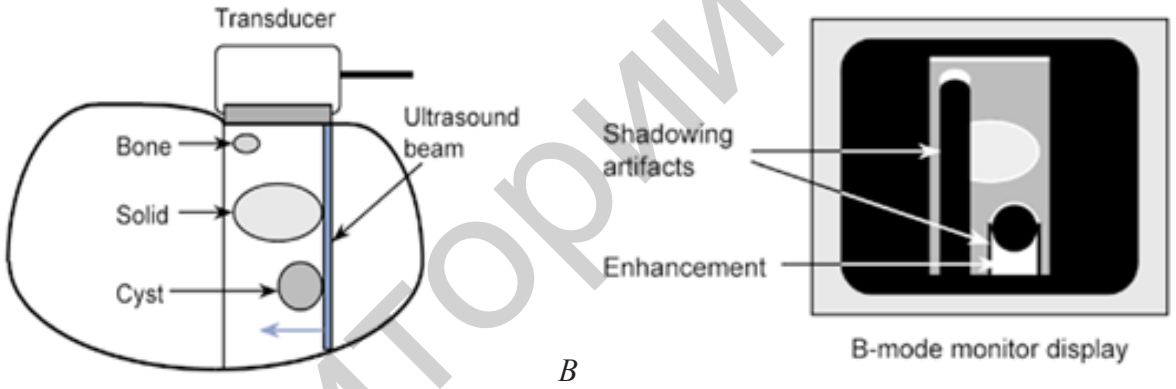


Figure 1.26 — (A to B) Schematic diagrams of displaying the US image. Typically, a cyst has not few any echoes, because it is mostly water. Tissues such as liver and spleen gives a picture with rather homogeneous small echoes due to the fibrous interstitial tissue. High-intensity echoes are caused by calcification, bone, and air

An anechoic structure yields (any liquid) a black image, since no echo is generated. Inversely, an echoic structure generates echoes, and will give a gray image. It can be more (closer to white) or less (closer to black) echoic.

An image defined as hypoechoic, isoechoic or hyperechoic. The approach from the anatomical structure means:

— A solid tissue mass is echoic: parenchyma, muscle, thrombosis, alveolar consolidation, or tumor (Figures 1.26–1.27).

— A pure fluid mass is anechoic (with acoustic enhancement: circulating blood, vesicular bile, urine, pure fluid collections).

— A pathological fluid mass can be rich in echoes: abscess, hematoma, thick bile, necrosis, etc. If the collection contains tissue debris or bacterial gas, it can be highly heterogeneous.

— A gas structure is hyperechoic with posterior echoes of reverberation: air or microbial gas.

— Deep fat is hyperechoic such as mesenteric fat.

— An ossified structure is hyperechoic with posterior shadow: bone or calculus.

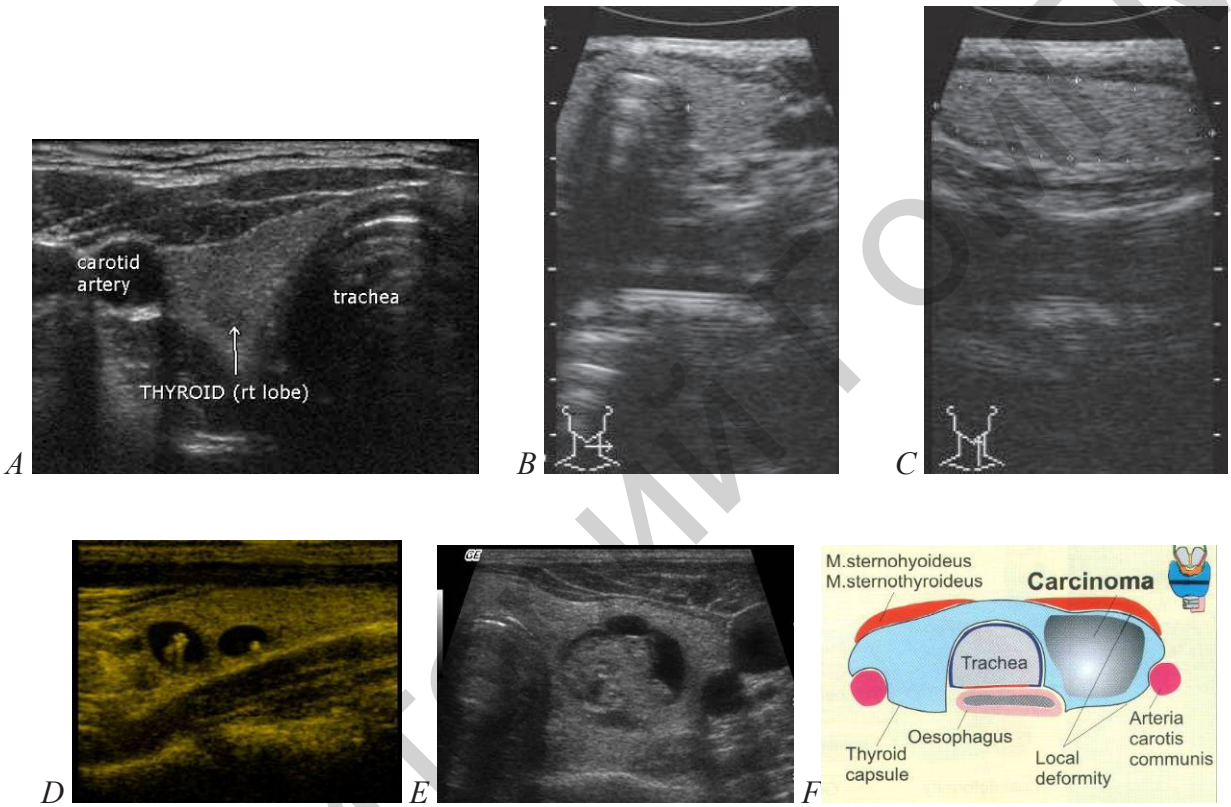


Figure 1.27 — (A, B) Transverse anterior cervical sonoscan at the thyroid isthmus. The posterior shadow of the trachea are recognized. Since an air barrier is visible immediately pos-terior to the anterior wall of the trachea, it can be possible to conclude that the anterior wall, at this level, is thin. (C) Longitudinal paramedian sonogram of the neck. Note a marker of the right lobe thyroid gland and a marker of the position probe (bottom). (D) Sonogram of the thyroid cysts into the parenchyma lobe. (E) Transverse cervical sonogram at cancer of the left lobe thyroid gland and (F) diagram. All of the sonograms is result B-mode diagnostic ultrasonography

A patient who has just been subject to an ultrasound examination is, of course, not radioactive. But as with X-rays, ultrasounds can be used as a diagnosis procedure limited to anatomical imaging.

Magnetic resonance imaging

Magnetic resonance imaging does not use X-rays (or any other type of "ionizing" radiation). Instead, it is a technique that combines a large magnetic field and some radio frequency antennas ("coils"). The pictures look like "sections" or "cuts" — just like in CT. Except in the MR, the resulting image primarily reflects the water protons in the patient, as well as their chemical association with proteins, etc.

Principle MRI:

First, the magnetic field causes the protons in the atoms of water within the patient to all "line-up".

Then, a high-frequency electro-magnetic pulse knocks many of the protons out of alignment. Next, a very sensitive radio antenna "listens" for the "resonance" signal that each proton gives off, as it goes back into alignment. These minute resonance signals occur in a pattern that a computer uses to create diagnostic information MRI. By using gradients in different directions 2D images or 3D volumes can be obtained in any arbitrary orientation (Figures 1.28–1.29).

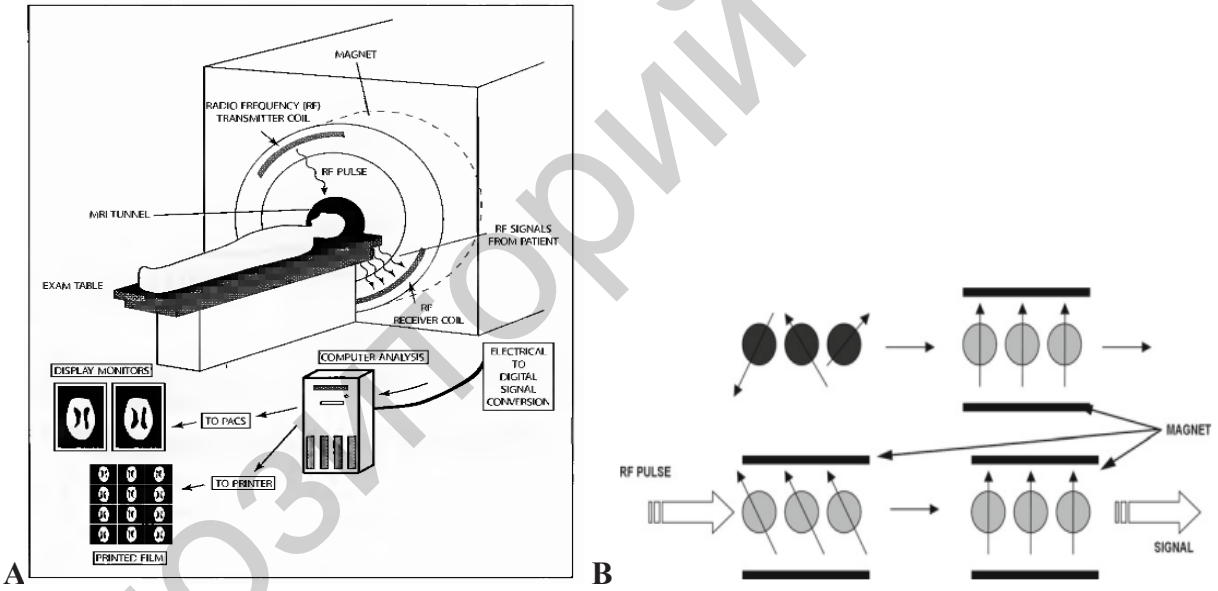


Figure 1.28 — (A) Diagram of the standard magnetic resonance imaging (MRI) and production of MR images. (B) The basic principles behind MRI. In their natural state, hydrogen atoms are spinning with their axes of rotation randomly oriented. When placed in a magnetic field, they align in a uniform direction. An RF pulse is applied, knocking the H-atoms out of their magnetic fi eld orientation. Once the RF pulse is stopped, the atoms return to their previous alignment, giving off a signal which is then used to form the image

MRI utilizes the potential energy stored in the body's hydrogen atoms. The atoms are manipulated by very strong magnetic fields and radiofrequency pulses

to produce enough localizing and tissue-specific energy to allow highly sophisticated computer programs to generate 2- and 3-dimensional images.

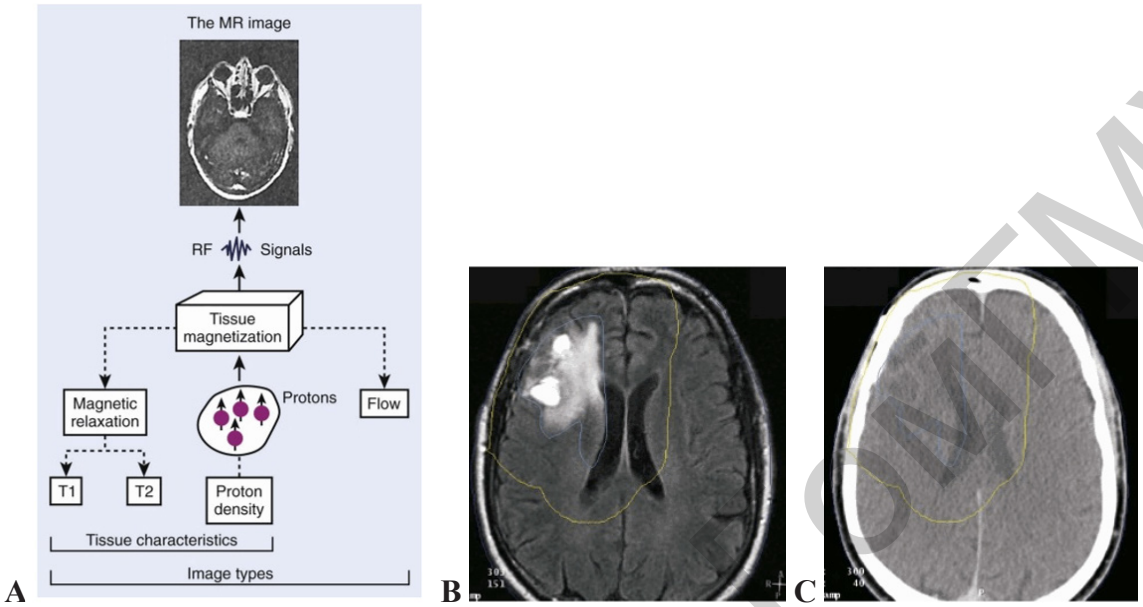


Figure 1.29 — (A) Physical characteristics of the tissue that are displayed in the magnetic resonance image. MR – magnetic resonance; RF – radiofrequency; T1 – spin-lattice relaxation time; T2 – spin–spin relaxation time. (B) Axial T1 magnetic resonance image of the head and brain. Malignant tissue appears as brighter areas in the upper left. (C) Axial computed image of the same patient (for comparison)

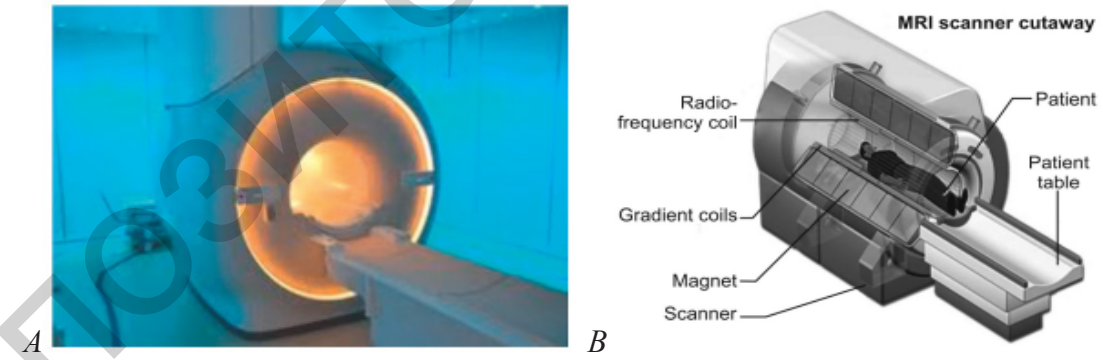


Figure 1.30 — (A) Modern MRT closed unit with a 70-cm-bore with 3-Tesla magnet. (B) Magnetic resonance imaging scanner indicating position of various coils

Hydrogen is also the majority atom in human tissue because it is the main element in water and fats, matter making up almost nine tenths of our body weight. Therefore, three-dimensional displays of the body density of water, fats and other organic matter containing hydrogen can be obtained with MRI (Figure 1.29). As this density differs from one organ to another, it is easy to obtain the outline of these

elements with precision to within a few millimeters. Much more powerful tools are being developed that will give a resolution of under a millimeter.

Advantages:

— No ionizing radiation exposure.

— Multi planar imaging.

— High contrast resolution between the different soft tissues of the body, which makes it especially useful in imaging the brain, muscles, the heart, and cancers compared with other medical imaging techniques.

— Non-invasive vascular imaging.

— Provides 2D and 3D cross-sectional images of the body.

— Ideal for soft tissue structures, cartilage, and ligament imaging.

— Vascular and cardiac applications.

Functional analysis is possible in some very specific cases, like brain irrigation or heart functioning monitoring, via live analysis of the rate of oxygen contained in the blood.

Disadvantages:

— Have been artifacts due to a patient`s motion.

— The inability to bring ferrous objects near the magnet.

— MRI is less sensitive than CT in the detection of small amounts of calcification and in the detection of acute haemorrhage (brain).

— Expensive equipment — the most expensive imaging modality.

— Time consuming, requiring patient cooperation, ability to lie still, often for 30–60 minutes.

— MRI is undertaken in a relatively enclosed space – unsuitable for patients with claustrophobia and young children (may need general anaesthesia).

— Relatively contraindicated in pregnancy, particularly first trimester.

— Contraindicated in patients with ferrous metal implants – pacemakers, cochlear implants, metallic foreign bodies in the eyes.

The major safety problem with these magnets is that they are so strong that if bringing a ferromagnetic object (such as a wrench) into the room, it can accelerate to 150 miles per hour as it is ripped out of hand and flies into the bore of the magnet. If a patient is in the machine at the time, lethal consequences will result.

Example indications:

— Head and neck — neuroimaging — clear differentiation between the grey and white matter, diagnosis of demyelinating disease, cerebrovascular disease, detailed imaging of malignancies and infectious diseases, epilepsy imaging, functional MRI brain studies.

— CT is more accurate in the detection of acute blood; new MRI techniques, e.g. diffusion weighting, can detect cerebral ischaemia very early (mi-nutes) when compared with CT.

— Spine imaging — nerve compression (cord and cauda equina), malignancies, disc disease.

— Hepatobiliary — liver, pancreas, and biliary lesions, MR cholangiopancreatography (MRCP) for structural imaging of the biliary tree.

— Small bowel — Crohn's disease diagnosis.

— Knee and other joints – used in cartilage and ligament imaging.

— Angiographic, vascular protocols, cardiac MRI.

— Prostate imaging, diagnosis, and staging prostate cancer.

— Rectal, gynaecological cancer staging.

There are also known side effects from the radiofrequency waves that such scanners produce and possible adverse effects due to some MRI contrast agents. If MRI was not as expensive and was more widely available, it would easily replace most of the techniques described above. For the time being, it is kept for examinations for which diagnosis seems more difficult (the soft tissue such as muscles, tendons, brain, tumours) or in indications for which this method is much more effective or unique (neurology, ophthalmology, cardiovascular, endocrinology, oncology, etc.). A patient that has just undergone an MRI examination is no more radioactive than a patient that has received ultrasounds, or are they magnetised or magnetic.

Nuclear medicine

Nuclear medicine utilizes radionuclides that have been given the property to "target" different organs of the body to evaluate the physiology and anatomy of those organs. In nuclear medicine studies, however, carrier molecules labelled with a radioactive tracer, usually metastabile ^{99m}Tc, are injected into the patient. Because the patient is injected with the tracer, he or she becomes the source of the radiation and emits gamma rays. A patient who has been injected with a radioactive tracer is slightly radioactive, but the activity is constantly falling.

Radionuclides can be produced artificially (most frequently by neutron enrichment in a nuclear reactor or in a cyclotron) or may occur naturally. Naturally occurring radioisotopes include uranium and thorium. The vast majority of radionuclides used in medicine are produced artificially. Radiopharmaceuticals are combinations of radionuclides attached to a pharmaceutical that has binding properties that allow it to concentrate in certain body tissues, such as the lungs, thyroid, or bones. Radioisotopes used in clinical nuclear medicine are also referred to as radionuclides, radiotracers, or, sometimes, simply tracers.

Various body organs have a specific affinity for absorption of different biologically active chemicals. For example, the thyroid takes up iodine, the brain — utilizes glucose, bones — utilize phosphates and particles of a certain size can be trapped in the lung capillaries.

After the radiopharmaceutical is carried to a tissue or organ in the body, usually via the bloodstream, its radioactive emissions allow it to be measured and imaged using a detection device called a gamma camera (Figures 1.31–1.32).

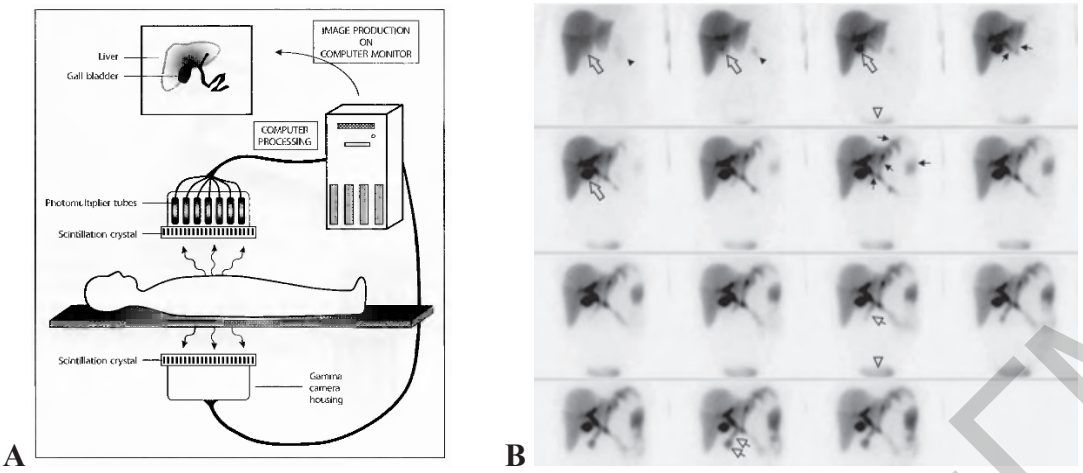


Figure 1.31 — (A) Diagram of the standard two-head gamma camera and production of nuclear medicine scintigraphy images. (B) Normal dynamic hepatobiliary scintigrams

Figure 1. 32 — (A) A gamma camera. This model has two detectors mounted on the circular gantry ring to the left of the picture. SPECT studies are acquired by rotating these detectors around the patient. (B) A current generation dual-detector SPECT system is much bulkier (example of a system designed specifically for cardiac SPECT)

Single-photon emission computed tomography (SPECT) is a nuclear medicine modality in which a gamma camera is used to acquire several two-dimensional images from multiple angles, which are then reconstructed by computer into a three-dimensional data set that can be manipulated to produce thin slices in any projection. To acquire SPECT scans, the gamma camera rotates around the patient.

Positron emission tomography (PET) is used to produce three-dimensional images that depict the body's biochemical and metabolic processes at a molecular level. It is performed using a positron positive electron-producing radioisotope attached to a targeting pharmaceutical.

PET scanning is most often used in the diagnosis and treatment follow-up of cancer. It is frequently used to locate hidden metastases from a known tumor or to detect recurrence. Oncologic PET scans make up about 90% of the clinical use of PET. Some tumors take up more of the radiotracer than others and are referred to as FDG-avid tumors, with FDG referring to the contrast agent fluorodeoxyglucose (FDG).

Compared with CT and fluoroscopy, nuclear medicine studies, in general, produce less patient exposure. The types of scans that deliver the highest dose relative to other nuclear scans are cardiac studies and PET examinations.

Principle:

— Uses unsealed radioactive substances in diagnosis (and therapy).

How it is done:

— Studies start with injecting or inhaling or ingesting a radionuclide.

— The type of isotope used varies with each study.

— The radionuclide concentrates in the organ that is being tested.

— Scanning of the body or the organ follows.

— When to start and to end scanning, varies with each study.

— Majority of diagnostic tests involve the formation of an image using gamma camera.

— Most diagnostic radionuclides emit gamma rays.

Advantages:

— Radionuclide imaging is safe since it does not carry the risk of allergic reaction encountered with contrast.

— High sensitivity.

— Radiation exposure is minimal.

— Provides functional information of the organs and the disease processes.

— Advancement of the treatment options for cancer patients.

— Allows early or improved detection of metastases (PET).

— Provides detailed and accurate information in hard to reach areas.

Disadvantages:

— Non-specificity.

— Not good resolution.

— High cost.

— Exposure to radiation doses, which may be significant, e.g. PET.

— Not all techniques are widely available, e.g. PET.

Example indications:

— Renal scintigraphy: to evaluate renal function.

— Bone scintigraphy: to evaluate bone metastasis.

— Lung scan perfusion: suspected patients with pulmonary embolism.

— Myocardium view: suspected patients with a coronary artery disease.

— Testicular scan: to evaluate testicular torsion.

Main imaging modalities in nuclear medicine:

— Genitourinary scan — assessment of a renal blood flow and function, evaluate renovascular hypertension, and assess vesicoureteral reflux.

— Bone imaging — assessment of bone metastases, infection.

— PET — imaging of metastases, neuroimaging — imaging of brain activity in dementias, combining injection of metabolically active substances, e.g. fluorodeoxyglucose (FDG) and tomography/CT detection.

Myocardial perfusion scan – assessment of the function of myocardium for diagnosis of hypertrophic cardiomyopathy and coronary artery disease, in combination with MRI +/– CT.

In nuclear medicine studies, a dose of radiation is given internally to the patient and the x-rays are counted as they leave his or her body. Some nuclear medicine studies provide functional information in addition to the anatomic information of conventional radiographic techniques.

Radionuclide diagnostic in vitro

Radionuclide methods performed outside the body (in vitro), without introducing a radioactive substance to the patient is of radioimmune analysis or radioimmunoassay (RIA). Their feature is the ability to determine the desired substance in a test tube using diagnostic test kits containing a radioactive label. For analysis, 1–5 ml of the blood or other biological medium is sufficient. There is no radiation load on the patient. Radionuclide diagnostics in vitro (since all studies are carried out in test tubes) refers to microanalysis and occupies a borderline position between radiology and clinical biochemistry. It allows you to detect the presence in biological fluids (blood, urine) of various substances of endogenous and exogenous origin, which are there in negligible or, as chemists say, disappearing concentrations. These substances include hormones, enzymes, drugs introduced into the body for therapeutic purposes, etc. Radionuclide analysis in vitro became known as radioimmunological, since it is based on the use of immunological antigen-antibody reactions.

Radioimmune analysis is based on the competition of the determined antigen from clinical material with a certain amount of identical, radioisotope-labeled antigen with a limited number of antibodies. Indications: determination of the concentration of biologically active substances (hormones, enzymes, amino acids, tumor markers, etc.) in the blood serum (any biosubstrate as urine, saliva, etc.). Radioimmune analysis is used in oncology, endocrinology, cardiology, pediatrics, obstetrics and gynecology, toxicology, allergology. Immunoradiometric analysis is based on the determination of antibodies using an radionuclide label. Examples include a radioallergosorbent test, as well as the determination of cancer markers in the blood.

Although the RIA technique is extremely sensitive and extremely specific, requiring specialized equipment, it remains among the least expensive methods to perform such measurements. It requires special precautions and licensing, since radioactive substances are used.

In contrast, an immunoradiometric assay (IRMA) is an immunoassay that uses radiolabeled molecules but in an immediate rather than stepwise way. A radioallergosorbent test (RAST) is an example of radioimmunoassay. It is used to detect the causative allergen for an allergy.

Method

Classically, to perform a radioimmunoassay, a known quantity of an antigen is made radioactive, frequently by labeling it with gamma-radioacti-ve isotopes of iodine, such as ^{125}I, attached to tyrosine. This radiolabeled antigen is then mixed with a known amount of antibody for that antigen, and as a result, the two specifically bind to one another (Figure 1.33). Then, a sample of serum from a patient containing an unknown quantity of that same antigen is added. This causes the unlabeled (or "cold") antigen from the serum to compete with the radiolabeled antigen ("hot") for antibody binding sites. As the concentration of "cold" antigen is increased, more of it binds to the antibody, displacing the radiolabeled variant, and reducing the ratio of antibody-bound radiolabeled antigen to free radiolabeled antigen. The bound antigens are then separated and the radioactivity of the free (unbound) antigen remaining in the supernatant is measured using a gamma counter.

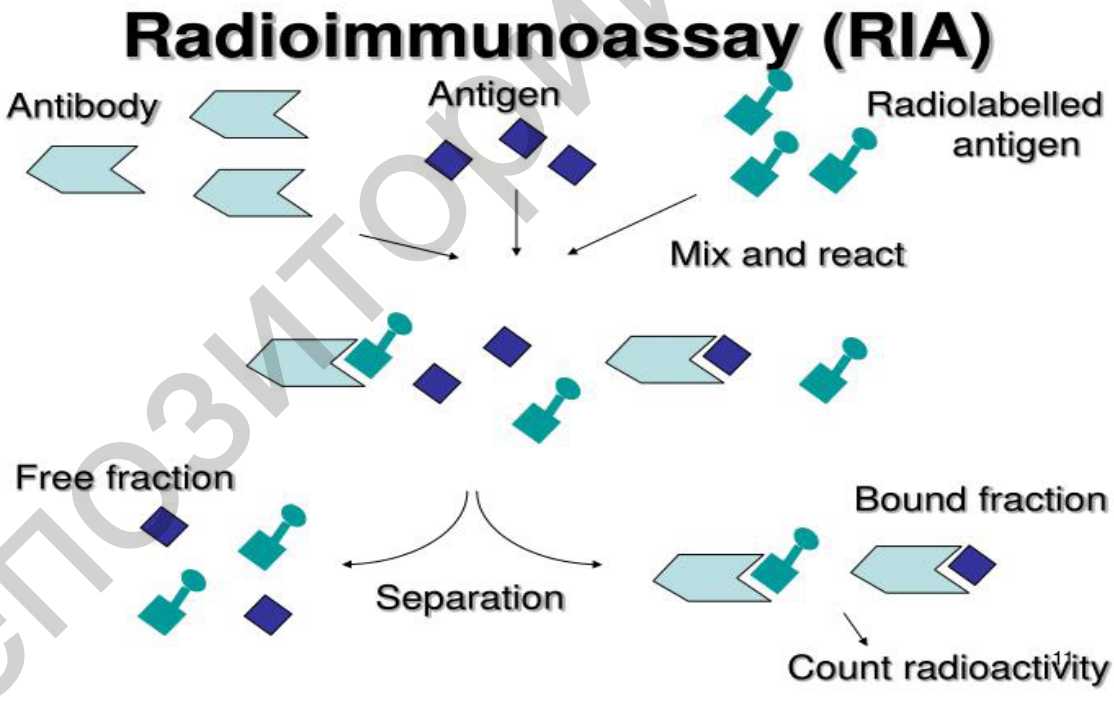


Figure 1.33 — Schematic representation of the radioimmune analysis (RIA)

This method can be used for any biological molecule in principle and is not restricted to serum antigens, nor is it required to use the indirect method of measuring the free antigen instead of directly measuring the captured antigen. For example, if it

is undesirable or not possible to radiolabel the antigen or target molecule of interest, a RIA can be done if two different antibodies that recognize the target are available and the target is large enough (e.g., a protein) to present multiple epitopes to the antibodies. One antibody would be radiolabeled as above while the other would remain unmodified. The RIA would begin with the "cold" unlabeled antibody being allowed to interact and bind to the target molecule in solution. Preferably, this unlabeled antibody is immobilized in some way, such as coupled to an agarose bead, coated to a surface, etc. Next, the "hot" radiolabeled antibody is allowed to interact with the first antibody-target molecule complex. After extensive washing, the direct amount of radioactive antibody bound is measured and the amount of target molecule quantified by comparing it to a reference amount assayed at the same time. This method is similar in principle to the non-radioactive sandwich ELISA method.

Three-dimensional reconstruction in diagnostic radiology

The majority of work performed in radiology is presented as 2-D information, from conventional x-ray images to the most advanced CT, MRI or PET-CT studies. When axial imaging began with CT and US, imaging information became available in a digital form. The next step was to try and obtain volumetric information from the 2-D slices. Reconstruction uses the 3-D data to show other planes that were not acquired directly during the acquisition, including sagittal and coronal cross-sections reconstructed from the axial images.

Two methods for 3-D reconstruction are available *in radiology*; the first is 3-D Surface shaded display (3-DSSD) that recognizes the tissue by its density (similar to CT) or manually by drawing the contour of the organ. The view is as though one is looking from a certain point and what surface the viewer can see. This method actually shows only the surface of the organs as an opaque object. A virtual light source is computed for each polygon and the object is displayed with the resulting surface shading.

Secondary method for 3-D reconstruction is volume rendering reconstruction (VR) — takes the entire volume of the data, calculates the contributions of each voxel (volume pixel) along a line from the viewer's eye through the data set, and displays the resulting composite for each pixel of the display. Opacity values range from 0, which is totally transparent, to 1, which is totally opaque. So surfaces are displayed by mapping the corresponding data va-lues to almost opaque values and the remainder to transparent values.

A software program may display the volume in an alternative manner. A big advantage of the volume rendering is that this interior information is not discarded, so that it enables one to look at the 3-D data set as a whole (Figure 1.34).

Multiplanar reconstruction is the simplest method of reconstruction. A volume is built by stacking the axial slices. The software then cuts slices through the volume in a different plane (usually orthogonal). Modern software allows the reconstruction

in non-orthogonal (oblique) planes so that the optimal plane can be chosen to display an anatomical structure.

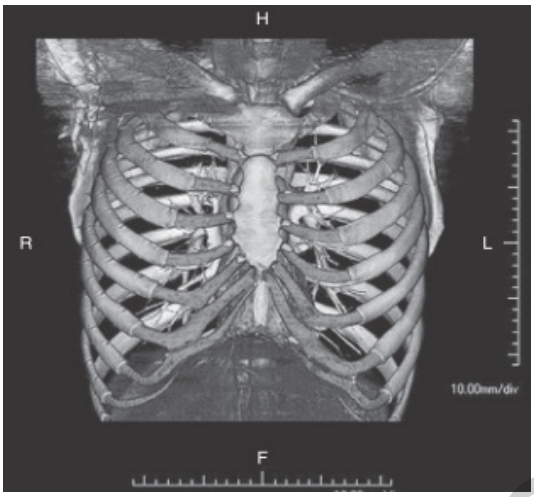


Figure 1.34 — Three-dimensional computed tomography rendering of the normal rib cage. This grayscale version (color online) of a three-dimensional surface rendering of the rib cage is made possible by the acquisition of multiple, thin computed tomographic sections through the body. These sections can then be reconstructed to demonstrate the surface anatomy, as in this illustration. The same data set could have been manipulated to show the heart or the lungs (which are digitally removed here) and not the rib cage. Such renderings are especially helpful in demonstrating the exact anatomic relationships of structures, especially for surgical planning. F, Foot; L, left; H, head; R, right

Unlike other reconstruction techniques, CT and MRI perfusion use time as the third dimension. Acquisition is performed on a set of slices without a contrast material. Then, at known intervals after the injection of the contrast material, changes in the tissue enhancement over time are followed. The results are displayed as color maps which include blood volume in the region of interest, blood flow and time of travel of the blood through the region of interest.

Post-processing 3-D application used with MRI, CT, US and NM studies. When the two sets are aligned, it is possible to fuse them into one image.

Reconstructed 3-D data offers several advantages:

1. It enhances viewing of pathology.
2. It is used to more easily compare current and previous exams.
3. It improves service to referring physicians, since selected 3-D images can be attached to the radiology report. These images illustrate the diagnosis and may even be shown to patients while discussing the condition and recommended treatment.

Contrast radiologic examinations

At the same time, contrast agents used in radiology have made a considerable progress, adding to the quality and resolution of the images. As soon as it was un-

derstood that the density of the matter crossed by the ray was linked to the opacity of the image, it was also understood that a specific image could be taken of the irrigated regions, as long as a contrast liquid could be injected into them. A contrast medium that was neutral, therefore non-toxic, and which could be eliminated rapidly still needed to be found (Table 1.1).

Table 1.1 — Radiographic contrast agents at practice

Groups of medias	Chemical variant and solubility	Contrast agents	Usage
Radiopositive medias (on x-ray image look like shadow)	Salts of heavy metals, unsoluble	Barium sulphate	Gastrointestinal organs (as a barium meal or barium enemas)
	Organic iodide preparations, water soluble, ionic	Urographin, verographin, bilitrast, bilignost and so on	Normal and pathologic cavities, fistulas, to use intravenously or to arteries
	Organic iodide preparations, water soluble, non-ionic	Omnipaque, ultravist	Vessels, normal and pathologic cavities, fistulas, various ducts
	Organic iodide preparations, fat-soluble (iodinated oils)	Iodolipolum, lipiodolum	Bronchography, lymphography
Radionegative medias (on x-ray image look like enlightenment)		Gas (air)	Different normal cavities and spaces (pneumogastrography, pneumoencephalography, pneumomediastinum and so on)

Contrast agents, often based on iodine or barium, have now become unavoidable, as they give an extremely precise display of certain anatomic details such as very small vessels, for example.

Radiography is adequate for the situations in which natural radiographic contrast exists between body structures, such as the heart and the lungs, or between the bones and the adjacent soft tissues. To examine structures that do not have inherent contrast differences from the surrounding tissues, it is necessary to use one of several contrast agents. Three areas deserve specific mention: gastrointestinal tract, urinary tract, and blood vessels.

Radiographic contrast agents

Various structures within the body are recognizable on imaging studies either because of their inherent densities (e.g., the bone distinguished from the muscle) or because they contain one of the basic natural materials (e.g., air). However, be-

cause most of the internal viscera are of the radiographic density of water or close to it, it is necessary to introduce into these structures a material that will outline walls, define anatomy, and demonstrate any pathologic conditions.

An X-ray contrast medium is an exogenous substance used to alter the contrast in X-ray imaging by affecting the attenuation of X-rays. Introducing gases into hollow viscera, cavities will reduce the attenuation of X-rays; such substances are called negative contrast media. The vast majority of X-ray contrast media are positive or radiopaque, for they increase the attenuation of X-rays. The increased attenuation is accomplished by two different atoms: barium, which is used in the form of insoluble barium sulphate for examinations of the gastrointestinal tract, and Iodine, which is the main component of all other X-ray contrast media.

Barium preparations

Barium sulfate (water-suspension), in one of its many forms, provides the mainstay for radiographic examinations of the gastrointestinal tract. Barium is of high atomic weight, which results in considerable absorption of the x-ray beam, thus providing excellent radiographic contrast. In the usual pre-paration, finely pulverized barium mixed with dispersing agents is suspended in water. When administered orally or rectally, it provides excellent coating and distention of the GI tract.

Water-soluble contrast media

Water-soluble contrast agents can be categorized based on their osmola-lity: high-osmolality contrast media, iso-osmolality contrast media, and low-osmolality contrast media, which have different biochemical profiles and prices.

Water-soluble contrast agents can be injected directly or indirectly into the body to provide contrast enhancement. After the contrast has had time to pass through the body (30 to 60 seconds), contrast-enhanced images can be taken with an excellent resolution of the soft tissue organ and vascular detail.

A water-soluble contrast can also be injected into various body parts with subsequent diagnostic imaging, including the blood vessels (angiography), the spinal canal (myelography), and joints (arthrography). Water-soluble contrast can also be injected into the GI and into the genitourinary tract (cystogram, nephrogram, hysterosalpingogram, etc.) for a detailed radiology evaluation.

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

Arteriography

Principle: arteriography is a procedure in which a contrast material is injected into an artery to evaluate the vasculature.

How it is done:
— Contrast material is injected into the blood vessel and x-rays are taken.
Advantages:
— Arteriograms give the best pictures of the arteries.
— Arteriograms are used to make specific diagnoses.
Limitation:
— Invasive procedure.
— Bleeding and injury to the artery.
— Contrast sensitivity, renal failure.
— Contrast complications.
Example indications:
— Cerebral angiography: aneurysms, tumors.
— Renal angiography: renovascular hypertension.
— Aortic dissection, aneurysm.
— Pulmonary angiography: pulmonary embolism.

Adverse reactions of contrast examinations

Extravasation

Contrast does not always end up in the intended location. For example, when a patient is injected with intravenous contrast for a CT examination, it is possible for that agent to extravasate into the subcutaneous tissues of the arm. This can be a painful condition, which can lead to morbidity with skin necrosis if not treated correctly.

Allergic reaction

Although normal persons may not suffer any severe, long-lasting effects from the administration of contrast, one must remember that contrast, like any drug or medication, can result in an allergic reaction which can potentially result in death. Depending on the severity of the allergy, the patient can be premedicated with a combination of steroids and diphenhydramine before receiving the intravenous contrast.

Contrast-induced nephropathy

Excretion of these intravenous agents is largely performed by glomerular filtration within the kidney. In the kidneys, especially in a dehydrated patient and patients with borderline renal function (including diabetics), glomerular and tubular damage may result in temporary impairment of renal function and oliguria, which has been labeled contrast-induced nephropathy. In patients with poor renal function contrast is contraindicated and the radiologist needs to discuss the case with the referring physician and the patient.

With the intravenously or intra-arterially administered agents, a small but real risk of contrast reaction exists. This is something that you should consider before ordering an intravenous pyelogram or a contrast-enhanced CT scan. About 5% of patients will experience an immediate mild reaction, such as a metallic taste or a

feeling of warmth; some experience nausea and vomi-ting, wheeze, or get hives as a result of these contrast agents. Some of these mild reactions can be treated with 50 mg of intramuscular diphenhydramine (Benadryl). Because contrast agents also can reduce renal function, they should not generally be used in patients with a compromised renal function.

A small number (about 1 in 1000) patients have a severe reaction to intravascular contrast. This may be a vasovagal reaction, laryngeal edema, severe hypotension, an anaphylactic-type reaction, or cardiac arrest. A va-sovagal reaction can be treated with 0,5 to 1,0 mg of intravenous atropine. The most important initial therapeutic measures in these severe reactions are to establish an airway, ensure breathing and circulation, and give intravenous fluids. Other drugs obviously may be necessary as well. The risk of death from a study using intravenously administered contrast agents is between 1 in 40,000 and 1 in 100,000.

Molecular and functional imaging, multi-modality radiology

Molecular imaging is defined as the ability to visualize and quantitatively measure the function of biological and cellular processes in vivo. Molecular imaging can be applied to all avenues of medical imaging: early detection/screening, diagnosis, therapy delivery/monitoring, and treatment follow-up. The current status of clinical molecular imaging is limited, with most current applications using positron-emission tomography and single photon-emission computed tomography imaging, and less for MRI and US. Contrast-enhanced molecular ultrasound with molecularly-targeted contrast agent microbubbles is explored as a clinically translatable molecular ima-ging strategy for screening, diagnosing, and monitoring diseases at the molecular level. Doxirubicin, to a superparamagnetic iron oxide nanoparticle, which is then encapsulated in liposomes, attach to tumour angiogenic vessels, and the localization of these magnetic particles can be visualized using MRI. The main advantage of in vivo molecular imaging is its ability to characterize diseased tissues without invasive biopsies or surgical procedures (Figure 1.35).

Molecular imaging is often thought to be a highly specialised technique that is more applicable to research than everyday clinical practice. Contrary to this perception, there are many imaging techniques in a widespread use that have been shown to correlate with particular biomolecular events. For example, the degree of enhancement of the lung nodules on CT correlates with the expression of a vascular endothelial growth factor, a molecule that stimulates tumour angiogenesis. Uptake of radio-iodine in thyroid tumours, one of the oldest techniques in nuclear medicine, results from the expression of the sodium-iodide molecule on the tumour cell surface.

Nuclear medicine has shown that **functional** and **physiological** imaging offers two advantages over a purely structural approach: (A) the potential for earlier diagnosis before anatomical changes have developed; and (B) a closer correlation between the functional status of disease and clinical outcome which

translates to improved clinical decision-making. Many of the methods developed for nuclear medicine can be applied to magnet resonance, computed tomography and ultrasound to produce techniques that combine the benefit of functional imaging with the high spatial resolution achieved with modern equipment.

The development of combined imaging SPECT-CT and PET-CT systems allows the superimposition of nuclear medicine and CT images, a technique known as functional–anatomical mapping (Figure 1.36).

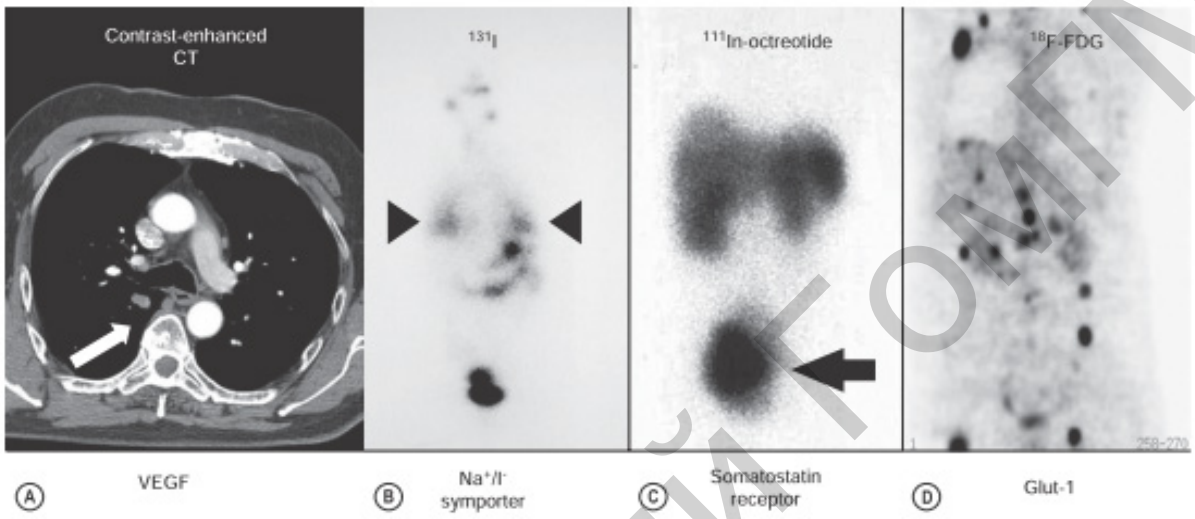


Figure 1.35 — Examples of "everyday" molecular imaging.
(A) Peak contrast enhancement of a lung nodule (arrow) on CT correlates with the expression of a vascular endothelial growth factor (VEGF).
(B) Uptake of radioiodine (^{131}I) in miliary lung metastases (arrowheads) of thyroid cancer reflecting expression of the sodium/iodide (Na+/I–) symporter.
(C) Uptake of ^{111}In-octreotide in a pelvic carcinoid tumour (arrow) indicates the expression of the somatostatin receptors. (D) Uptake of ^{18}F-fluorodeoxyglucose (FDG) in multiple metastases due to the expression of glucose transporters

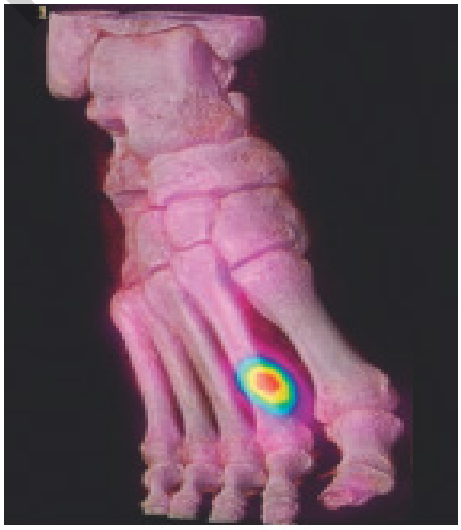


Figure 1.36 — Hybrid 3D SPECT-CT image showing uptake of ^{99m}Tc-polyphosphate in the second metatarsal neck due to a stress fracture. The radionuclide uptake is displayed on a 3D reconstruction of CT images of the foot

Technical and clinical advances in medicine have led to the understanding that one modality cannot be a substitute for the other; they are complementary to each other. The combined PET/CT is more sensitive and specific for detecting otherwise occult malignancy, tumor staging, and detecting disease recurrence and/or metastasis.

Interventional radiology

New, minimally invasive surgical procedures are emerging which can be performed on an outpatient basis together with the diagnostic imaging procedure, for instance CT, MR or ultrasound. By combining delivery of therapy with the diagnostic procedure, the healthcare system can realize significant savings. Like angiography, interventional radiology is not a distinct imaging modality, but it plays a major role in contemporary medical and surgical therapeutics as well. Interventional radiology involves the use of various imaging modalities, including fluoroscopy, CT, ultrasound, and even MRI, in conjunction with equipment such as wires, catheters, needles, and endoluminal stents, to perform a variety of therapeutic procedures that were formerly either impossible or required more laborious, hazardous, and costly techniques. It should be noted that angiography and interventional radiology are closely related fields, and both are often practiced by the same subspecialists. To develop a general sense of what interventional radiology does, let us briefly review one very common interventional procedure, percutaneous abscess drainage (using CT, US, fluoroscopy) (Figure 1.37).

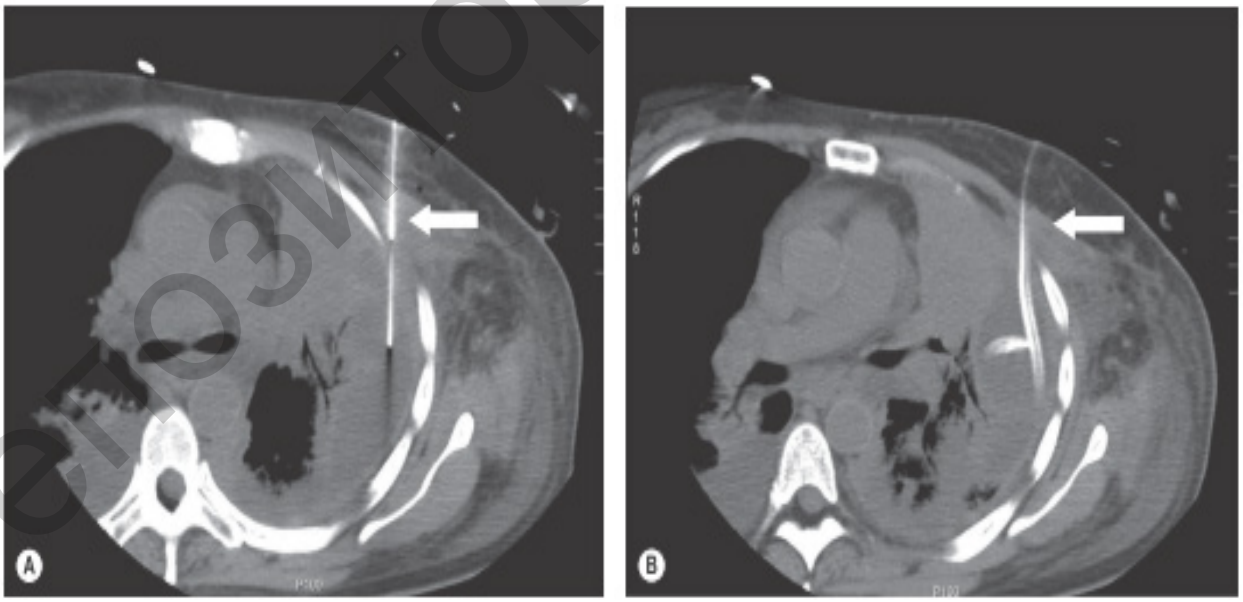


Figure 1.37 — CT-guided chest drain insertion for empyema in a 49-year-old male using tandem-troachar technique. (A) Guide needle (arrow) was placed through an anterior approach into a left chest collection. (B) Chest tube (arrow) placed parallel to guide a needle

Other interventional radiology procedures and activities include but are not limited to the following:

1. Intraoperative cases (e.g., thoracic and abdominal aortic stent grafts).
2. Noninvasive cardiac and vascular imaging.
3. Percutaneous oncologic interventions.
4. Percutaneous biopsies (using CT, ultrasound, and/or fluoroscopy).

In interventional radiology, iodinated contrast is selectively injected into blood vessels or other ducts that can be imaged fluoroscopically to demonstrate normal anatomy, pathology, or the position of catheters or other devices.

An approach to image interpretation

White and black

These are not radiologic terms, but almost every modality displays its images in white, black, and various shades of gray.

Remember, the denser an object is, the more x-rays it absorbs and the "whiter" it appears on radiographic images. The less dense an object is, the fewer x-rays it absorbs and the "blacker" it will appear on radiographs.

Unfortunately, the specific terms used to describe what appears as **white** or **black** on an image change from one modality to another. Table 1.2 is a handy chart that lists the terms used to describe what shows as black or white using various modalities.

Table 1.2 — White and black: terms for each modality

Modality	Terms Used for "White"	Terms Used for "Black"
Conventional radiographs	Increased density Opaque	Decreased density Lucent
CT	Increased (high) attenuation Hyperintense, hyperdense	Decreased (low) attenuation Hypodense
MRI	Increased (high) signal intensity Bright	Decreased (low) signal intensity Dark
US	Increased echogenicity Sonodense	Decreased echogenicity Sonolucent
Nuclear medicine	Increased tracer uptake	Decreased tracer uptake
Barium studies	Radiopaque	Nonopaque, radiolucent

"En face" and "in profile"

— These terms are used primarily in describing conventional radiography and barium studies.

— When you look at a lesion directly "head-on", you are seeing it en face. A lesion seen tangentially (sideways) is seen in profile.

— Only a sphere, which, by definition, is perfectly round in every dimension, will appear exactly the same shape no matter in which plane it is viewed (e.g., a nodule in the lung).

— Naturally occurring structures, whether normal or abnormal, of any shape other than a sphere will appear slightly different in shape if viewed en face or in profile.

Typical x-ray projections

X-ray projections are typically listed as AP or PA. This depends on whether the x-ray beam passed to the patient from anterior to posterior (AP) or the reverse (Figure 1.38). Lateral (LAT) and oblique (OBL) views also are commonly obtained. Note: the word "view" is often used erroneously to describe a radiographic projection.

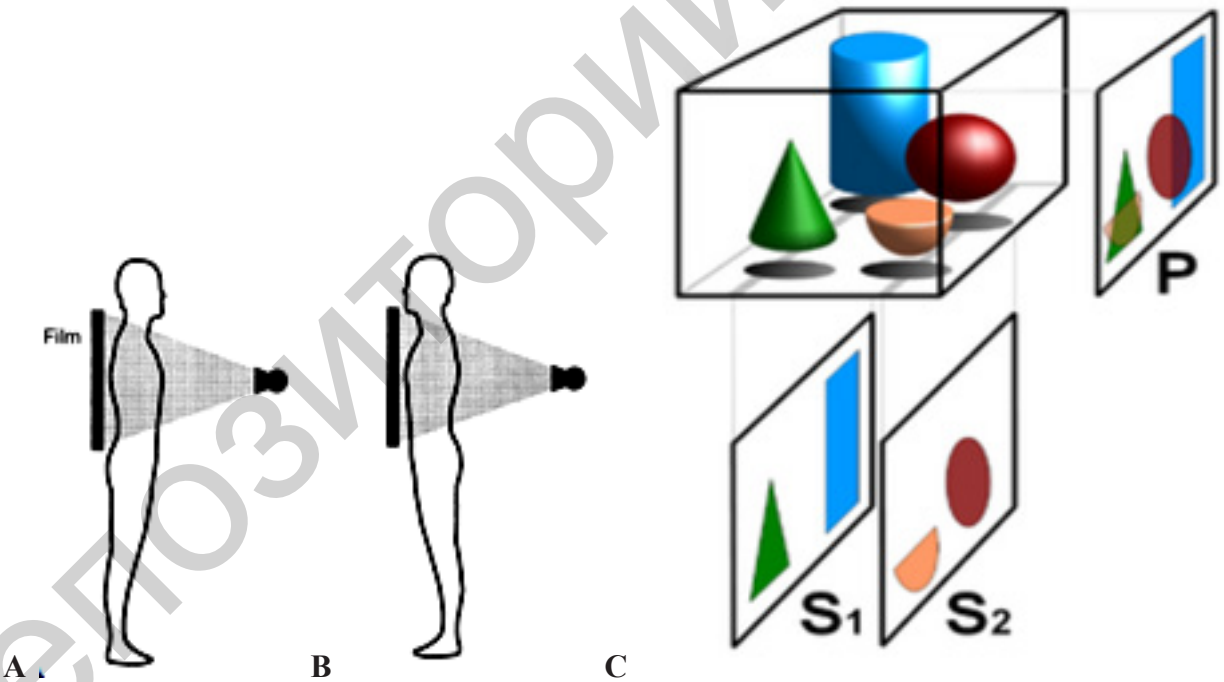


Figure 1.38 — (A) Variants antero-posterior and (B) postero-anterior of the projections. (C) Principles of (P) projections and (S) tomography

Basic radiologic projections:

— *Frontal* — projection taken with the central ray to the midsaggital plane.

— *Lateral* — projection taken with the central ray perpendicular to the midsaggital plane.

— *Oblique* — projection taken with the central ray at an angle to any of the body planes. Described by the angle of obliquity and the portion of the body the X-ray beam exits; right or left and posterior or anterior. For example “a 45 degree right anterior oblique of the cervical spine”.

— *Prone* — patient lies on their front, also known as “planking”.

— *Supine* — patient lies on the back.

— *Decubitus* — patient laying down. Further described by the downside body surface: dorsal (backside down), ventral (front side down), or lateral (left or right side down).

When you view your images, remember that you and the patient are always looking at each other, face to face. This is the convention by which most images are viewed, no matter that the position of the patient was when the image was exposed. The patient’s right side, whether it is on conventional radiographs or a CT scan, is on your left side, and the patient’s left side should be on your right side (Figures 1.39–1.40).

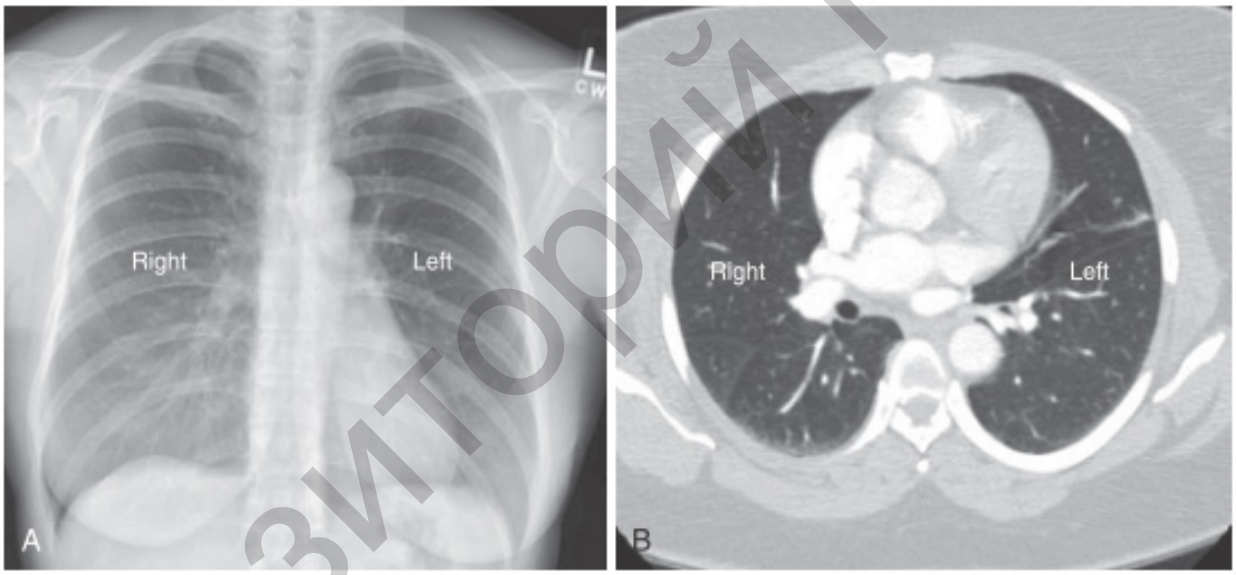


Figure 1.39 — Orientation of images. By convention, images are viewed as if the patient were facing you. (A) When you view a chest radiograph, the patient’s right (labeled right) is on your left. (B) Likewise, when you view a computed tomographic scan (of any body part), the patient’s right is on your left. With today’s digital displays automatically orienting almost all images correctly, it is more difficult to view an image backward

Typically, one expects to find the exact location of a problem and hopes to make the diagnosis. Although some diseases present a very characteristic picture, most can appear in a variety of forms depending on the stage. As a result, image interpretation will yield a differential diagnosis that must be placed in the context of the clinical findings.

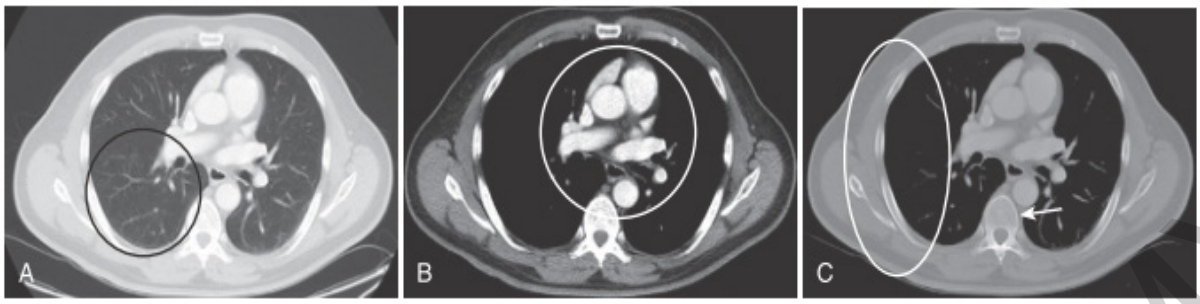


Figure 1.40 — Windowing the thorax. Chest computed tomography scans are usually "windowed" and displayed in several formats to optimize anatomical definition. (A) Lung windows are chosen to maximize the ability to image abnormalities of the lung parenchyma and to identify normal and abnormal bronchial anatomy (black circle). (B) Mediastinal windows are chosen to display the mediastinal, hilar, and pleural structures to best advantage (white circle). (C) Bone windows are utilized as a third way of displaying the data to visualize the bony structures to their best advantage (white oval and arrow). It is important to recognize that the displays of these different windows are manipulations of the data obtained during the original scan and do not require rescanning the patient

Examination of images requires a logical approach. First you must understand the type of the image, the orientation, and the limitations of the technique used. For example, you begin by mentally stating, "I am looking at a coronal computed tomography scan of the head done with an intravenous contrast." This is important, because intravenous contrast can be confused with fresh blood in the brain.

Next, look at the name and age on the film label to avoid mixing up patients, and it allows making a differential diagnosis that applies to a patient of that age and sex. You would not believe the number of times that this seemingly minor step will keep you from making very dumb mistakes.

The next step is to determine the abnormal findings on the image. This means that you need to know the normal anatomy and variants of that particular part of the body as well as their appearance on the imaging technique used. After this, you should describe the abnormal areas, because it will help you mentally to order a differential diagnosis. The most common mistake is to look at an abnormal image and immediately to name a disease. When you do this, you will find your mind locked on that diagnosis (often the wrong one). It is better to say to yourself something like, "I am going to give a differential diagnosis of gene-ralized cardiac enlargement with normal pulmonary vasculature in a 40-year-old male", rather than to blurt out "viral cardiomyopathy" in a patient who really has a malignant pericardial effusion.

After reviewing the common causes of the x-ray findings that you have observed, you should reorder the etiologies in light of the clinical findings. At this point, you probably think that you are finished. Not yet. Often a plethora of information is contained in the patient's film jacket or in the hospital computer information system. This comes in the form of the previous findings and histories supplied for

the patient's other imaging examinations. Reviewing the old reports has directed us to the areas of pathology on the current film.

You probably think that you have finished now. Wrong again. A certain number of entities could cause the findings on the image, but you have just not thought of them all. After radiologists have finished looking at the case, they try to go through a set sequence of categories in search of other differential possibilities. The categories they use are congenital, physical/chemical, infectious, neo-plastic, metabolic, circulatory, and miscellaneous.

Protection in radiological practice

The benefit of using ionizing radiation in medicine is widely acknow-ledged. Although alternative methods of imaging — for example, ultrasound and magnetic resonance imaging — have been developed, ionizing radiation will continue to be used for the foreseeable future. However, it is recognized that ionizing radiation can cause harm and it is therefore important that the users of radiation are aware not only of the clinical benefits, but also of the possible risks to their patients and themselves and the legislation that is in place to control the risks (Table 1.3).

Table 1.3 — Common imaging examinations, their cost, radiation risk of fatal cancer and equivalent to number of cigarettes smoked

Examination	Cost^{-1} ($) (in Europe)	Dose (mR)	Risk of fatal cancer (per million)	Equivalent to number of cigarettes smoked
Chest (PA, Lateral)	130	100	1.6	12
Abdomen (supine, upright)	130	1500	48.0	350
Wrist	110	4	—	—
Lumbar (5 view)	200	900	85.0	615
Mammogram	200	300	4.0	29
Barium enema	300	5000	350.0	2540
Intravenous urogram	330	600/image	170.0	1225
Abdominal angiogram	1500	150 /image	—	—
Cranial CT	700	4500	72.0	525
Chest CT	800	1500	300.0	2280
Abdominal CT	830	3500	300.0	2220
Abdominal ultrasound	500	0	0	—
Pelvic obstetric US	550	0	0	—
Cranial MR	1200	0	0	—
Pelvic MR	1200	0	0	—
Bone scan (radionuclide)	300	300-whole body	—	—
Lung scan (radionuclide)	300	1000-lung, 60-whole body	—	—

Distance

The intensity of X-radiation decreases with the square of the distance from a point source and applies at distances greater than 1 m from an irradiated patient or a patient containing radionuclide. Application of the use of distance is seen in the following practices:

— Making as full a use as practicable of the length of the exposure cable in fluoroscopy or mobile radiography.

— Ensuring adequate distance between patients when they are radiographed.

— Stepping back when carrying out image acquisition in a fluoroscopy act.

— Using remote handling tools to maximize the distance of the hands from a radioactive source.

— Arranging the nuclear medicine waiting area so that injected patients do not have to wait in close proximity to reception staff or visitors.

— Ensuring nuclear medicine patients returning home are given instructions if they should avoid close contact with others for a period of time.

Time

The amount of radiation received is directly proportional to the length of the exposure time and so may be minimized by conducting procedures as quickly as possible. Application of the use of time to minimize dose is seen in:

— Use as fast imaging systems as practicable to reduce exposure times.

— Use of image storage facilities and last image hold.

— Training, including the use of simulators to practise technique, so that the procedure can be done as quickly as possible in the patient.

— Practicing radioactive manipulations with an inactive material.

Shielding

Positioning of a barrier between the source of radiation and the recipient will reduce the dose by an amount dependent on the energy of the radiation source and the nature and thickness of the barrier. It is most effective to place barriers as close to the radiation source as practicable. The use of shielding is seen at all levels — from the design of an X-ray room and provision of protective clothing, down to syringe shields used in nuclear medicine.

In undercouch fluoroscopy, the X-ray tube is located beneath the table, while the intensifier is mounted above. Most of the scattered radiation is in the downward direction (with the table horizontal) and is absorbed in the floor or the protection side-panels of the table.

Staff working close to the patient during fluoroscopic procedures should wear a personal protection consisting of lead-equivalent aprons. Aprons of 0,3 mm lead equivalent attenuate the radiation by a factor of about 10, depending on the thickness and the kVp and provide a reasonable compromise between weight and attenuation.

Dose monitoring

There is a legal requirement for radiation doses to be monitored. This is normally done by film or termoluminescent dosimeter badges to assess the whole body dose. The badge should be positioned at a waist level under the lead apron if one is worn. In addition, if there is potential for the eyes, hands, feet to be irradiated significantly, additional dosimeters should be worn to assess these doses.

Protection of patient

Each exposure justified on a case-by-case basis. Minimize number of X-ray films taken and minimize screening time. Only trained personnel to ope-rate the equipment. Good equipment to be used including rare earth screens, adequate filtration of X-ray beams, etc. Use ultrasound or MRI where possible. Quality assurance programmes in each department, including correct installation, calibration and regular testing equipment.

Protection of staff (including medical students) from radiation

Only the necessary staff to be present in a room where X-ray procedures are being performed: TV monitors placed outside the screening room usually mean that students may observe procedures at a safe distance. Staff to wear protective clothing (e.g. lead aprons). At no time should staff be directly irradiated by the primary beam: lead gloves must be worn if the hands may be irradiated (e.g. in immobilizing patients or performing stress views). There is no threshold for stochastic effects so any imaging procedure or therapy that involves the use of radiation involves some risk. When performed properly, the risk is usually very small and is far outweighed by the medical benefit of having the procedure. Regardless, the concept of ALARA (keeping the radiation dose As Low As Reasonably Achievable should always be employed to minimize the risk).

Radiation therapy and interventional fluoroscopy procedures may result in radiation doses that exceed the threshold dose for skin injuries, and less frequently for cataract induction. The procedures performed in these areas are often life-saving and every effort to minimize the magnitude of these effects is taken.

Radiation risks

Radiation risk calculations are based on the type of radiation, amount of energy absorbed, and which part of the body these energies is deposited. For example, certain amount of radiation energy deposited to the wrist has really no effect, however, similar amount of energy deposited to blood forming organ may have an effect. The probability of cancer induction is low at a low dose but never zero theoretically and therefore calls for the optimization of radiation doses for all radiological investigations. One should keep in mind that it is not possible to differentiate or detect the cancer caused by diagnostic X-rays from cancer caused by other factors, such as environmental, chemical or biological. The latency period of cancer induction may be in years or even in a decade. This may be true for all carcinogens include radiation. This is especially true for a low dose and a low-dose rate radiation. If the low level of radiation exposure has occurred today, its effect as a cancer may be expressed after a few years of exposure.

II. RADIOLOGY OF MUSCULOSKELETAL SYSTEM

Introduction

Musculoskeletal radiology has emerged as an important subspecialty in radiology and currently gains increasing significance due to age-related diseases of the musculoskeletal system. A number of imaging modalities are available, the most important for learning, being conventional radiography.

Examination techniques of musculoskeletal system

Routine radiography

Today, routine radiography continues to be the most appropriate screening technique for musculoskeletal disorders. Appropriate evaluation of routine radiographs results in diagnosis or selection of the next most appropriate imaging procedure.

Multiple views are required for minimal evaluation of osseous and articular anatomy. Specific views will be discussed in subsequent anatomic chapters. In some cases, fluoroscopically positioned spot views are useful to optimize positioning and reduce a bony overlap. This approach is especially useful in the foot and wrist. This technique is also appropriate to evaluate interfaces of arthroplasties and metal fixation devices. Fluoroscopic positioning is particularly useful in the shoulder and knee.

Computed tomography

CT is a fast and efficacious technique for evaluating the musculoskeletal system. The basic components of the system are a gantry, which houses a rotating x-ray tube and radiation detectors, and a movable patient table. The output of the radiation detectors is manipulated by a computer to produce the images. The table is moved in increments to obtain axial images with conventional scanners. Spiral (helical) scanners move the patient continuously as the tube and detectors rotate, resulting in a spiral volumetric data set. Skeletal imaging is typically performed using sections 3 to 5 mm thick, but thinner sections are used for, a fine detail, if reformatting, or if three-dimensional reconstruction is required.

CT is particularly suited for evaluating complex skeletal anatomy in the spine, shoulder, pelvis, foot, ankle, hand, and wrist. Thin-section images allow reformatting in multiple planes. This provides an excellent osseous and articular detail. CT characterizes complex fractures (pelvis, ankles, hips). Precontrast and postcontrast images (intravenous iodinated contrast) are useful for evaluation of the soft tissue lesions. CT is useful for evaluating numerous musculoskeletal disorders, including neoplasm, arthropathies, and subtle or complex fractures.

Magnetic resonance imaging

MRI is a proven technique with expanding musculoskeletal applications. Most imaging is performed at 1,5 Tesla; however, 3T imaging is more common today, and there are multiple open bore units and extremity units available at lower field strengths for musculoskeletal imaging. Obvious risk factors, such as cardiac pacemakers, cerebral aneurysm clips, metallic foreign bodies, and electronic devices, which may place the patient at risk, can be detected using the questionnaire and with verbal clarification of questions from patients. When metallic foreign bodies are suspected, radiographs or CT should be obtained for confirmation.

Metallic implants may create artifacts that significantly degrade an image quality, especially if the implants contain ferromagnetic impurities. Fortunately, most orthopedic implants, except screws, cause a minimal local distortion. The extent of the image degradation depends on the size and configuration of the implant. Cast material do not create significant image artifacts.

Ultrasound

Musculoskeletal applications for ultrasound have expanded considerably in recent years. The joints, soft tissues, and vascular structures are particularly suited to an ultrasound examination. Evaluation of the cortical and trabecular bone is now feasible and permits examination of the calcaneus for osteoporosis. Because of its low cost and availability, ultrasound is now used more frequently to evaluate various conditions of the soft tissues and bones.

Nuclear medicine

Bone scan (osteoscintigraphy) is inexpensive, very sensitive for detecting occult fractures. PET scanning is most often used in the diagnosis and treatment follow-up of cancer. It is frequently used to locate hidden metastases from an known tumor or to detect recurrence. Oncologic PET scans make up about 90 % of the clinical use of PET.

Normal radiographic anatomy bones

Before exploring the general principles describing diagnostic image it is important to understand some of the anatomical structures used in a skeletal system. The human skeleton contains more than 200 bones. All of these bones can be classified into five groups based on shape. Below are the definitions and a few examples of the bone classifications.

— Long bones — bones of the extremities that have a length greater than the width (e.g., femur) (Figure 2.1).

— Short bones — bones of the wrist, ankle and foot that are cuboidal in shape (e.g., carpals and tarsals).

— Flat bones — diploic bones of the vault of the skull (e.g., parietal and frontal) and the iliac bone.

— Sesamoid bones — small, rounded bones located in tendons.

— Irregular bones — bones have irregular shapes (e.g., vertebrae, coccyx).

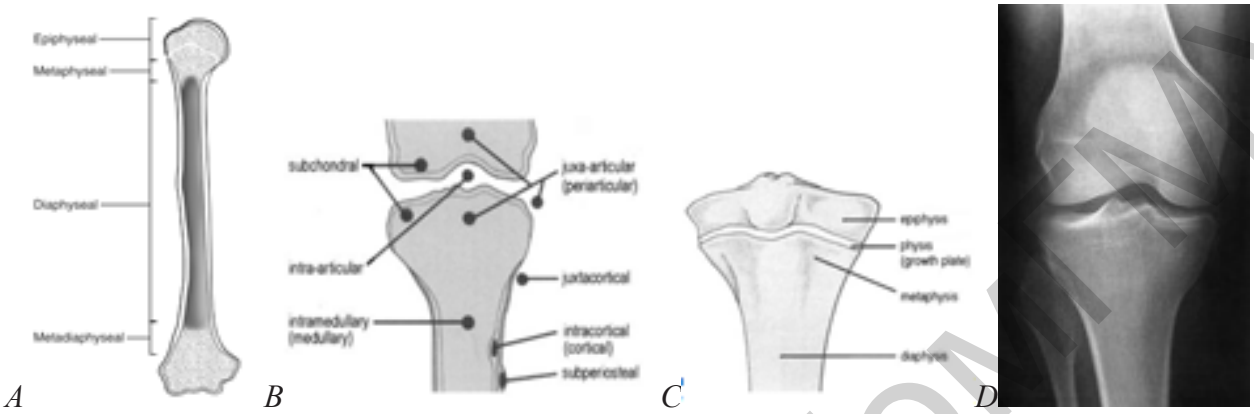


Figure 2.1 — (A) The principal parts of a long bone, in this case the femur. (B) Terminology used to describe the different portions of a long bone and terminology used to identify the location of a lesion in the long bone of the growing skeleton. (C) At maturity (post-skeletal fusion) the physis (growth plate) fuses and is no longer visible. (D) Normal knee frontal radiograph (adult patient)

For precise assessment of skeletal age, the Greulich and Pyle atlas or similar publications should be consulted. Table 2.1 outlines the age of appea-rance and fusion of the primary and secondary ossification centers.

Table 2.1 — Outlines the age of appearance and fusion of the primary and secondary ossification centers. Wrist and hand: approximate age of appearance and fusion of ossification centers (examples)

Ossification center	Primary (P) or secondary (S)	No. of centers age of appearance	Age of appearance	Age of fusion (years)
Wrist				
Capitate	P	1	Birth to 6 months	
Triquetrum	P	1	1–3.5 years	
Navicular	P	1	3–9 years	
Pisiform	P	1	7–13 years	
Distal radial epiphysis	S	1	6–24 months	20–25
Distal ulnar epiphysis	S	1	5.5–9.5 years	19–25
Hand				
Metacarpal heads	S	4	10–24 months	14–21
Phalangeal bases	S	4	1–2.5 years	14–21
Phalangeal bases (first)	S	1	1–2.5 years	14–21

A thorough understanding of normal developmental anatomy is essential for accurate interpretation of radiographs of the pediatric wrist and hand (Figure 2.2). These radiographs show the radiographic appearance of many important ossification centers and other developmental landmarks from infancy through adolescence. Both the chronologic age and skeletal age are listed for each of these examples.

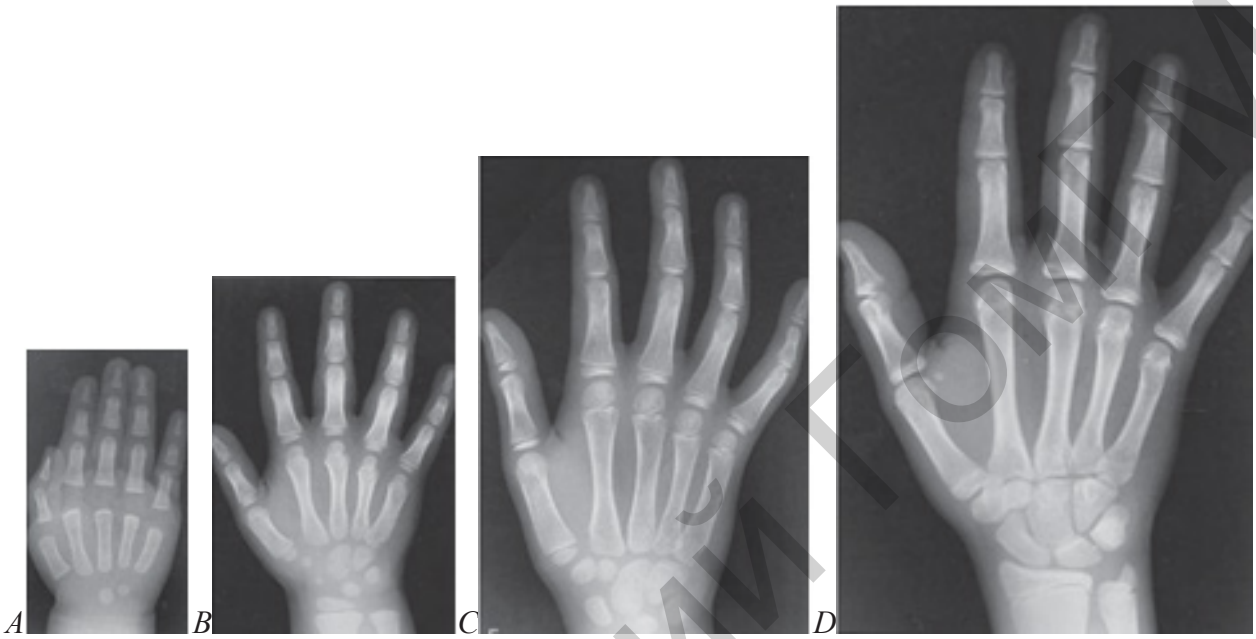


Figure 2.2 — Skeletal maturation and normal development: posteroanterior radiographs of the hand and wrist. (A) Male; CA = 13 mo; (B) Female; CA = 4 yr; SA = 4 yr. (C) Male; CA = 7 yr; SA = 7 yr. (D) Female; CA = 15 yr; SA = 13 yr. CA, Chronologic age in months (mo) or years (yr); SA, estimated skeletal age in months (mo) or years (yr). Note: These radiographs were randomly selected from teaching files from a variety of sources to demonstrate only general trends in osseous development

Bone age assessment is frequently performed in pediatric patients to evaluate growth and to diagnose and manage a multitude of endocrine disorders and pediatric syndromes. There is still good correlation between Greulich and Pyle atlas skeletal age and mean chronological age in modern populations.

X-ray diagnostics of skeletal trauma

The easiest way of showing a fracture in a bone is using conventional x-rays. Radiography is the mainstay for assessment of acute extremity trauma. Fractures are usually diagnosed on conventional radiographs, which should be obtained at least in two different projections. CT and MRI are often utilized to detect injuries not visualized on radiographs and to depict the full extent of underlying osseous and soft tissue injuries. Fracture is a broken bone. Fractures can be classified according to the type and complexity of the break, the location of the break, and certain other special features.

Classification of fractures

1. Complete, incomplete and comminuted.

At complete fracture the line of fracture intercrosses both cortical layers of a bone; the rift intercrosses one cortical layer and disappears inside a bone. The bone breaks completely into pieces.

Incomplete (partial): the bone does not break completely into two or more pieces. Comminuted: a fracture that results in more than two fracture fragments.

2. Localization:

— Epiphyseal.
— Metaphyseal.
— Diaphyseal.
— Apophyseal.

3. Direction of a line of fracture:

— Transverse fracture.
— Longitudinal fracture.
— Oblique fracture.
— T-shaped fracture.
— V-shaped fracture.
— Impacted fracture: the bone is broken when one part is forcefully driven into another.

4. Traumatic and pathologic.
5. Intraarticular and extraarticular.
6. Apophyseolisis.
7. With and without displacement of fragments (Figure 2.3).

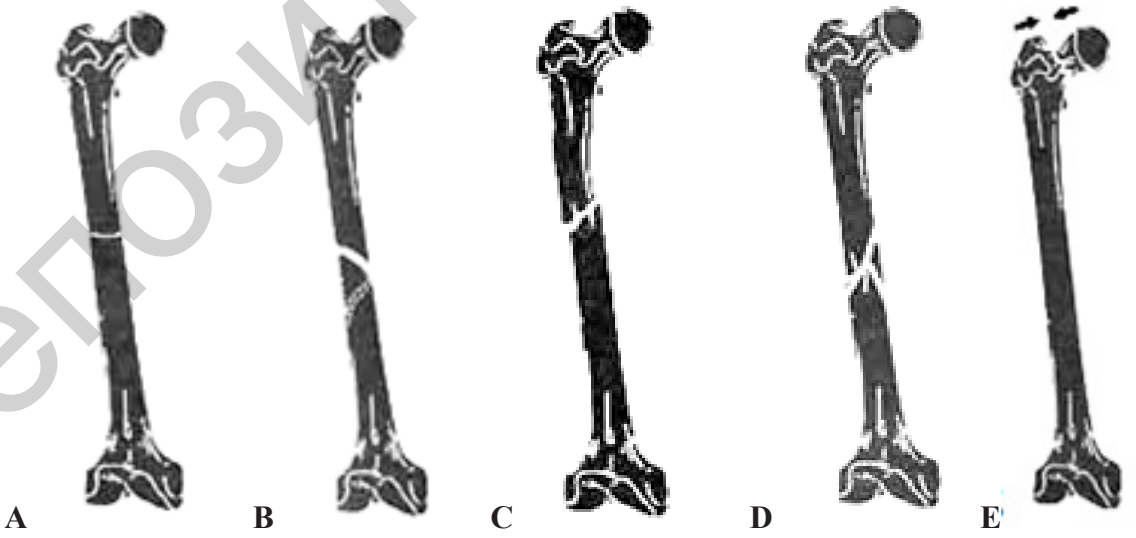


Figure 2.3 — Diagram (A to E) common the X-ray signs of fractures patterns. (A) Transverse fracture; (B) spiral fracture; (C) oblique fracture; (D) comminuted fracture (2 or more fragments); (E) impacted fracture (arrows)

Fracture definition: a complete or incomplete break in the continuity of bone or cartilage. Here are the definitions for the fracture patterns:

— Simple transverse fracture — a fracture in which the fracture line is perpendicular to the long axis of the bone and that results in two bone fragments.

— Spiral fracture — a severe form of oblique fracture in which the fracture plane rotates along the long axis of the bone. These fractures occur secondary to rotational force.

— Avulsion fracture — a fracture in which the tendon is pulled away from the bone, carrying a bone fragment with it.

Radiographic symptoms of fractures

1. Direct signs:
— Line (plane) of fracture.
— Displacement of bone's fragments.
2. Indirect signs:
— Enlargement of volume of soft tissues (an edema and hematoma).
— Step-shaped deformation of cortical layer.
— Breakage of cortical layer.

Displacement of fragments at a bone fracture

Fractures are also described in terms of alignment. Below are the definitions of the various types of alignment that result from the fracture patterns just described. Displacements are described according to the direction of the movement of the distal fragment relative to proximal fragment (Figures 2.3–2.4).

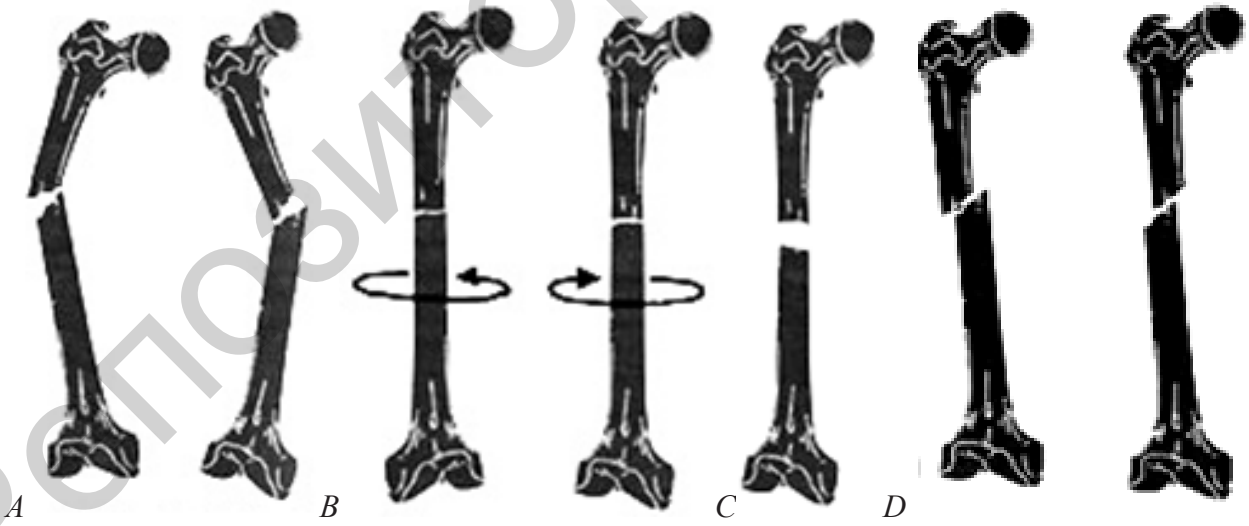


Figure 2.4 — Diagrams of fractures (A to D). (A) Varus vs valgus — varus and valgus deformities are both angulations. In varus deformity, there is apex angulation away from the midline and the distal structure moves medially. In valgus deformity, there is apex angulation toward the midline and the distal structure moves laterally. (B) Rotation of fragments. (C) Distraction — longitudinal separation of fracture fragments. (D) Displacement of fragments medial vs lateral

— Longitudinal displacement with a divergence of fragments (distraction) — is a separation of fragments.

— Longitudinal displacement with convergence of fragments (fore shortening) — fragments override each other.

— Longitudinal displacement with impacting fragments — occurs when fragments have been driven together.

— Angular displacement (angulation) — occurs when there is an angular deformity created by fragments.

— Rotation — occurs when fragments rotate over long axis.

— Displacement is a change in the anatomic axis of lateral fragment with respect to proximal fragment.

Fractures through abnormal bone are called "pathological" fractures. Pro-bably the most common cause of this is an underlying tumor, either benign or malignant.

With chronic repetitive stress, one can break any bone in the body. If the fracture is fairly new, then there may be no plain film evidence of it. Later, once the fracture has been around long enough, periosteal reaction is often seen adjacent to the fracture site. A radionuclide bone scan or MRI can be used to screen for stress fractures. The bone scan will show a stress fracture as an area of increased uptake of tracer, while MRI will show focal or diffuse marrow edema at the fracture site.

The main reason prompting the early diagnosis of stress fracture is so that the patient can be advised to rest the affected part. If the affected part continues to be loaded, then a stress fracture may develop into a completed fracture through the bone.

Fractures in children

The patterns of bony injuries in the child are somewhat different to the adult as the skeleton is more elastic and less brittle. Children have fractures more often than adults because children have slender bones and are more active.

Healthy bones of children mend faster and better than the more brittle bones of older people. (A femur broken at birth is fully united within 3 weeks, but a similar break in a person over 20 may take 5 months to heal completely.

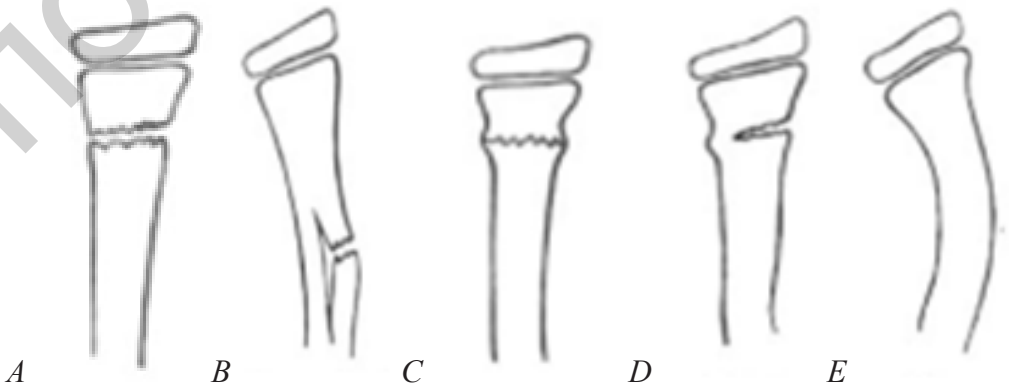


Figure 2.5 — (A to E) Diagrams of typical fracture patterns in children. (A) Complete fracture. (B) Greenstick fracture. (C) Buckle fracture. (D) Lead pipe fracture. (E) Bow fracture

Fractures in children (Figure 2.5) are classified as:

— Complete.

— Greenstick fracture. A greenstick fracture is an incomplete fracture. The cortex is broken on one side and buckled on the other with a bending deformity concave to the buckled side.

— Torus (buckle) fracture. A buckle fracture is a buckling of the cortex produced by compression (impaction) forces.

— Pipe fracture. A pipe fracture is a combination of an incomplete transverse fracture of one cortex and a torus fracture of the opposite side.

— Bowing injury. A bowing injury results without a line of fracture.

— Epiphyseal/metaphyseal fractures.

— Avulsion injuries.

— A fragment of the bone may be avulsed (pulled-off) at the insertion of a ligament or tendon at any age.

Fracture healing

Successful fracture healing is dependent on a fragment apposition, fracture fixation, and ample blood supply.

Consolidation. Osteoclasts are introduced with the penetrating capillary buds and assist the osteoblasts to alter the bone callus from the woven to the lamellar bone. Callus — new bone formed at/around fracture site approximately 3 weeks after the initial trauma. It is visible on a radiograph. X-ray signs of fracture's consolidation:

— Smoothing the bone's margins (at recent fracture they are sharp).

— Tender calcifications in fracture area (in 3 weeks after trauma).

— Bone callus formation.

— Disappearance of fracture line.

Remodeling. Over a period of months to years, the bony bridge is remo-deled to the pretrauma size and shape, or as near to it as possible. Excessive callus is removed and the medullary canal is recanalized. Children have greater powers of remodeling and may correct deformities and even discrepancies of length after a fracture.

The time it takes for union varies depending on age, health status, and bone injured. Generally a weak bone callus is formed by weeks 3 to 6, becoming thicker over months. This callus may be faintly seen on radiographs. Healing continues as the bone regains much of its initial strength by 3 to 6 months [4].

Dislocation and subluxation

Dislocation — complete disalignment of articular surfaces, complete and constant shift of the articular ends of bones (Figure 2.6). It is considered to be dislocated a peripheric (distal) bone.

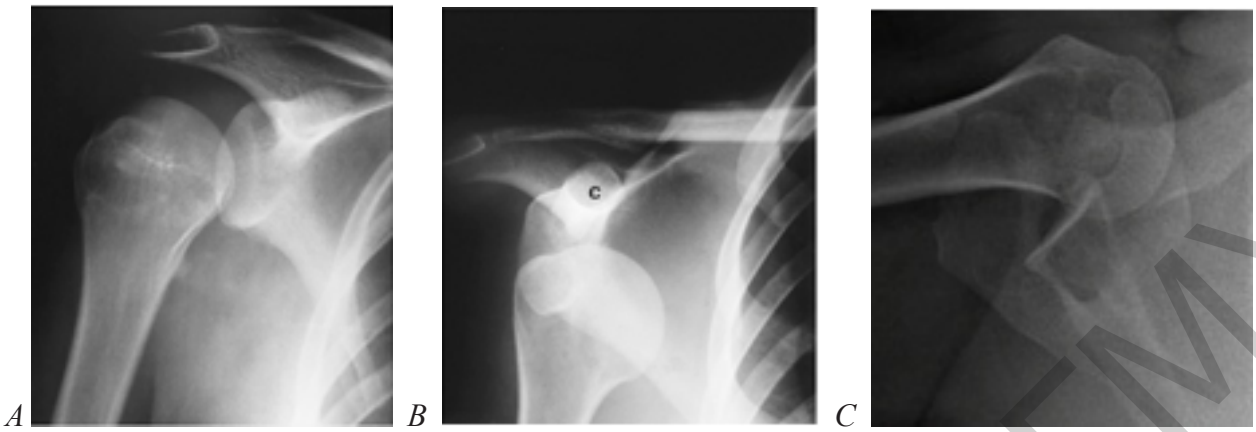


Figure 2.6 — (A) Normal anteroposterior view region of the right shoulder. Note in this example of a normal shoulder that the humeral head slightly overlaps the glenoid, which has been termed the crescent sign. (B) Anterior shoulder dislocation, anterior view. An anteroposterior view of the right shoulder shows the humeral head to lie medial to the glenoid and inferior to the coracoid process (c). This is diagnostic of an anterior dislocation of the shoulder. (C) Anterior shoulder dislocation, axillary view

The main X-ray signs of a dislocation: complete absence of contact of articular surfaces with complete incongruence of articular surfaces, apposition between them is lost. Dislocation may occur in isolation or with a fracture (so-called fracture-dislocation).

The main X-ray signs of a dislocation:

— Joint is dislocated when its articular surfaces are wholly displaced one from the other, so that apposition between them is lost.

— Subluxation exists when the articular surfaces are partly displaced but retain some contact with each other.

— Dislocation may occur in isolation or with a fracture (so-called fracture-dislocation).

Subluxation — incomplete conformity (discrepancy between) of articular surfaces. Subluxation exists when the articular surfaces are partly displaced but retain some contact with each other. The main X-ray signs of a subluxation:

— Incomplete conformity (dislocation) of articular surfaces .

— Clinoid deformation of an X-ray articular fissure.

— Shift of an axis of the dislocated bone.

Order of radiological examination of fractures and dislocation to included rule of 2's:

— 2 views — AP and lateral.

— 2 joints — include the joints above and below fracture.

Additional views should be pursued when there are uncertainties in areas with complex anatomy.

When describing a fracture, one should describe the location, pattern and alignment. Remember, the alignment is described for the distal fragment relative to the proximal, with the patient in anatomical position.

The plan of the description of a roentgenogram at trauma:

— Image's name, age (osteal age).

— Area and of projection (view) of examination.

— Method of examination.

— At presence of fracture specify it on classification.

— Are there signs of a consolidation (smoothing of fragment's edges, pre-sence of osteal callus)?

— Is there a luxation (subluxation)?

— Conclusion (diagnosis) (Example: Oblique complete fracture of a distal thirds of diaphysis of the right humerus with a lateral displacement 2cm of distal bone fragment and 1cm distraction).

Non tumour diseases of skeleton

The non tumour diseases of bones and joints can be divided into majority of groups among which the main are the next: inflammatory diseases, degenerative diseases and lesions at defects of the mineral metabolism (Figure 2.7). Among the inflammatory diseases the most common are osteomyelitis and tuberculosis of bones and joints but other infections and even aseptic inflammation is possible. Degenerative bones and joints diseases are very common in clinical practice and the X-ray examinations allow to reveal it in the majority of cases.

Metabolic bone disease

Metabolic bone disease is best shown using x-rays. The commonest metabolic bone disease is osteoporosis, and this is best shown using a dual energy x-ray absorption scan, which scans the lumbar spine and pelvis on a special machine, and gives a value for bone density, compared with a standard matched for age, sex, and ethnic origin. This is a reproducible test, and can be used serially to monitor treatment for osteoporosis.

Osteoporosis — decrease of amount of osteal matter without change of a bone volume. X-ray signs: thinning of cortical layer of bones, dilatation of the medullar canal, increase of a bone transparency for X-rays. Osteoporosis is characterized by diminished bone density with otherwise normal bone architecture, whereas osteomalacia (in adults) or rickets (in children) is characterized by a normal bone density in the setting of abnormal quality of the bone. Both may manifest as osteopenia (i.e., diffusely inreased lucency of bone) on radiography or CT.

Osteosclerosis — thickening and increase of amount of osteal trabecules in a constant volume of a bone, thickening of cortical layers, narrowing of the medullar

canal. The volume of a bone does not change. The osteosclerosis can be physiological, pathological (posttraumatic, inflammatory, toxic), idiopathic.

Hyperostosis — increased amount of osteal tissue with the increase of the bone's volume.

Osteodestruction — destruction of a bone with displacing by pathological tissue (tumoral tissue, pus, granulations, etc.). It is detected at an osteomyelitis, tuberculosis, tumors, etc.

Osteonecrosis — necrosis of a fragment of a bone as a result of affection of its nutrition, inflammatory lesion, radiation injury or functional overload (Figure 2.7).

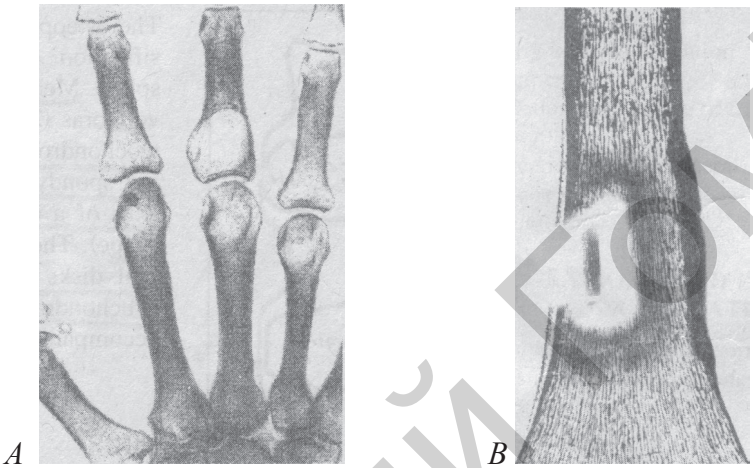


Figure 2.7 — (A) POSITIVE radiograph of part hand frontal projection. Local osteoporosis (white color) of phalanges and metacarpal bones. Rheumatoid arthritis. (B) Scheme sequestration, at the centre of a bone cavity is sequester of a linear shape

Sequestration — casting-off of a dead fragment of a bone. The formation of a sequester is always preceded by an osteonecrosis. It is detected at bone's tuberculosis or osteomyelitis.

Periosteal reactions

The periosteum is a membrane several thick layers of cell that covers almost of every bone. About the only parts not covered by this membrane are the parts covered by cartilage. Besides covering the bone and sharing some of its blood supply with the bone, it also produces a bone when it is stimulated appropriately. What does it take to make this happen? Practically anything that breaks, tears, stretches, inflames, or even touches the periosteum.

With slow-growing processes, the periosteum has plenty of time to respond to the process. That is, it can produce a new bone just as fast as the lesion is gro-wing. Therefore, one would expect to see a solid, uninterrupted periosteal new bone along the margin of the affected bone (Figure 2.8).

With rapidly growing processes, the periosteum cannot produce a new bone as fast as the lesion is growing. This may result in a pattern of one or more concentric

shells of a new bone over the lesion. This pattern is sometimes called lamellated or "onion-skin" periosteal reaction.

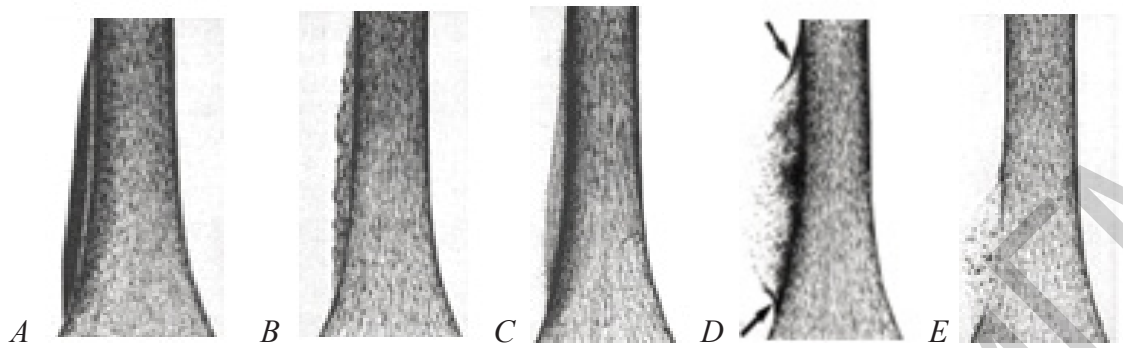


Figure 2.8 — The schemes various types of periosteal reaction. Types A and B are benign in appearance, and may be described as (A) thick and (B) undulating. Types C through E are more aggressive and more likely malignant and may be described as (C) lamellated or "onion skin", (D) perpendicular or "sunburst» (Codman's triangle figures, arrows), and (E) amorphous

Although not a perfect indicator, the pattern of periosteal reaction is one visual manifestation of a lesion's biological behavior.

If the lesion grows rapidly but steadily, the periosteum will not have enough time to lay down even a thin shell of the bone, and the pattern may appear quite different. In such cases, the tiny fibers that connect the periosteum to the bone ossify, they produce a pattern sometimes called "sunburst" or "hair-on-end" periosteal reaction.

Another pattern seen in rapidly growing processes is called the Codman's triangle. This is a bit of a misnomer, since there is really not a complete triangle. When a process is growing too fast for the periosteum to respond with even thin shells of a new bone, sometimes only the edges of the raised periosteum will ossify. When this little bit of ossification is seen tangentially on a radiograph, it forms a small angle with the surface of the bone, but not a complete triangle.

If we see a solid pattern of a periosteal reaction, the usual way that this may manifest is when there is a fracture or infection in the same area as a tumor. In this case, we may see a fairly complex pattern of a periosteal reaction that demonstrates some elements that look benign and some that look very aggressive.

Causes of solid periosteal reaction:

— Infection.
— Benign neoplasm.
— Eosinophilic granuloma.
— Hypertrophic pulmonary osteoarthropathy.
— Deep venous thrombosis (lower extremity).

Causes of aggressive periosteal reaction: osteomyelitis; malignant neo-plasm (osteosarcoma, chondrosarcoma, metastasis.

Approaches to arthropathies

Many classifications of joint diseases are available based on differing criteria (X-ray appearances, a etiology, etc.). It is most useful to decide first whether there is an involvement of a single joint (monoarthropathy), or multiple joints (polyarthropathy).

Polyarthropathies may be divided into three large categories: inflammatory, degenerative, metabolic.

These arthropathies tend to present with symmetrical arthropathy involving the peripheral small joints, especially the metacarpophalangeal and proximal interphalangeal joints. X-ray signs may be subtle and include soft tissue swelling and periarticular osteoporosis. Erosions are less common than with rheumatoid arthritis (RA). Soft tissue calcification is common, especially around joints. Inflammatory arthropathies present with painful joints with associated soft tissue swelling.

The presence of crystal deposits (chondrocalcinosis or tophi) indicates one of the crystalline arthropathies. In calcium pyrophosphate dehydrate deposition (CPPD) disease, the most common site of radiographic calcifications is in cartilage and in the joint capsule or synovial membrane.

Degenerative conditions

Degenerative bone disease is common, and is most usually imaged with conventional x-rays, although a degenerative change in the soft tissue is best shown with using ultrasound.

A common etiology for osteoarthritis of the knee joint is the development of a varus or valgus deformity at the knee. In a varus deformity, increased stress applied across the medial femurotibial articulation; in a valgus deformity, the increased stress is applied across the lateral femurotibial articulation. In either deformity, the stress produces subchondral osteosclerosis in the underlying tibial condyle and loss of its articular cartilage. Other common findings are periarticular osteophytes (a consequence of the subchondral bone formation and remodeling) and subchondral cysts.

The radiographs were taken with the patient standing upright, so as to show the configuration of the knee when weight-bearing. The pertinent findings exhibited in the radiographs are as follows:

— The AP view shows a varus deformity at the knee. There is a marked loss of articular cartilage in the medial femurotibial articulation, as evidenced by the almost obliterated space between the medial femoral and medial tibial condyles. Such localized narrowing of a joint cartilage space is characteristic of osteoarthritis.

— There is subchondral osteosclerosis of the medial tibial condyle, as evidenced by the fact that the subchondral bone of the medial tibial condyle is more radiopaque than that of the lateral tibial condyle.

— The AP view shows periarticular osteophytes along the medial margin of the medial tibial plateau.

— The lateral view suggests that there is also narrowing of the patelofemoral joint space.

— The AP and lateral radiographs together show a calcified body behind the medial part of the distal femur.

Deforming arthrosis — slowly developing degenerative non-inflammatory disease of joints, mostly large jonts, mostly in elder people and occur due to intensive physical activity, vibrations, traumas, etc. Pathological changes might be localized in a single joint or multiple affections are possible. In the basis of the disease is the degenerative process and destruction of the articular hyaline cartilage and the follow-up affection of the articular surfaces of the bones (Figure 2.9). The main radiologic changes detected are:

— Narrowing of the joint space (at the severe affection, up to disappearance of the joint space).

— Sclerosis of the opposing articular surfaces.

— Roughness of the articular surfaces.

— Marginal bone peaks (osteophytes).

Additional findings: cystic bone resorption (so-called pseudocysts), osteoporosis, luxations and subluxations.

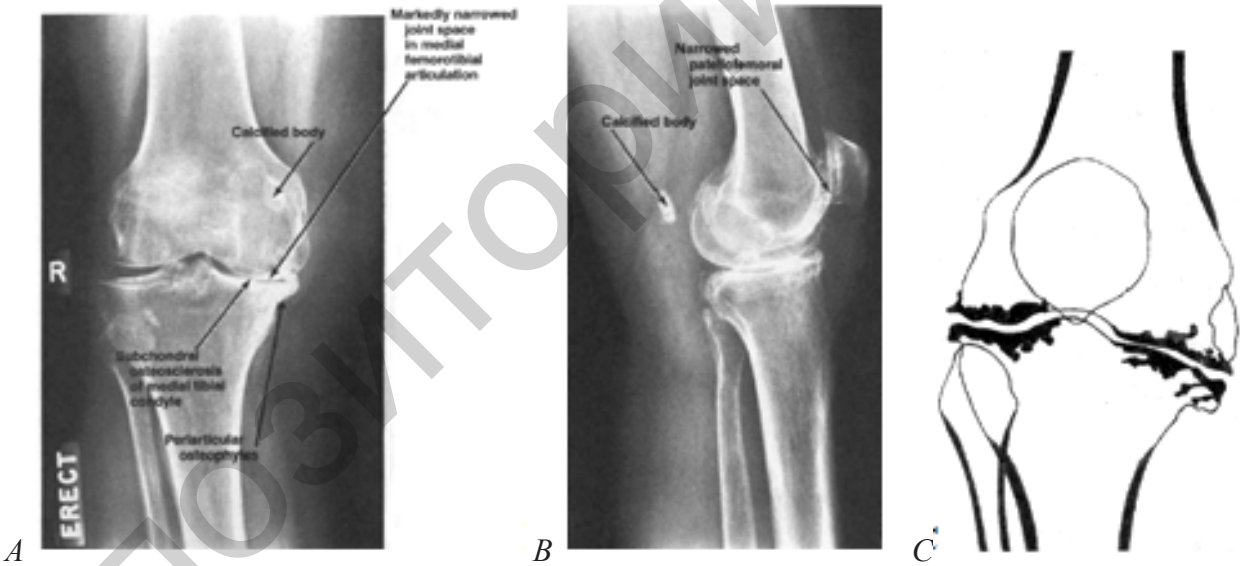


Figure 2.9 — The frontal (A) and lateral (B) radiographs show evidence of severe osteoarthritis of the right knee, x-ray showing serious degenerative disease. (C) Scheme of deforming arthrosis. Markedly narrowed of the joint space, osteosclerosis (subchondral) of articular surfaces, marginal bone peaks — periarticular osteophytes (lateral and medial surfaces of knee)

Degenerative: osteoarthritis.

Primary osteoarthritis (OA) refers to degenerative arthropathy with no apparent underlying or predisposing cause. Secondary OA refers to degenerative change complicating underlying arthropathy such as RA, trauma or Paget's disease. Distribution

of primary OA: asymmetric, large weight-bearing joint (hip, knee). X-ray signs of OA include:

— Secondary degenerative change with subchondral cysts and joint space narrowing is common.

— Osteophyte formation.

— Periarticular erosion and cyst formation.

— Periarticular sclerosis.

— Loose bodies due to detached osteophytes and ossified cartilage debris.

Any joint in the body can be affected by secondary osteoarthritis due to trauma, infection or another arthropathy. However, the findings of primary (idiopathic) osteoarthritis are usually seen in the distal interphalangeal and metacarpal joints.

Arthritis

Radiographic hallmarks: in general, the presence of erosions bespeaks some type of inflammatory disease, whether the erosions are due to synovial hypertrophy, crystalline deposits, or infection. Osteophytes can be seen in both primary and secondary osteoarthritis. Osteophytes can also be seen at various entheses (sites of tendinous or ligamentous attachment to the bone), often due to altered or increased stress there.

Other findings, such as joint space narrowing, subchondral sclerosis, subchondral cyst formation, ankylosis, or subluxation are not especially specific and may occur in a wide variety of degenerative or inflammatory disorders in the appendicular skeleton. It is important to describe these findings, as they tell us a lot about the severity of the patient's disease — it is just that they do not tell us a whole lot about what specific disease is causing them.

Septic arthritis: joint may be radiographically normal at the time of the initial pre-sentation. Later a joint effusion and swelling of surrounding soft tissues may occur, followed by bone erosions and destruction.

Rheumatoid arthritis

Rheumatoid arthritis (RA), characterized by periarticular osteoporosis, marginal erosions, boutonniere deformity, swan neck deformity, subluxations, and dislocations, tends to affect the metacarpophalangeal joints and proximal interphalangeal joints (Figure 2.10).

Radiographic symptoms:

— Symmetrical distribution.

— Affects predominantly the small joints, especially hand and wrist.

— Bone erosions: occur earlier in the feet than the hands.

— Periarticular osteoporosis.

— Abnormalities of joint alignment: subluxation of joints.

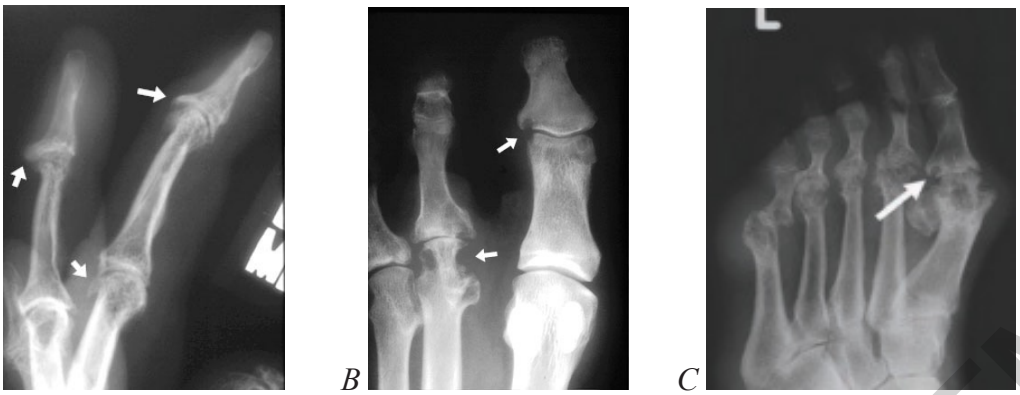


Figure 2.10 — (A) Marked osteophytosis (arrows) and (B) erosions (arrows) at rheumatoid arthritis. (C) Frontal radiograph part of the foot, rheumatoid arthritis. Subluxation, concentric loss of joint space, erosions (arrow), and the destruction of the articular surfaces are hallmarks of RA. The soft tissue swelling is anticipated

Osteomyelitis

Osteomyelitis is an infection of the bone and the bone marrow. Although it is usually caused by bacteria, it can also be caused by fungi and other microbes. Although any bone can develop an infection, the bones of the knee, hip, and shoulder are most commonly affected. Osteomyelitis tends to affect long bones, particularly those in the lower extremities. In children, hematogenous osteomyelitis is usually located in the metaphyseal region of long bones, with the most commonly affected bones being the femur and tibia. The epiphysis is more commonly involved in neonates and adults than in children.

Plain film radiography may not detect the early stages of bone infection, the features of which often do not appear for several weeks or even months after implantation; repeat examinations are usually necessary. One of the earliest signs of osteomyelitis is deep soft-tissue swelling. Distortion or obliteration of fat planes and subcutaneous edema may be evident 3 to 10 days after infection. Focal osteopenia within the medullary cavity typically occurs first, followed by cortical destruction in a focal or multifocal presentation (Figure 2.11). Radiographic symptoms of osteomyelitis includes:

— Usually normal for up to 7–14 days following infection.
— Soft tissue swelling, loss of fat planes.
— Metaphyseal destruction and periosteal reaction.
— Epiphyseal lucency in infants.

During the middle stage of osteomyelitis, a cortical breach develops and leads to periostitis approximately 3 to 6 weeks after infection. As suppurative osteomyelitis develops, pus moves into the vascular channels, raising the intramedullary pressure and impairing blood flow. Ischemic necrosis hastens the damage and results in the pockets of the dead bone called sequestra. The sequestra appear no earlier than 3 weeks after infection.

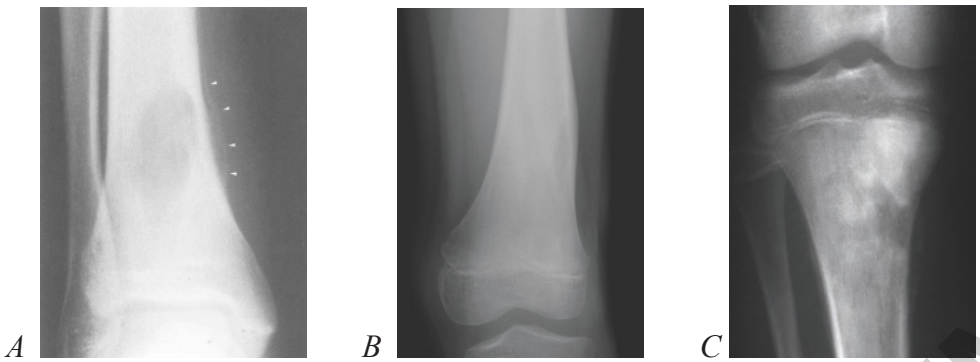


Figure 2.11 — Frontal radiographs of the leg. (A) Osteomyelitis (i.e. Brodie's abscess). Magnified radiograph of the right ankle showing a large lytic tibial lesion. Notice the periosteal reaction medial to the tibia (arrow heads) and soft tissue component. (B) Radiograph of the distal thigh showing a lytic lesion of medial area of femur at early osteomyelitis. (C) Chronic osteomyelitis of proximal tibia

Tuberculosis of bone

Tuberculosis of the skeleton is a pathology that was rare in recent times, except in those areas where there is recent immigration from the third world. Since more than a third of our catchment population is from Gujerat in India, we are used to seeing tuberculosis of the bone.

The radiograph will show a bone destruction and this process will breach fibrous tissues boundaries more easily than tumour. A joint space loss would be as well as the patches of the bone destruction. The characteristic feature of tuberculous arthritis as opposed to pyogenic infection is the relative preservation of weight bearing surfaces and destruction at the joint margins (Table 2.2, Figure 2.12). The following of findings historically have suggested tubercular arthritis:

— juxtaarticular osteoporosis;
— peripherally located osseous erosions;
— gradually narrowing joint space.

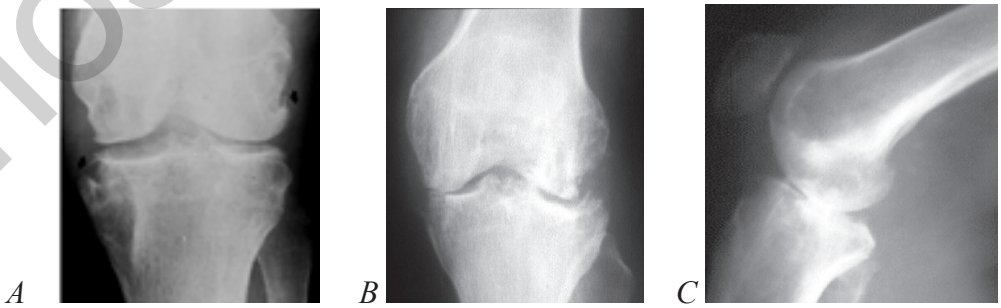


Figure 2.12 — Radiographs region of knee. (A) Tuberculous arthritis of the knee. On both sides of the joint there are destructive bone lesions (arrows) involving the medial and lateral condyles and the medial aspect of the proximal tibia. Note the relative sparing of the articular cartilage and preservation of the joint space in view of the degree of bone destruction. (B, C) Different patient with two views, tuberculous arthritis of the knee

Table 2.2 — Main principles of a differential X-ray diagnosis

Diagnostic criteria	Osteomyelitis of bones and joints	Tuberculosis of bones and joints
Patient's age	Any	Anv. But often not more than 20 vears old
The most often localization	Metaphysis and diaphysis	Epiphysis and metaphysis, vertebral bodies
Number of the affected bones	As a rule — one	The adjacent bones can be affected
General characteristic of a bones lesion	Combination of destructive and sclerotic changes and a sequestration	Mainly destructive process with a sequestration
Condition of a surrounding osteal tissue	Osteosclerosis	Osteoporosis. The sclerotic changes arise only at decrease of inflammatory process
Periostitis	Linear or fimbria-shaped	Defected seldom — only at diaphyseal lesions
Condition of the adjacent joints	As a rule, are not changed	The destructive process often transfers to a joint
Sequestration	The sequesters are dense, surrounded with a area of an enlightenment	Small spongiform sequesters of small density
The contours of the destruction zone	In beginning of disease – unclear, later become clear	Unclear, blurred

Neoplastic bone diseases

Neoplastic bone disease may be either primary or secondary. Secondary malignant bone disease is much more common than primary, and is best imaged using either nuclear medicine or magnetic resonance imaging. Although magne-tic resonance imaging is more sensitive than bone scanning and does not use ionizing radiation, it is more expensive and takes much longer time. For this reason, bone scanning is the primary investigation in the United Kingdom.

Imaging studies are essential for detecting, characterizing, and staging bone lesions. Radiographs, computed tomography, magnetic resonance imaging, and radionuclide scans all play a role (Table 2.3). Angiography is useful for evalua-ting tumor vascularity and for preoperative embolization.

Bone tumours can be further classified according to their tissue of the origin including:

— Bone-forming (osteogenic) e.g. osteosarcoma.

— Cartilage-forming (chondrogenic) e.g. chondrosarcoma.

— Fibrous (fibrogenic) e.g. fibrosarcoma.

— Vascular e.g. angiosarcoma.

Radiographic patterns of bone destruction or production (Figures 2.13):

— Geographic: least aggressive. Margins may be sclerotic, well defined without sclerosis, or ill defined.

— Moth-eaten: more aggressive, less well defined. A longer zone of transition. Seen with malignant lesions and osteomyelitis.

— Permeative: most aggressive with more rapid destruction. Margins are not defined.

— Bone formation with calcification or ossification, periosteal response.

Table 2.3 — Effectiveness of imaging studies for evaluating features of bone tumors

Radiographs	CT	MRI	Radionuclide scans
Lesion morphology	Thin cortical bone	Lesion extent	Early detection in marrow and soft tissues
Site (cortical, marrow, diaphysis, epiphysis)	Bone destruction or production	Joint space involvement	Skip lesions
Bone production or destruction	Periosteal response	Marrow edema	Metastasis
Periosteal response	Calcifications/ matrix	Cortical destruction	—
Soft tissue calcification or ossifications	Trabecular destruction	—	—

Primary bone tumors

There are several different types of bone tumors. Their names are based on the area of the bone or surrounding tissue that is affected and the kind of cells forming the tumor. Some primary bone tumors are benign (not cancerous), and others are malignant (cancerous). Most bone cancers are called sarcomas. This is a term that describes the type of the tissue that the cancer started in. Sarcomas are cancers that start in the bone, the muscle, the fibrous tissue, the blood vessels, the fat tissue, and other tissues. In primary bone neoplasms, the age of the patient and the site of the disease are important pointers to the diagnosis. Although conventional x-ray images are often obtained, the best form of imaging is magnetic resonance imaging.

Benign bone tumors (Figure 2.14) do not spread to other tissues and organs and are not life threatening. They are generally cured by surgery. Types of benign bone tumors include osteoma, osteochondroma, enchondroma, and chondro-myxoid fibroma.

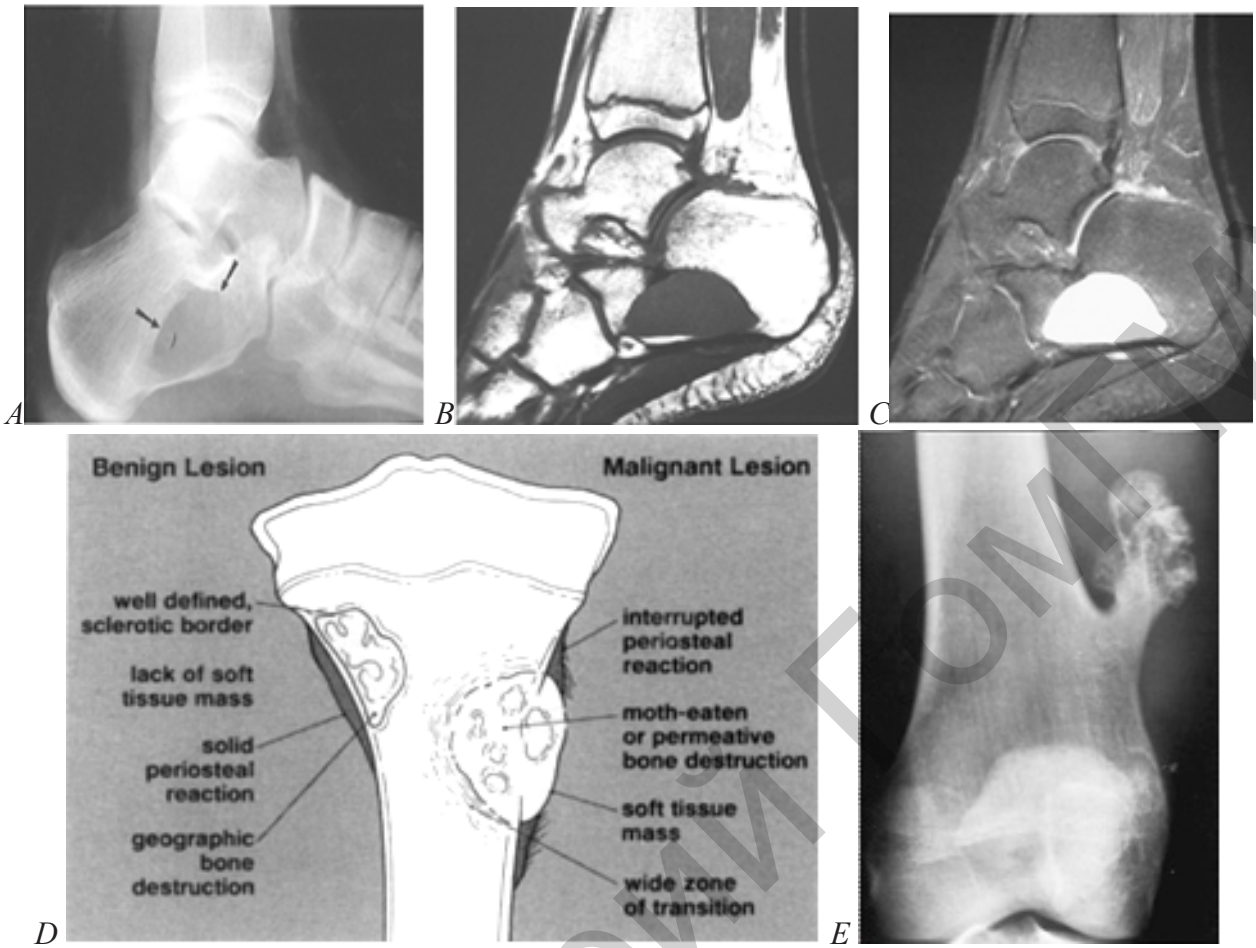


Figure 2.13 — Patterns of bone destruction "geographic".
(A) Lateral radiograph of the calcaneus showing a well-defined geographic lytic lesion (arrows).
(B) T1-weighted and (C) T2-weighted magnetic resonance images showing homogeneous fluid signal caused by a benign unicameral bone cyst. (D) Schematic diagram of the radiographic features that can help differentiate benign from malignant bone lesions.
(E) Frontal radiograph distal region of thigh. Osteochondroma of the distal femur.
The long axis of the tumor is parallel to that of the femur and pointed away from the knee joint

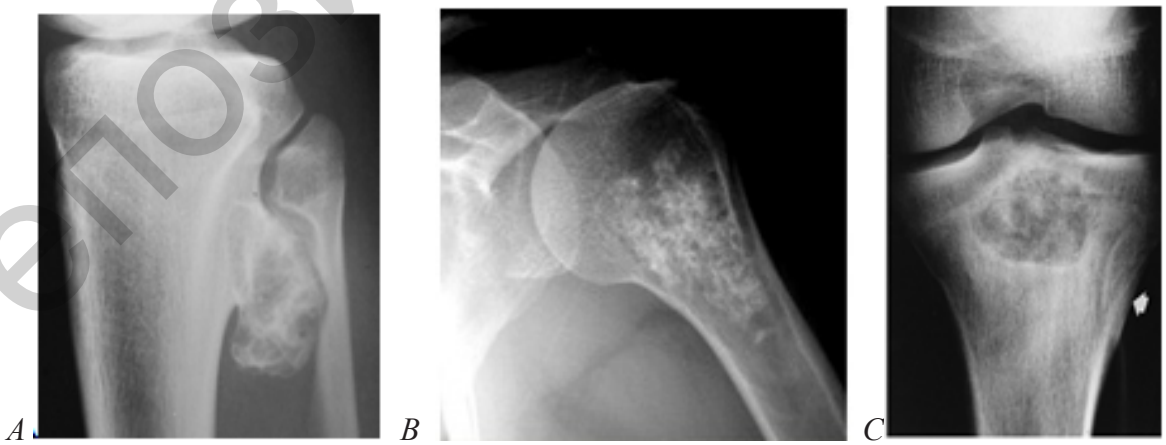


Figure 2.14 — (A) AP radiograph demonstrates a proximal tibia osteochondroma.
(B) Central enchondroma. Radiograph of the humerus showing a chondroid lesion with calcifications.
(C) Chondroblastoma. AP radiograph demonstrates a proximal tibial lesion with sclerotic margins and calcifications. There is a subtle periosteal reaction (arrow)

Osteoma — a benign dense/sclerotic focal new bone formation (bone island) with well-marginated (clear of border), wide variety in appearance, may be at the variant of the exostosis. Benign (non-cancerous) tumors of cartilage are more common than malignant ones. These are called enchondromas. Radiographic features: medullary with sharp margins, small round or oval cystic defects, typically with stippled matrix calcification and endosteal scalloping. May be multiple. Another type of benign tumor is the osteochondroma. This is a bony projection capped by cartilage. Both of these benign tumors rarely turn into cancer. Common locations: distal femur, proximal tibia, proximal humerus. Radiographic features: bony projection with contiguous marrow and cortex from bone of origin. Sessile or pedunculated ("coat hanger" exostosis or "cauliflower cap") cartilage capped bony outgrowth that is continuous with underlying bone.

Giant cell tumor of the bone: this type of the primary bone tumor has benign and malignant forms. The benign (non-cancerous) form is most common. These tumors typically affect the leg (usually, near the knees) or arm bones of young and middle-aged adults. Radiographic features: a subarticular, eccentric lytic lesion with a geographic, nonsclerotic margins originating in the metaphysis but extending to subchondral bone, cortical break.

Malignant bone tumors

Osteosarcoma (also called osteogenic sarcoma) is a cancerous tumor of the bone itself, and it is the most common primary bone cancer (Figure 2.15). Common locations: distal femur or proximal tibia (48%), pelvis and proximal femur (14%), shoulder and proximal humerus (10%).

Radiographic features: metaphyseal lytic, blastic, or mixed appearance. Lesions poorly defined with aggressive periosteal response (spiculations or Codman triangles). The soft tissue extension is common. Differential diagnosis: Ewing sarcoma, fibrosarcoma, chondrosarcoma, giant cell tumor, osteomyelitis.

CT features: similar to radiographic features. MRI features: imaging features are nonspecific. Signal intensity varies with matrix (decreased with blastic, increased with lytic on T2-weighted sequence). Staging of marrow and soft tissue involvement is the primary indication for MRI.

Magnetic resonance imaging is also used in a secondary malignant bone disease, especially where there are neurological complications as surgical intervention may be needed, and the exquisite detail on a magnetic resonance image is invaluable to the surgeon.

Chondrosarcoma is a cancer of cartilage cells and is the second most common primary bone cancer. It is mostly developed in the bones such as the pelvis, leg bone or arm bone. Radiographic features: destructive lesions appearing as a central lesion in the bone with stippled calcifications, and cortical scalloping, or as a peripheral lesion extending from the bone's surface appearing as an exploded osteochondroma.

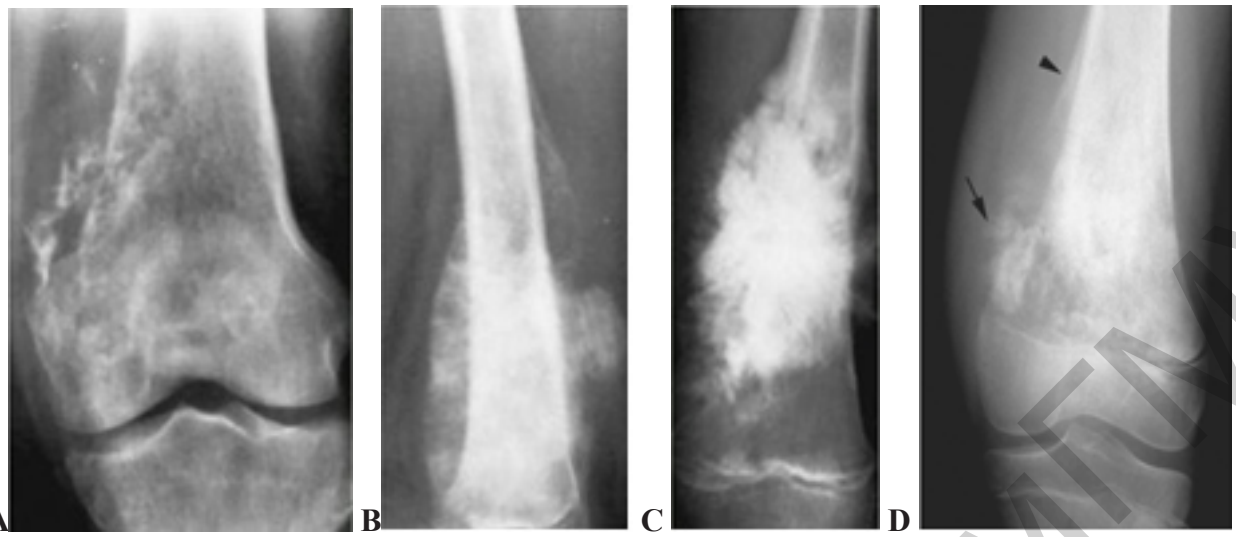


Figure 2.15 — Osteosarcoma. (A to D) Four examples of osteogenic sarcoma of the femur illustrate the broad spectrum of radiographic changes. There are various amounts of exuberant, irregular periosteal response and irregularly dense ragged bone destruction. (D) AP radiograph of the distal femur showing a classical osteosarcoma with mixed lytic and sclerotic areas, tumour bone formation in the extraosseous mass (arrow), and a proximal Codman's triangle (arrowhead)

Ewing tumor: (also called Ewing sarcoma). Ewing tumors usually develop in bones, and less than 10 % arise in other tissues and organs. They most often arise in the long bones of the legs and arms but may also develop in the pelvis and other bones. Ewing tumor is the third most common primary bone cancer. Unlike osteosarcoma, Ewing tumors of bone form in the cavity of the bone. Cancer is usually uncommon in adults. Radiographic features: long diaphyseal lesion with permeative pattern. May have sclerosis or mixed appearance. Aggressive periosteal (laminated characteristic of Ewing sarcoma) response and soft tissue mass common (Figure 2.16).

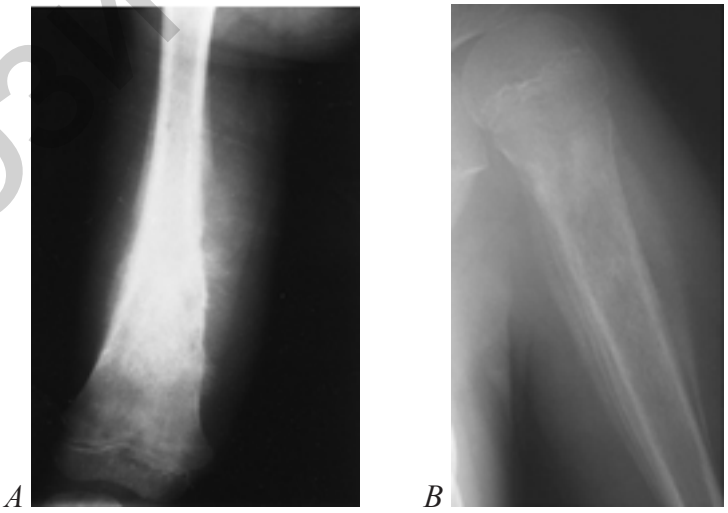


Figure 2.16 — Ewing sarcoma. (A) An anteroposterior plain film of the femur of a child shows a predominantly sclerotic process with large amounts of sunburst periostitis in the diaphysis. (B)Typical appearance in the proximal humeral metadiaphysis with permeative marrow destruction, 'hair-on-end' and multilaminated periosteal reaction

CT features: similar to radiographic features; periosteum and soft tissue better defined. MRI: signal intensity variable in mixed or sclerotic lesions. High signal intensity on T2-weighted and low signal intensity on T1-weighted with lytic permeative lesions. Differential diagnosis includes: lymphoma, osteosarcoma, osteomyelitis.

Myeloma

Myeloma is the most common primary bone malignancy. Common locations: skull, axial skeleton, ribs. Radiographic features: typically multiple small lytic foci, osteopenia, "punch-out" lesions, "raindrop" skull (Figure 2.17). May be a solitary lesion, bone expansion and soft tissue mass common, especially in the ribs. Differential diagnosis: metastasis, lymphoma.

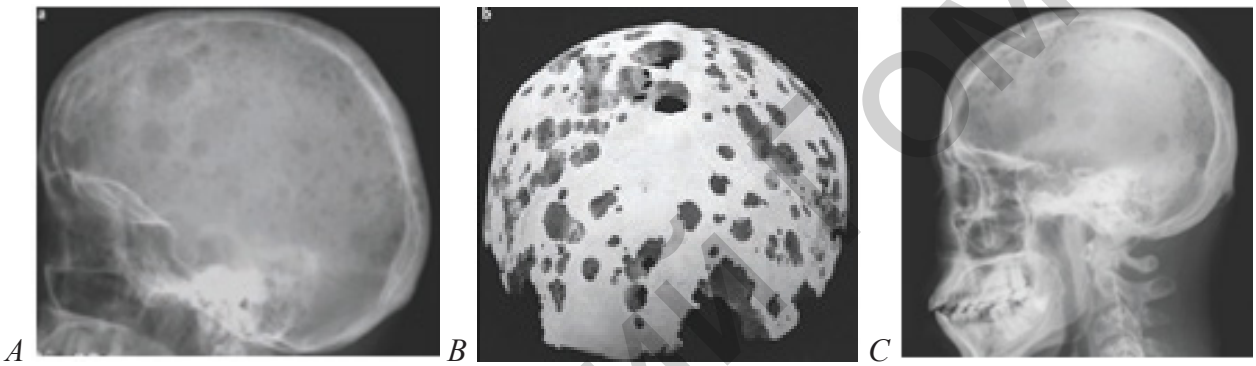


Figure 2.17 — (A) A lateral head radiograph demonstrates innumerable variably sized lytic lesions throughout the skull. (B) 3-D CT-reconstruction of the skull. This appearance is typical for advanced multiple myeloma, which was this patient's diagnosis. (C) A lateral head radiograph of different patient, multiple myeloma of the skull

Most bone scans in metastatic disease look fairly similar and simply tell us that there is a widespread disease. They do not usually indicate the primary. Bone metastases are often clinically occult, or they present with bone pain, pathological fracture or hypercalcaemia. X-ray patterns includes:

— Most commonly lytic solitary or multiple lesions. Lesions may be sclerotic, or mixed, depending on primary tumor (Figure 2.18).

— Cortical destruction, without periosteal reaction.

— Most common sites are axial skeleton, proximal long bones.

MRI is useful for staging of musculoskeletal tumors. US and CT are more often used for image-guided biopsy. Nuclear medicine techniques are often used to detect metastatic disease, and have a high sensitivity of detection.

Bone scintigraphy

Skeletal radionuclide imaging is performed with 99m-technetium tagged to methylene diphosphonate (^{99m}Tc-MDP) 10 mCi. Increased uptake of the radiopharmaceutical is seen in conditions producing both an increased metabolic activity and blood

supply, including tumors, infections, fractures, metabolic diseases, and joint diseases. Radionuclide bone imaging is sensitive to early pathologic processes but is not as specific in defining anatomy as most other imaging systems. A major advantage of radionuclide imaging is that the entire skeleton can be imaged in a single examination.

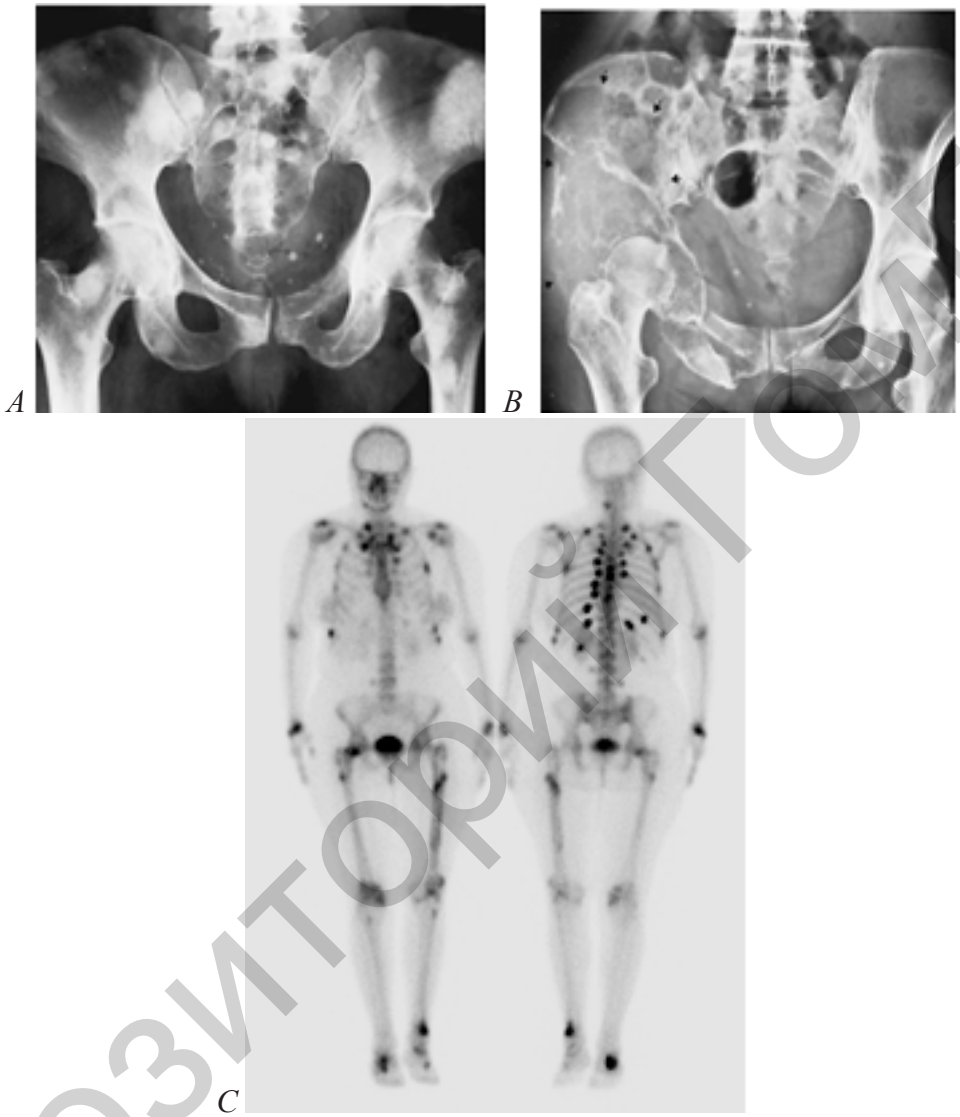


Figure 2.18 — (A) Osteoblastic metastases. Multiple areas of increased density involving the pelvis and proximal femurs representing metastases from carcinoma of the urinary bladder. (B) Metastatic thyroid carcinoma. Large area of entirely lytic, expansive destruction (arrows) involves the left ileum. (C) Two scintigrams (anterior and posterior view) of the skeleton same patient. Note multiple areas of increased uptake of radiopharmaceutical in the pelvis, legs, vertebras and ribs. This indicates multiple sites of increased osteoblastic activity in a pattern typical of disseminated skeletal metastases. Metastases seen as areas of increased uptake of tracer (areas black color), bladder is normal

Images are most commonly obtained 2 to 3 hours after injection, which allows clearance of the isotope from the blood supply and incorporation into the bone. The imaging device in radionuclide scintigraphy is the gamma camera. The degree of the image darkening reflects the degree of radionuclide activity (Figure 2.19).

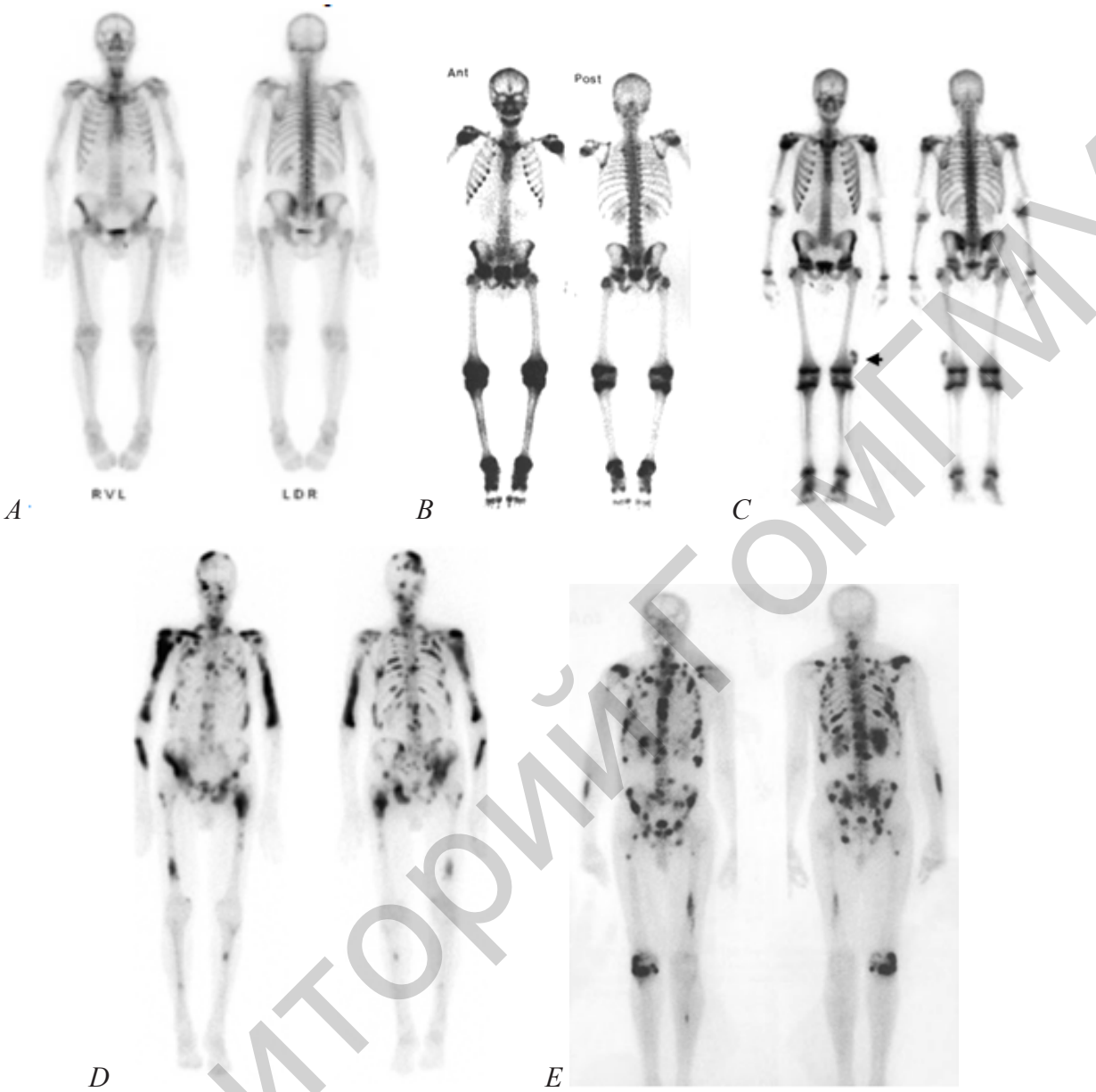


Figure 2.19 — (A) Normal adult bone scan (bone scintigraphy), anterior and posterior images. There is normal distribution of radiopharmaceutical in the bones and normal physiologic excretion of Tc-99m MDP by the kidneys into the urinary bladder.
(B) Normal bone scintigrams. This scan was performed with a 15-year-old boy. Anterior (left) and posterior (right) images demonstrate markedly increased activity around the epiphyseal plates. This is usually best seen around the knees, ankles, shoulders, and wrists.
(C) Osteochondroma. A fourteen-year-old male with pain and swelling of the left distal thigh for 1 week. The patient was referred to rule out trauma or heterotopic bone formation. The scintigrams shows increased pool activity in the lateral aspect of the distal left femur (arrow) representing the typical pattern of pedunculated osteochondroma.
(D, E, different patient) Skeletal metastases from prostatic carcinoma. Anterior and posterior whole-body technetium-99m methylene diphosphonate bone scans show multiple focal sites of intense uptake (areas of increased activity) involving both the axial and appendicular skeleton. The scintigrams shows the typical pattern of metastatic bone diseases of randomly distributed foci of increased uptake of radiopharmaceutical

In addition, it is important on the posterior view to examine the scintigram for the presence and location of renal activity; on the anterior view, for bladder activity. Asymmetric renal activity is not uncommon. Increased uptake is also found in the kidneys secondary to the excretion of the radioisotope, affording the radiologist an opportunity to also evaluate kidney anatomy and function.

Bone scintigram with nuclear medicine, for example, can be an important step in diagnosing various kinds of cancer, including breast cancer, because it can reveal if the cancer has metastasized beyond its primary site and developed secondary cancer growths in the bones. On an x-ray one might see that the bone is not broken, but on a bone scintigram, physicians can see metabolic changes caused by fine fractures, small tumors, or degenerative diseases such as arthritis.

Example indications: metastatic disease, tumor, malignant bone tumors, trauma, arthritis, osteomyelitis.

The normal scintigram varies significantly in appearance between children and adults. Nonpathologic increased uptake is noted in the most metabolically active regions of the body (e.g., epiphyses, costochondral junctions, sacroiliac joints, sternoclavicular joints). In children, areas of growth in the region of the epiphyses show intense uptake. In adults is usually a good visualization of the skull, with relatively increased accumulation of the activity in the region of the nasopharynx, which may be secondary to the high proportional blood flow in this region (Figure 2.19 A, D, E). Since the human skeleton is symmetric, any asymmetric osseous activity should be viewed with suspicion.

At any variants inflammatory and tumor diseases of the bones on scintigram there is a focal area of an increased flow, an increased blood pool activity and an increased delayed uptake (Figure 2.19 C to E).

III. CHEST IMAGING

Introduction

Pulmonary specialists will almost never provide a consultation without having seen a chest x-ray. In underdeveloped countries chest x-rays are obtained very selectively and physicians rely mostly on a physical exam and history for diagnosis. Physical examination of the chest has inherent limitations. Lesions located in the mediastinum, interstitium of lung parenchyma, and in the center of the lung are rarely picked up with a physical exam. Ease of availability of chest x-ray has made many physicians avoid time consuming physical exam which in most cases fails to reveal all of the problems. As a result, physicians have lost the skill of a physical exam. Just as physical examination has limitations, chest x-ray so has limitations, as well, and it should be recognized that a normal chest x-ray does not rule out pulmonary problems. The commonest type of imaging modality remains the X-ray. Chest X-rays are a frequently performed and particularly important test that all doctors should be able to interpret.

The radiological examination of chest

The imaging examinations of the chest may be considered under the following headings:

1. Simple X-ray (plain film radiography).
2. Fluoroscopy (roentgenoscopy).
3. Tomography.
4. Bronchography.
5. Pulmonary angiography.
6. Scintigraphy (radionuclide scanning).
7. Computed tomography.
8. MRI.

Chest radiology

Many chest radiographs are still acquired with conventional film-screen radiography systems that provide, at low cost, a good image quality and a high spatial resolution. The main structures imaged in the chest are the heart and lungs, although useful information may be obtained about the bones and soft tissues as well. A chest x-ray is the most commonly requested radiological examination, it is readily available and many patients present with some sort of chest symptoms such as cough or shortness of breath, followed up for a malignancy. A lot of information can be obtained from the chest x-rays; they deserve a careful study.

Sometimes a problem cannot be resolved with a plain x-ray. You can seek further help from:

1. Introduction of contrast material: bronchograms, angiograms.
2. CT chest: three dimensional, computerized evaluation, high resolution.
3. MRI scan (can be used to differentiate between an active alveolar process and fibrotic scars).

The plain film is the most common method of chest examination.

Positioning for a PA chest x-ray

Different views of the chest can be obtained with changing the relative orientation of the body and the direction of the x-ray beams. The most common views are posteroanterior, anteroposterior, and lateral. In an posteroanterior (PA) view, the x-ray source is positioned so that x-rays enter through the posterior (back) aspect of the chest, and exit out of the anterior (front) aspect where they are detected (Figure 3.1). To obtain this view, individuals stand facing a flat surface behind which is an x-ray detector. A radiation source is positioned behind the patient at a standard distance, and x-ray beams are transmitted toward the patient.

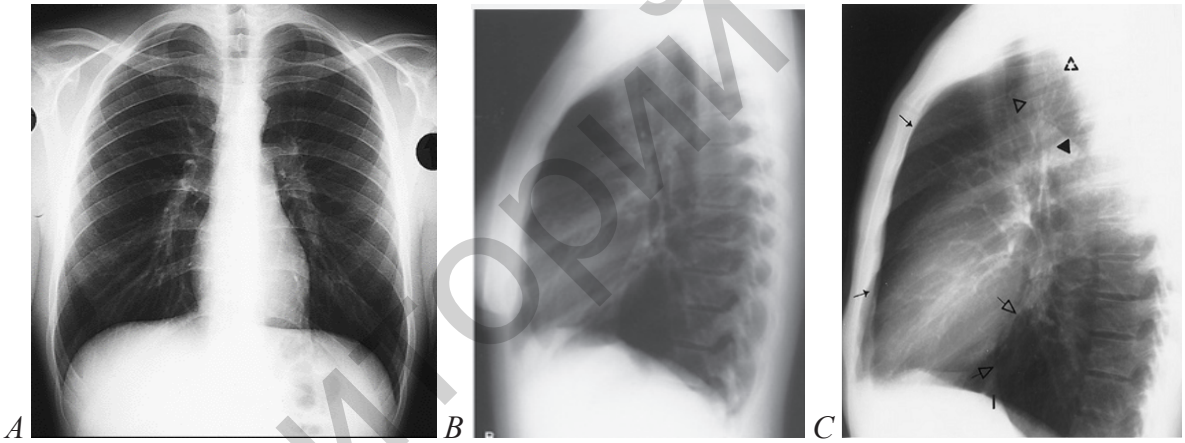


Figure 3.1 — (A) Normal lung PA and (B) lateral radiographs of the chest. Adequate penetration of the patient by x-rays, good quality PA film. (C) Radiolucent spaces on lateral chest radiographs. The retrosternal space is demarcated anteriorly by the posterior margin of the sternum (small arrows) and the heart and ascending aorta posteriorly and accounts for the anterior junction line seen on frontal radiographs. The retrotracheal triangle is marginated by the posterior wall of the trachea anteriorly (open triangle), the spine posteriorly (broken triangle), and the aortic arch inferiorly (solid triangle). The retrocardiac space is demarcated anteriorly by the posterior cardiac margin (upper open arrow) and the inferior vena cava (I, lower open arrow)

A lateral radiograph is used to localise lesions in the AP dimension; locate lesions behind the left side of the heart or in the posterior recesses of the lungs. A left lateral (with the left side of the chest against the film and the beam projected from the right) is the standard projection.

Inspiration

Chest X-rays should be taken with a good inspiration, resulting in at least six ribs being visible anteriorly. Expiratory films are used to assess air trapping in bronchial obstruction such as a foreign body. A pneumothorax always appears larger on an expiratory film and occasionally a small pneumothorax may only be visible on expiration.

The next point to define is the position of a patient, who underwent an X-ray — vertical (erect) or horizontal (supine). Whenever possible the chest X-ray film is to be taken in erect or sitting position, because many intrathoracic conditions (e.g., pleural fluid, pneumothorax, mediastinal width) are difficult to assess when the film is taken with the patient lying down.

The control of accuracy of a patient's posing is carried out on a correlation of the internal ends of clavicles and medial line of the body. The difference between these two distances is to be not more than 5 mm. Then the breath phase is to be determined — inspiration or expiration film is done (Figure 3.2). The position of the diaphragm shows the breath phase.

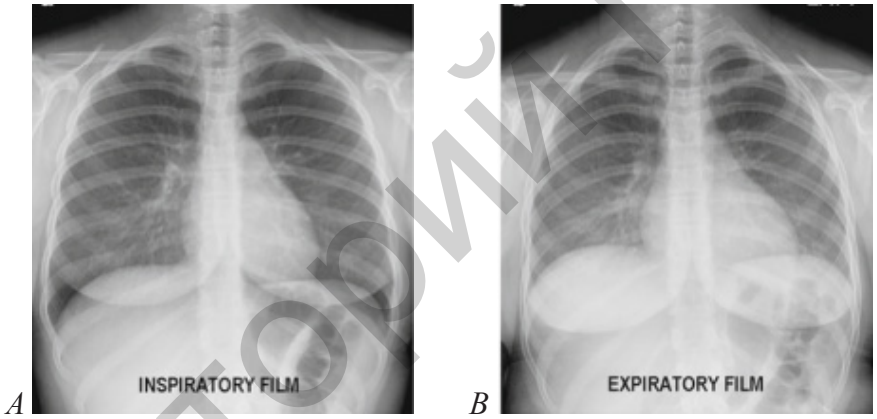


Figure 3.2 — (A) Inspiratory and (B) expiratory the radiographs female here are those of inspiration and expiration. Note the difference in the size of the lungs and their apparent difference in densities

At the inspiration phase the diaphragm is seen: on the right side — at the level of the 6th rib, on the left side — at the level of the 7th rib; at the expiration phase: on the right side — at the level of the 4th rib, on the left side — at the level of the 5th rib (frontal ends of ribs mentioned).

Rotation — the medial aspect of the clavicles should be symmetrically positioned on either side of the spine. The technologists are usually very careful to x-ray the patient flat against the cassette. If there is a rotation of the patient, the mediastinum may look very unusual. One can access patient rotation by observing the clavicular heads and determining whether they are equal distance from the spinous process of the thoracic vertebral bodies. Rotation causes the problem in the evaluation of the mediastinal borders and vascular status of the patient.

Quality of film

The final aspects of image quality that I will discuss are the concepts of exposure and penetration. With modern equipment, it is much less common to encounter problems in these areas.

Penetration is determined by the voltage setting on the x-ray tube. Penetration determines how well x-rays travel through the body. In a well-penetrated chest radiograph the vertebral bodies will be just discernable through the heart on the frontal film, the vertebral bodies should just be visible through the cardiac silhouette. Adequate penetration of the patient by radiation is also required for a good radiograph (Figure 3.3). On a good PA film, the thoracic spine disc spaces should be barely visible through the heart but bony details of the spine are not usually seen. On the other hand penetration is sufficient that bronchovascular structures can usually be seen through the heart.

In an under-penetrated film the vertebral bodies will not be visible. In an over-penetrated film the vertebral bodies will be seen too well. Over penetration is a problem because it means that pathology in the lungs will likely be missed.

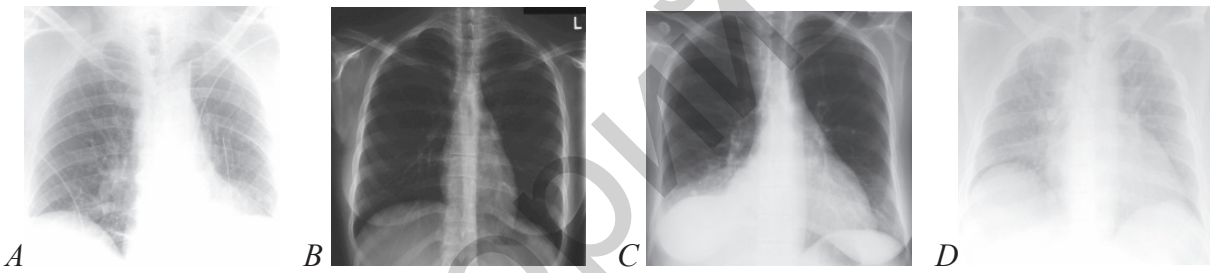


Figure 3.3 — (A) Under-penetrated radiograph. Notice that the overall degree of blackening in the lungs is appropriate (exposure) but there is essentially no detail visible through the heart (indicating poor penetration).
(B) Over-penetrated radiograph. Notice how unusually well the vertebral bodies are seen through the heart. The problem with over-penetration is evident in the lung fields, where detail of the parenchymal process is lost because of the poor technique.
(C) Over-exposed radiograph. Notice that the lung fields appear far too black and almost all detail is lost, though the penetration is correct (the vertebral bodies are just discernable through the heart).
(D) Under-exposed radiograph. Soft tissues in the image appear too white. The problem is clearly one of exposure, though, because the vertebral bodies are discernable through the heart

Exposure is determined by how many x-rays reach the film or the detector. In general it is determined by the current and time settings (mAs) on the x-ray tube. Since x-rays cause a film to turn black, a well-exposed film will have dark areas where there is pure air (airways, outside the patient, etc.) but the non-air regions will be lighter shades of gray. In an under-exposed film, the film looks too white and it is

difficult to determine whether there is pathology in the lungs. In an over-exposed film the film looks too black and all of the lung markings are lost. It should be noted that most over-penetrated films will also be over-exposed (because setting the voltage too high causes both problems), though most over-exposed films will not necessarily be over-penetrated (because setting the mAs too high does not affect penetration).

An underexpanded chest can create the impression of lung abnormality, for example, mimicking pulmonary oedema.

Lung fields

In the normal chest X-ray, the lungs are predominantly black and a branching pattern of vessels is seen. Lung fields is gray, have different size and shape: the right lung field usually is shorter and wider than the left. The transparency of lung fields is one of the most important signs. So, the transparency is to be analyzed by the comparing the symmetric parts of the lung fields. If there is any difference in a transparency of the symmetric zones, this appears to be a lesion. The lung fields should be of an equal density and one should not be any writer or darker than the other (Figure 3.4). There are two main groups of lung transparency changes: the shadow (opacification) and enlightenment (hyperlucent area).

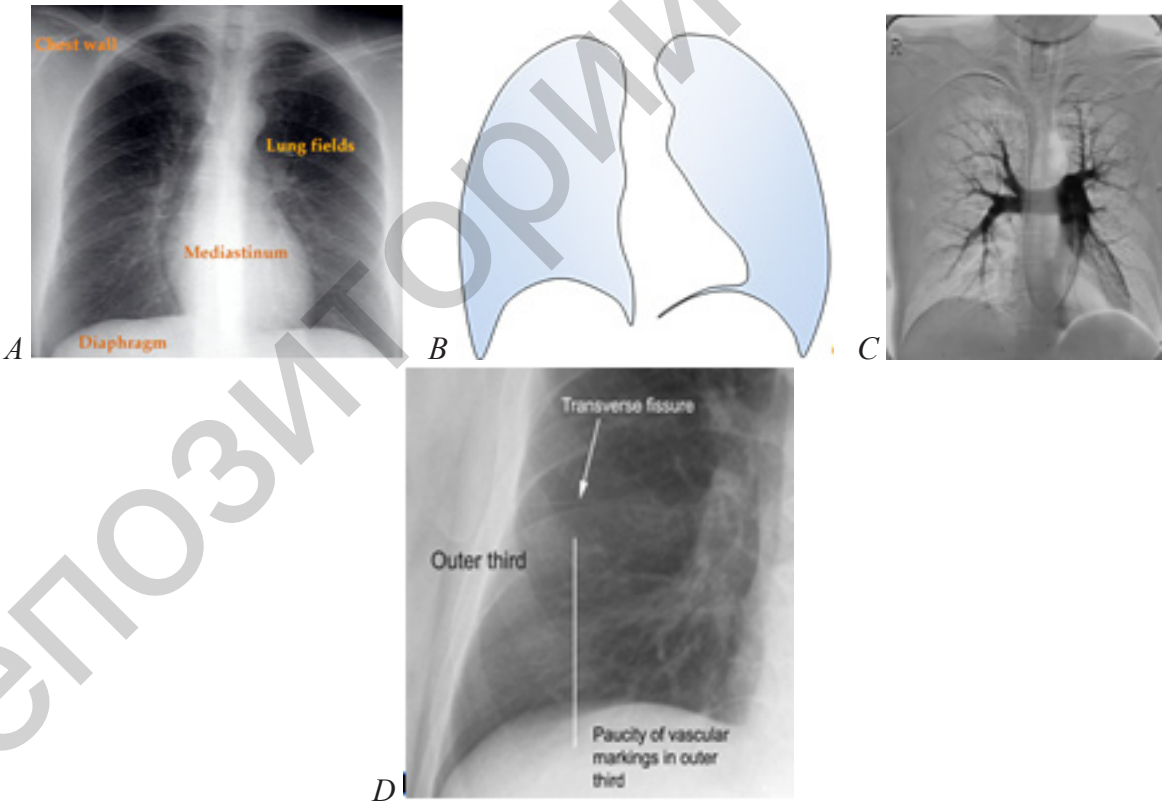


Figure 3.4 — (A) Radiograph chest with marked areas.
(B) Diagram lung fields frontal projection.
(C) Pulmonary digital angiogram shows appearances in arterial phase.
Note the difference in arrangement of the central arteries.
(D) Spot frontal radiograph of part chest, radiography without contrasting,
features of lung vessel marking

Lobes and fissures: on the PA chest x-ray, the minor fissure divides the right middle lobe from the right upper lobe and is sometimes not well seen. There is no minor fissure on the left. The major fissures are usually not well seen on the PA view because you are looking through them obliquely. It is not always possible to tell the left from the right major fissure because in the normal individual they overlie each other on the lateral radiograph. In some cases the minor fissure will also be visible on the lateral radiograph, running anterior to the major fissure. If there is fluid in the fissure, it is occasionally manifested as a density at the lower lateral margin.

Markings (vessels)

The pulmonary blood vessels are responsible for branching linear markings within the lungs. It is not possible to distinguish arteries from the veins in the outer two-thirds of the lungs on plain radiographs. The "lung shadows" are composed of the pulmonary arteries and veins. Apart from the pulmonary vessels, the lungs should appear black (on a negative film) because they contain air.

The "lung pattern" (pulmonary vascular patterns) is only a roentgenologic concept. The morphological basis of the lung markings pattern is the vessels of a lung blood circle the lung arteries and lung veins. Bronchi do not participate in formation of the lung pattern, as they contain air and are not visible on a back-ground of an airy lung tissue. The lung pattern looks as thin branchy shadows, directed from a hilus to the external end of a lung.

The criteria of a normal lung pattern: the shadows of the lung vessels have smooth outlines, regularly thin from hilus to the external border of a lung and their image disappears at the distance 1,5–2 cm from the lateral end of the lung field. (Because of presence of costodiaphragmal pleural sinuses the image of a lung pattern can be visible closely to diaphragm and even on a background of diaphragm). There are many types of a changed lung pattern; the main types are increased, decreased, absent.

Some vessels of a lung pattern are settled orthograde (directed from front to back) and their image looks like small focal lesions. It is necessary to differ-rentiate these images. There are five distinctive attributes of the orthograde vessels:

— Configuration of a shadow is always round or oval.
— Outlines of a shadow are smooth.
— Structure of a shadow is homogenous.
— Shadow is settled down on crossing the longitudinal vessels.
— Width of the orthograde vessel does not exceed the width of the adjacent longitudinal vessels.

There are many types of a changed lung pattern; the main types are increased, decreased, absent.

The increased lung pattern: there is no regularly thinning of the vessels shadows (the vessels on a long extent keep identical width) and their image disappears at the distance less than 1,5 cm from the lateral end of the lung field (the main reasons of increased lung pattern are dilatation of the lung vessels so they become visible on a greater distance — for example at venous congestion or hyperemia).

The decreased lung pattern: there is a quick thinning of the vessels shadows and their image disappears at the distance more than 2 cm from the lateral end of the lung field (the main reasons of decreased lung pattern are the increase of a lung tissue aeration (emphysema) or reduction of the blood supply (for example, lung artery embolism at an early stage, some heart diseases).

The absent lung pattern: if there is no lung pattern then there is no lung tissue at this area. Therefore the absence of the lung pattern is always on a background of shadowing (for example — pleural effusion) or enlightenment (for example — pneumothorax).

The central airways

The central airways can be well seen on both the frontal and lateral radiographs. It is always important to look for them and to evaluate both their patency and course. The trachea, carina and main stem bronchi can be well seen through the mediastinum because they represent air-filled structures surrounded by a soft tissue density (Figure 3.5).

The trachea is a straight tube that, in children and young adults, passes inferiorly and posteriorly in the midline. The trachea divides into the two mainstem bronchi at the carina.

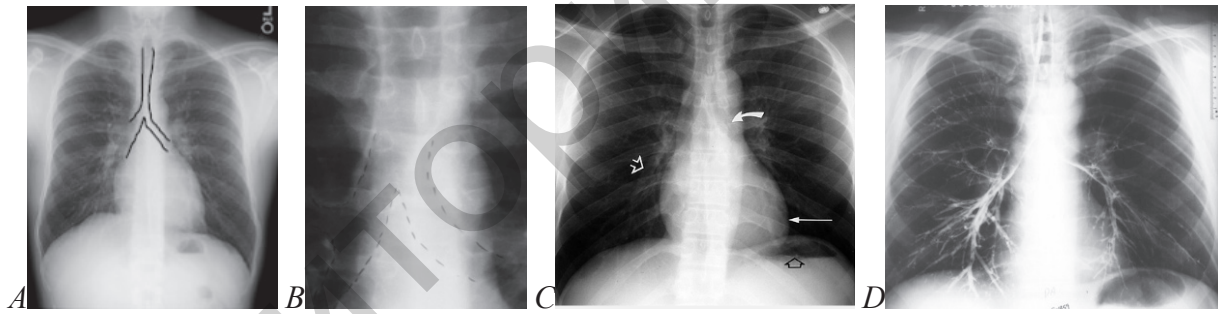


Figure 3.5 — (A-B) Marked trachea, carina and main bronchi. (C) Erect PA chest radiograph. The pulmonary arteries (white open arrow) are seen in the lung because the vessels are outlined by air in alveoli. The left cardiac border (long arrow) is crisply defined by the adjacent air-filled lung. The left main bronchus (curved arrow) is seen because its air-filled lumen is surrounded by soft tissue of the mediastinum. An air-fluid level (open black arrow) in the stomach confirms the erect position of the patient during exposure of the radiograph. (D) Normal bilateral bronchogram

Bronchi: you can see that the major bronchi are visible if you look carefully. It may be beneficial to practice drawing the bronchi and labeling them until you are entirely familiar with their names and locations.

The hila

Radiologists name as a hilus only intrapulmonary part, which is visible on an X-ray plain film. The shadow of a lung hilum is caused mainly by large vessels, all

the other anatomic formations are not visible under normal conditions. At research in a direct AP projection the lung hila are visible as non-homogenous shadows located on each side from mediastinum a little bit oblique to a medial line. The right hilum, as a rule, is seen well, the left hilus can be partially or completely closed by a heart shadow. On the X-ray image there are distinguished three parts of a lung hilus: the top part (head), middle part (body) and lower part (tail). The hilum is the anatomic connection of the lung to mediastinum and therefore consists of a variety of vessels, bronchi, and lymph nodes. The visible portion of each normal hilum is the right or the left pulmonary artery. The pulmonary veins are inferior and posterior to the arteries.

Location of lung hila. Under normal conditions the image of a right lung hilus is settled between the front ends of the second and fourth ribs. If the hilus is located within these limits, such location is needed to consider as normal. If the hilum is located above or below, it means it is displaced upwards or downwards. The left hilum, as a rule, is located little bit above the right (Figure 3.6). It is necessary to take into account, that the displacement of a hilum downwards can be variant of a normal position at patients with large lungs, for example, is the sportsmen, while the displacement of a hilum upwards always specifies a presence of a pathological process.

Width of lung hila. The patients are different under their constitution and consequently, the sizes of their lungs and other intrathoracic structures will be various. That is why it is impossible precisely to specify the width of a hilum. It is possible only to determine if the hilum is extended or not. For this purpose it is necessary to measure the width of a lung artery at the level of a hilum body and to compare it to the width of a light space between an internal contour of the artery and the right contour of the mediastinum. Under normal conditions the width of the lung artery does not exceed the width of this light space — hilum is not extended. If the artery width is more than that, this means the hilum is extended (Figure 3.6).

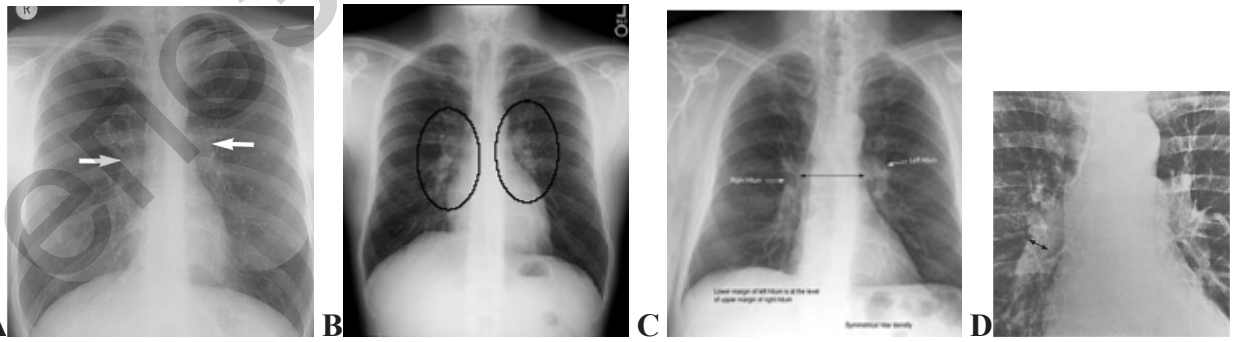


Figure 3.6 — Normal hilar anatomy. (A to C) Normal PA chest radiograph demonstrating position and density of the hilar structures. Arrows indicate the hilar points, where the superior pulmonary vein crosses the descending lower lobe artery, the left normally being level with or slightly higher than the right. (D) Frontal view of hila in plain chest radiograph. The measurement points for the diameter of the right lower lobe artery are indicated

Structure of lung hila. If on an X-ray film the components of a hilum: the lung artery and its branches, large veins and the light space of intermediate bronchus are well visible, their contours are clear, such structure of the hilum is normal. At many pathological processes the structure of a hilum is unclear and its image becomes indistinct.

Normal bones of chest

Ribs: the ribs are a common site for fracture or metastatic deposits but the remainder of the skeleton must also be carefully examined. Identify the first rib and carefully trace its contour from the spine to its junction with the manubrium. Each rib must be carefully and individually traced in this manner, initially for one hemithorax and then the contralateral side (Figure 3.7). A useful trick is to turn the film on its side, rib fractures may then appear more obvious.

Thoracic spine: look at the thoracic spine alignment — is it straight or is there a scoliosis? Take particular care to exclude pathology from the thoracic spine in trauma patients when even moderate symptom can be overlooked when projected through the heart or mediastinal shadows.

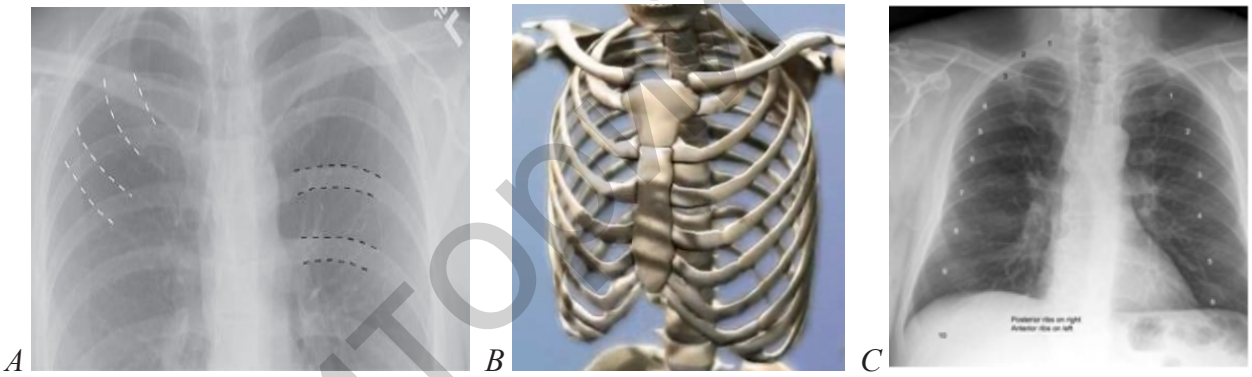


Figure 3.7 — (A) Frontal radiograph upper chest shows that the posterior ribs (outlined in black) have a horizontal course, while the anterior ribs (outlined in white) have a more sloping course as the move medially. The anterior ribs are generally not seen as well as the posterior ribs. (B) Model bones of chest. (C) Frontal radiograph chest indicate marketed anterior part of the ribs (left side chest) and posterior part of the ribs (right side)

Clavicles, scapulae and humerus: fractures and dislocation of the humerus are often obvious when looked for. Look for fractures, metastatic, abnormal calcifications or evidence of arthritis around the shoulders.

The mediastinum

On the frontal film, the left and the right sides of the mediastinum can be considered separately. Starting with the left side, from superior to inferiorly, the major border forming structures that should be recognized are the aorta (sometimes called the "aortic knob"), the main pulmonary artery and the left ventricle. It should also be

noted that the descending aorta, though behind the heart, can usually be seen quite well on a frontal film. The right side of the mediastinum is primarily formed by the superior vena cava and the right atrium of the heart. The position of a mediastinum is defined on a relation of trachea and medial body line. Under a normal condition and at the exact posing of a patient during X-ray, the medial line of a body should be settled precisely in the middle of the image of the trachea.

The mediastinum is conventionally divided into superior, anterior, middle and posterior compartments (Figure 3.8). The exact anatomical boundaries of these divisions are unimportant to the radiologist (indeed they vary according to different authors), since they neither provide a clear-cut guide to a disease have do their boundaries form any barriers to the spread of the disease.

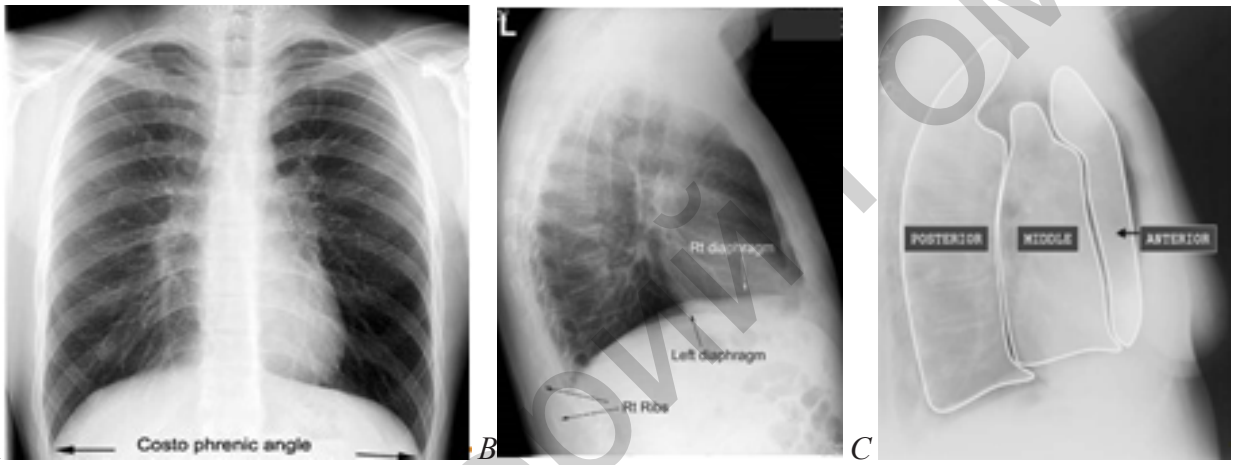


Figure 3.8 — (A) Normal frontal and (B) lateral radiograph of the chest. Check the shape, position and clarity/sharpness of both hemidiaphragms. Both costophrenic angles should be clear and sharp. The cardiophrenic angles should be fairly clear — cardio-phrenic fat pads can cause added density. The right hemidiaphragm is usually slightly higher than the left — up to 1,5 cm. On the lateral film, the right hemidiaphragm is seen in its entirety but the anterior aspect of the left hemidiaphragm merges with the heart, so is not seen. White arrows Rt, black arrows Lt. (C) Diagram of mediastinal compartments as defined on a lateral view

Diaphragm and soft tissue of the chest

In most individuals, the diaphragm has a smooth domed shape, but a scalloped outline is also common. The angle of the contact with the chest wall is acute and sharp, but blunting of this angle can be normal in athletes, because they can depress their diaphragm to a remarkable degree with deep inspiration. The normal right hemidiaphragm is found at about the level of the anterior portion of the sixth rib, with a range of approximately one interspace above or below this level. In most people, the right hemidiaphragm is 1,5–2,5 cm higher than the left, but the two hemidiaphragms are at the same level in some 9% of the population. In a few

normal individuals the left hemidiaphragm is up to 1 cm higher than the right one. The normal excursion of the diaphragm is usually between 1,5 and 2,5 cm.

A visual examination should be routinely performed on the chest wall, the neck and both the breast shadows. Look for emphysema and abnormal calcification. With reference to the breast shadows be sure to check whether there are two breast shadows and whether there is a symmetry of size, shape and position. The lung field missing a breast will appear a little darker than the other side.

The important review area in terms of the soft tissue includes below the diaphragms, the periphery of the chest wall, the supraclavicular region, and neck as far as included on the chest film.

How to read a chest radiograph

Reading a chest X-ray requires a methodical approach that can be applied to all films so that abnormalities are not overlooked. Clinicians and radiologists develop an individual approach but there are certain core areas that should be looked at on all films. These may be inspected in any order — this is largely down to personal preference. Being able to recognize normal appearances and structures as seen on a chest X-ray (CXR) is key to being able to correctly interpret any abnormal findings. In order to do this, you must first understand why we are able to see structures such as the heart border and the ribs as separate entities to surrounding tissues (Figures 3.9).

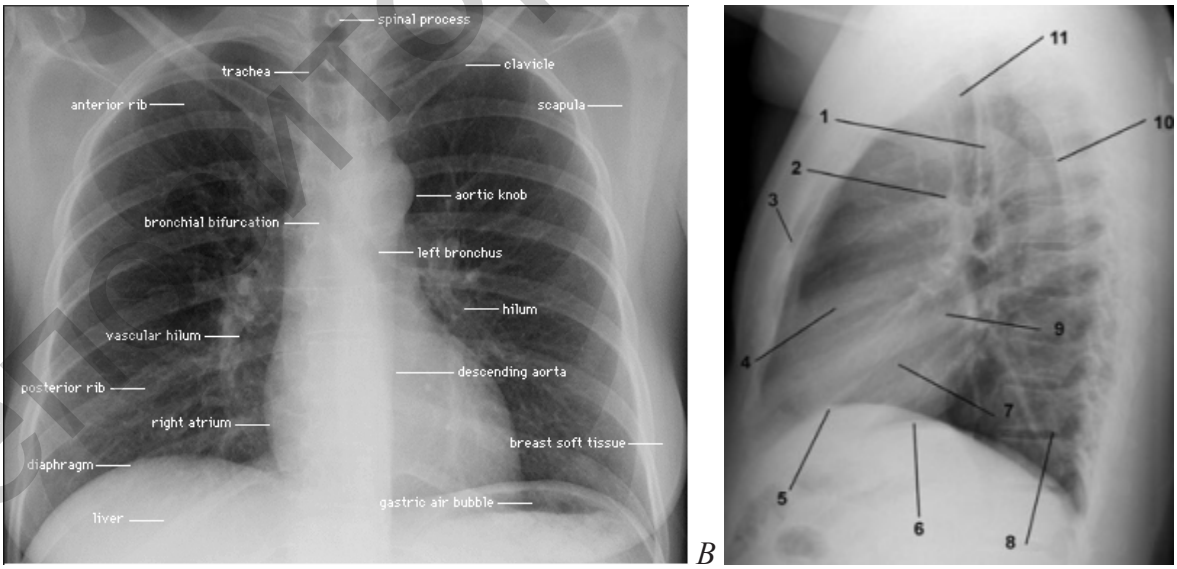


Figure 3.9 — (A) Frontal and (B) lateral radiograph chest indicate marked of roentgen anatomic structures. (B) 1 — Trachea. 2 — Aortopulmonary window. 3 — Sternum. 4 — Right ventricle. 5 — Right hemidiaphragm. 6 — Left hemidiaphragm. 7 — Left ventricle. 8 — Posterior recess of vertebra. 9 — Left atrium. 10 — Scapula. 11 — Lung field apex

Systematic analysis

The doctor inspecting a chest film should try to examine it in a systematic manner. The very first thing to be done is the correct placing of the film on a viewing box — the right side of the film is to be placed on the left side of the vie-wing box, as a patient is standing face-to-face to the doctor. If there is a side film, then it is to be placed on a correct side according to a notice on a film itself. Verify the patient's identity. In examination situations look at the name, if present, as this can give a clue to sex and ethnic background. The date and hospital where the film was taken give further clues. If a film has been taken at a centre for oncology or chest medicine, for instance, this may help with interpretation.

Radiographic report

1. Quality of radiograph (x-ray film) of the chest.

A. Penetration (the vertebral bodies should just be visible through the cardiac silhouette).

B. Rotation (the medial aspect of the clavicles should be symmetrically positioned on either side of the spine).

C. Inspiration (the diaphragm should lie at the level of the sixth or seventh rib anteriorly.

2. Review soft tissues (including breast) and chest wall.

3. Review bones spine and rib cage: lesions or fractures, lytic or blastic regions, disc space narrowing, etc.

4. Review of the lungs and pleura:

A. Compare lung field sizes, lung parenchyma, do not forget that the lungs extend below the diaphragms.

B. Evaluate pulmonary vascular pattern: compare upper to lower lobe, right to left, normal tapering to periphery, artery or vein enlargement.

Pleural surfaces: fissures — major and minor (if seen), compare hemidiaphragms.

C. Review hila: size, assess position and density.

5. Review mediastinum:

A. Overall size and shape, mediastinal contour (width?, mass? presence).

B. Trachea: position, midline or deviated, caliber.

C. Margins: aortic arch, aorta, main pulmonary arteries, left ventricle.

D. Retrosternal clear space (if lateral view).

6. Conclusion (diagnosis).

Sample of the protocol — the description of the normal radiograph chest (short form)

On the plain film of a chest, performed in a AP view it is to be determined: the chest skeleton does not show pathological changes. Lung fields have the usual shape and sizes. The lung fields transparency is not changed, there are no focal and infiltrative shadows. The lung pattern is not changed, it is clearly traced in all parts of the

lungs. The lung hila are normally located, not extended, the structure of them is normal. The mediastinum is not displaced. The diaphragm is normally located, the sinuses are free. The conclusion: pathological changes of the chest organs are not revealed.

You can summarise your findings in a few sentences: "This is a frontal chest radiograph of a young male patient. The patient has taken a good inspiration and is not rotated; the film is well penetrated. The trachea is central, the mediastinum is not displaced. The mediastinal contours and hila seem normal. The lungs seem clear, with no pneumothorax. There is no free air under the diaphragm. The bones and soft tissues seem normal".

Any cases you can summarise all the above information in a simple opening phrase: "The lungs, bones and soft tissues of the chest — variant of the norm".

Radiographic signs and patterns of lung disease

Each tissue reacts to injury in a predictable fashion. Multiple etiology can evoke a similar pathological reaction. Let us just exam the pathological process that can occur in the lung. Lung injury or pathological states can be either a generalized or localized process. In order for us to recognize these pathological process in a chest x-ray first we need to have good understanding of pathology.

Most of the disease states replace air with a pathological process which is usually a liquid density and appears white. Having a proper understanding of each of the pathological process or lung injury patterns is essential. Then we can develop roentgen signs that help us identify the nature of the pathological process.

Six *basic pathologic patterns* may alter the normal appearance of the lungs. The six abnormalities are as follows:

— Air space disease — consolidation.
— Interstitial changes — fibrosis and/or edema.
— Atelectasis — collapse.
— Pleural fluid accumulation — effusion.
— Emphysema — overinflation.
— Masses — tumors and tumor-like abnormalities.

Consolidative radiological findings

Consolidation is a commonly found abnormality on a chest X-ray and its correct interpretation is of relevance to the patient. Consolidation is also sometimes referred to as alveolar opacification or air space opacity.

Consolidation is the presence of a substance within the alveoli that displaces normal air. This results in a relative increase in radio-density of the affected area. These are fluid, cellular material (inflammatory or malignant cells), aspirated material and blood. Consolidation is a non-specific finding. Radiological characteristics include:

— Opacification (shadowing).
— Lobar/segmental distribution.
— No significant loss of the lung volume.

Consolidation is defined as alveolar space that contains the fluid instead of air, it is a filling of the alveolar spaces with a fluid. Consolidation is air space opacities that often indicate pneumonia.

In pneumonia, consolidation results when an infected lung passes from an aerated collapsible condition to one of airless solid consistency through the accumulation of exudates in the alveoli and adjoining ducts. The fluid can be pulmonary edema, inflammatory exudates, pus, inhaled water, or blood.

Consolidative radiological signs include: (Figures 3.10–3.11)

— Fluffy, cloud-like, coalescent opacities.

— Complete air bronchograms seen through the opacity.

— Obliterates pulmonary vasculature.

— There can be sharp edges when limited by fissures or pleura.

Consolidation may be mimicked by alveolar collapse, as in an airway obstruction.

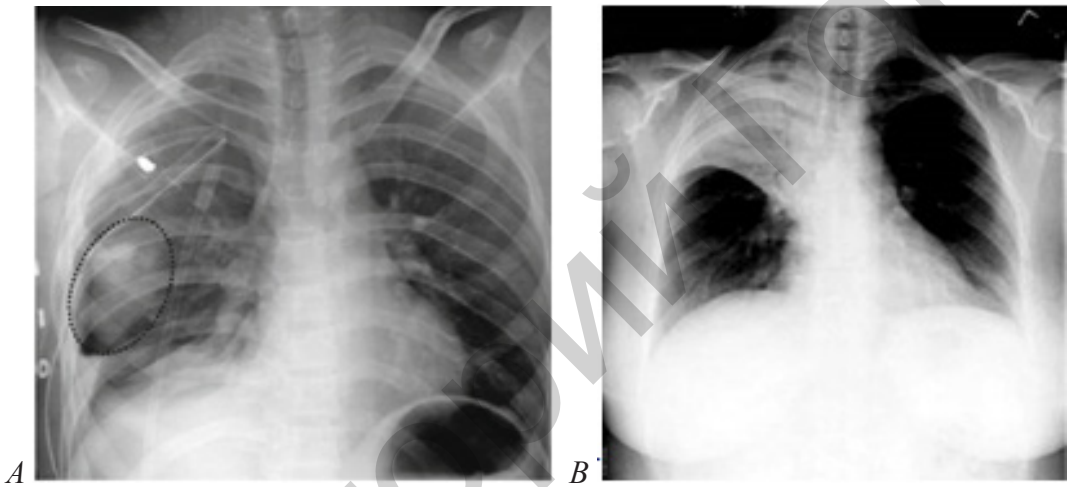


Figure 3.10 — (A) Consolidation representing hemorrhage (density highlighted by dotted oval). Additionally noted is chest tubes and blast metal fragment.
(B) Right upper lobe consolidation. There is opacification of the RUL zone.
A key feature is that there is no loss of the volume. There is no mediastinal shift and no fluid level

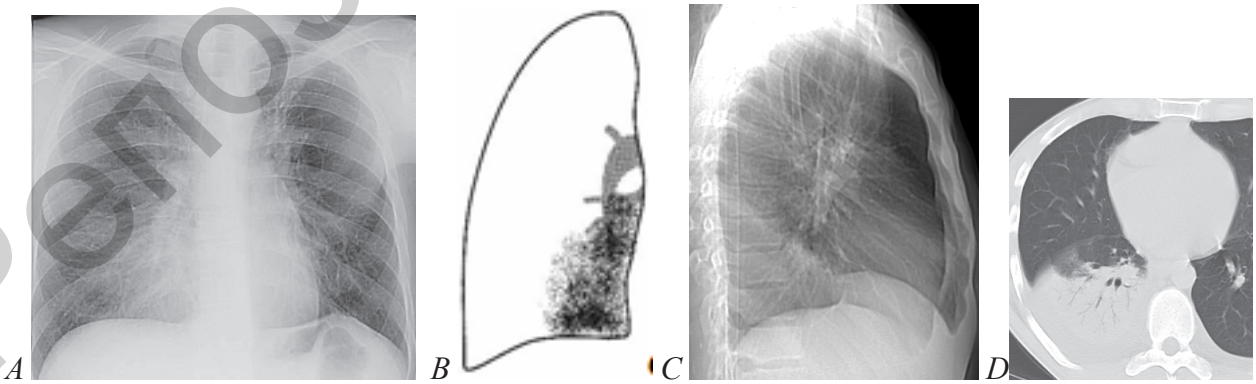


Figure 3.11 — (A) Frontal CRX, (B) scheme to (A), (C) lateral CXR and (D) axial CT tomogram shows a focal shadow in the right lower lobe. There is opacification within the lower zone of the right lung field. In the given example there is a loss of definition of the right heart border. From this you can work out where the consolidation is located

As you may have gathered consolidation (air space opacity) is a rather non-specific finding and can represent the effect of a large number of pathological processes. Having identified air space opacity, it is important to review the remaining film to see if there are any ancillary features that would help in esta-blishing the underlying cause.

Pneumonia

Parenchymal lung disease can be divided into those processes that produce an abnormal increase in the density of all or a portion of the lung on chest radiographs (pulmonary opacity, shadow) and those that produce an abnormal decrease in a lung density (pulmonary lucency) (Figures 3.12–3.14). The normal density of the lungs is a result of the relative proportion of the air to the soft tissue (blood or parenchyma) in a ratio of 11 to 1.

Infection via the tracheobronchial tree is generally secondary to inhalation or aspiration of infectious microorganisms and can be divided into three subtypes based on gross pathologic appearance and radiographic patterns: lobar pneumonia, lobular or bronchopneumonia, and interstitial pneumonia.

Lobar pneumonia is typical of pneumococcal pulmonary infection. In this pattern of the disease, the inflammatory exudate begins within the distal airspaces. The inflammatory process spreads to produce nonsegmental consolidation. If untreated, the inflammation may eventually involve an entire lobe (Figures 3.12–3.13). Because the airways are usually spared, air bronchograms are common and significant volume loss is unusual.

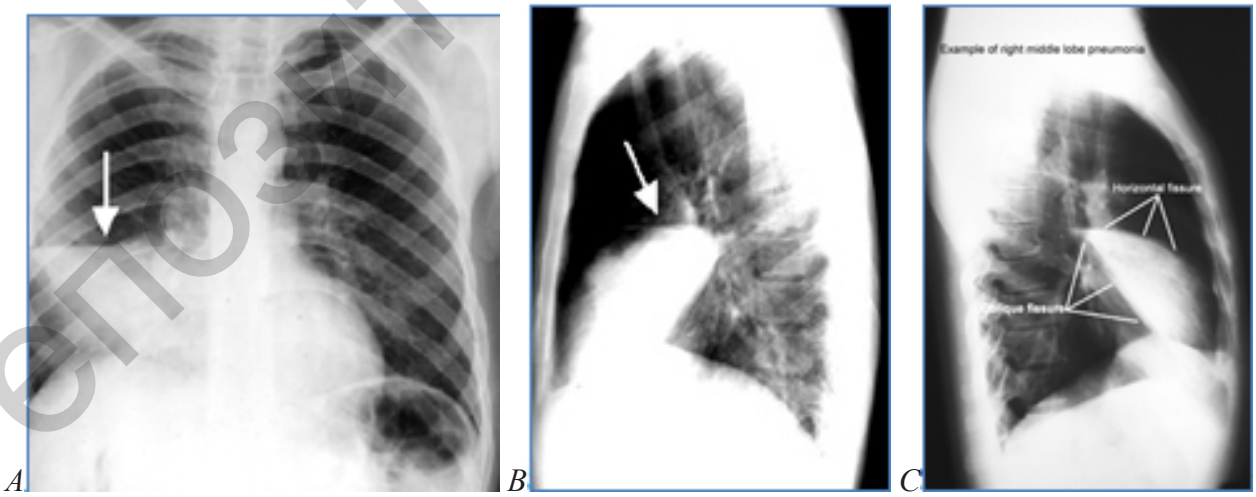


Figure 3.12 — Pneumonia. (A) PA and (B to C) lateral projections of the right middle lobe consolidation. Frontal chest radiograph demonstrates obliteration of the right borders of the heart. Patchy, diffuse air-space acute lobar consolidation, infiltrate with a focal area of consolidation in the right middle lobe (arrow)

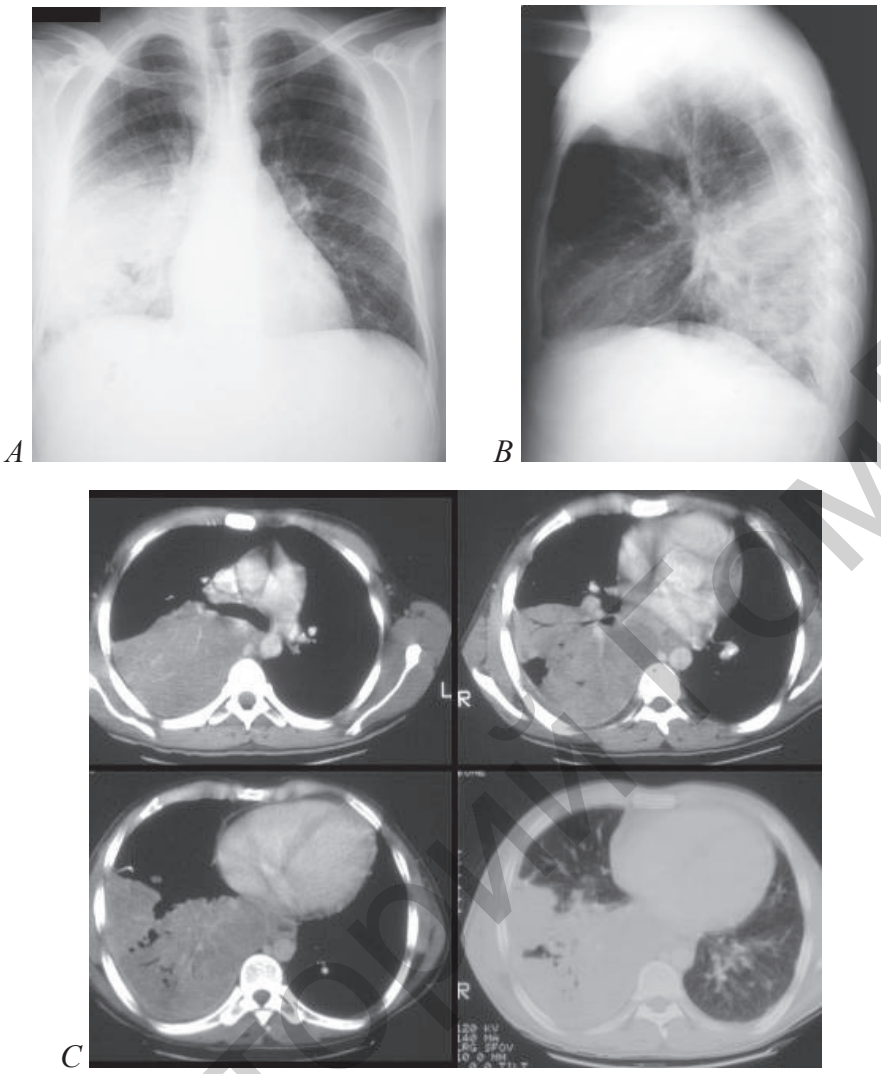


Figure 3.13 — Pneumonia. (A) Frontal chest radiograph, (B) lateral film and (C) CT scans demonstrates a middle lobe airspace opacification with areas of cavitation

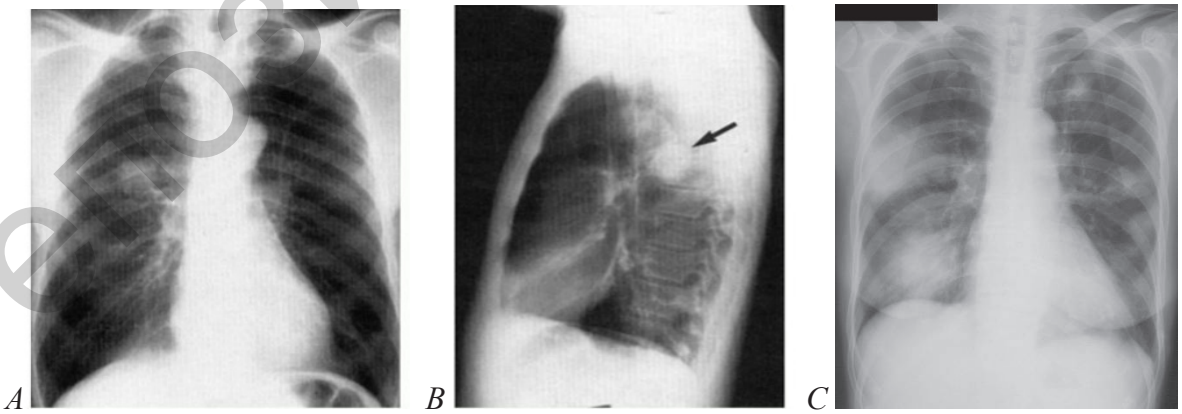


Figure 3.14 — Round pneumonia. Well-defined round mass (arrow) in the right mid-lung in (A) posteroanterior and (B) lateral chest radiographs. (C) Legionnaire's disease. "Spherical" pneumonia with a nodular and focus areas of infiltrate. Frontal view of the radiograph chest shows a rounded soft-tissue density of both lung fields with mild bilateral hilar prominence

Bronchopneumonia is the most common pattern of a disease and is most ty-pical of staphylococcal pneumonia. At the early stages of bronchopneumonia, the inflammation is centered primarily in and around lobular bronchi. As the inflammation progresses, exudative fluid extends peripherally along the bronchus to involve the entire pulmonary lobule. While bronchopneumonia is the most common cause of multifocal patchy airspace opacities, there is a broad list of differential diagnostic considerations. Exudate within the bronchi accounts for the absence of air bronchograms in bronchopneumonia. With coalescence of affected areas, the pattern may resemble lobar pneumonia.

Interstitial patterns

In interstitial pneumonia, seen in viral and mycoplasma infection, there is inflammatory thickening of bronchial and bronchiolar walls and the pulmonary interstitium (Figure 3.15). This results in a radiographic pattern of the airways thickening and reticulonodular opacities. Air bronchograms are absent because the alveolar spaces remain aerated. Segmental and subsegmental atelectasis from small airways obstruction is common.

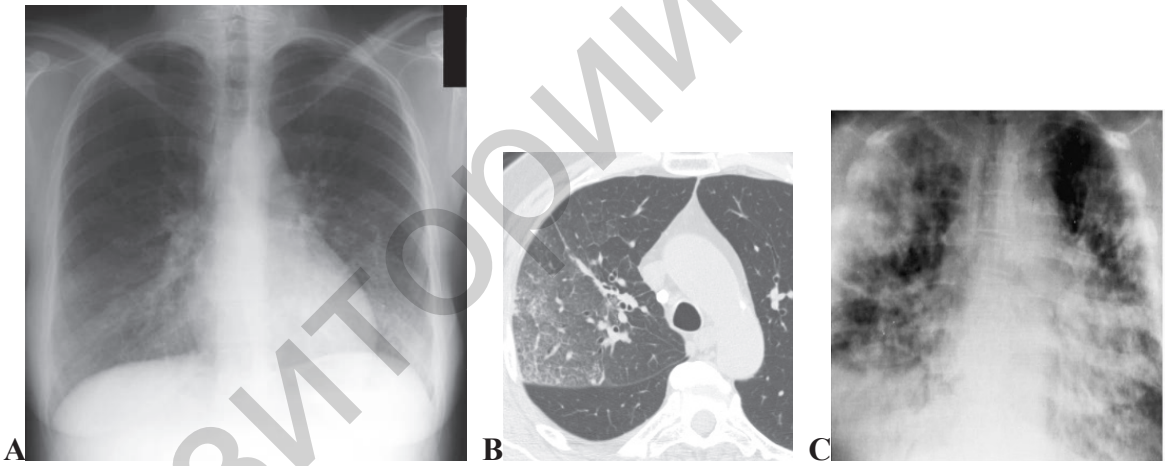


Figure 3.15 — (A to B) Frontal chest radiograph and CT-tomogram an axial a plane same patient. Loss normal lung architecture with interstitial markings and increased pulmonary vascular patterns. (C) Viral pneumonia. Diffuse peribronchial infiltrate with associated air-space consolidation obscures the heart border (shaggy heart sign). A patchy alveolar infiltrate is present in the right upper lung field

The hallmark of the interstitial pattern is the presence of linear and irregular shadows. Unlike the patterns of alveolar flooding and atelectasis, the interstitial pattern is often subtle and may be difficult to distinguish from normal in some patients because the lines are mistaken for vessels. Look at the pattern of the lines and decide if you are simply looking at the vessels or if there are too many lines and the pattern is too irregular to represent normal vessels alone. Figure 3.16 shows a patients with a viral pneumonia presenting with an interstitial pattern.

The interstitial pattern includes many categories of diseases and there are several subsets of the interstitial pattern. A typical pattern, such as the one shown in the above case, is commonly seen in patients with “interstitial” pneumonias (classically viral pneumonias and mycoplasma pneumonia.

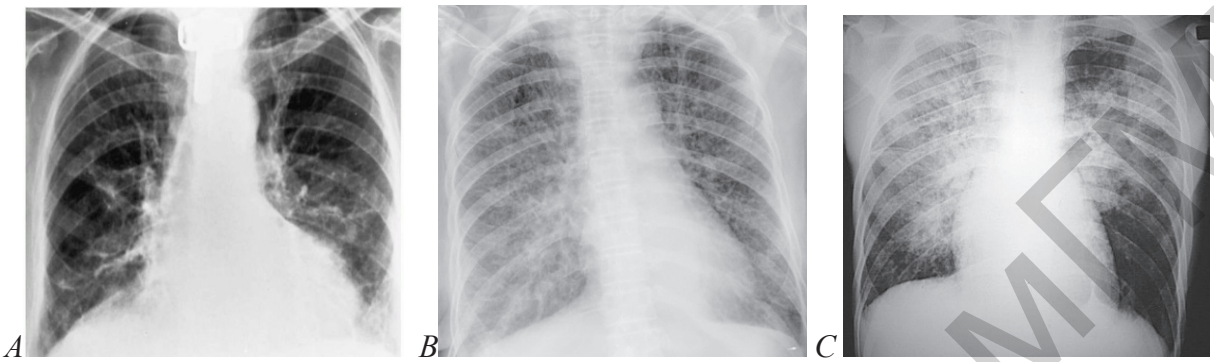


Figure 3.16 — (A to B) Interstitial pneumonia. Notice the excessive number of linear and irregular shadows throughout the film. In subtle cases it may be difficult to distinguish the increased linear prominence from the normal vessels. (C) Pulmonary edema in congestive heart failure. Diffuse, coarse reticulonodular pattern. Chest radiograph demonstrates a paucity of vascular markings along with increased interstitial markings elsewhere. With the onset of congestive heart failure, there is patchy interstitial and alveolar edema that does not affect the segments in which the vascularity had been severely diminished. Diffuse bilateral symmetric infiltration of the central portion of the lungs along with relative sparing of the periphery produces the butterfly, or bat’s wing, pattern

Atelectasis (collapse)

The term atelectasis (collapse of small peripheral airways and alveoli) means incomplete expansion of the lungs. To make the diagnosis of atelectasis requires evidence of a volume loss. Lobar consolidation may have similar appearances. A common cause of atelectasis is pneumonia. Radiological characteristics includes:

1. Opacity (shadow, airless lung).
2. Signs of loss of the lung volume:
— mediastinal shift;
— elevated hemidiaphragm;
— movement of fissures;
— shift of hilum;
— change of proportion of the lung fields;
— smaller hemithorax.
3. Compensatory hyperinflation.
4. Vessels asymmetry.
5. Fissure appears as an edge (Figures 3.17–3.18).

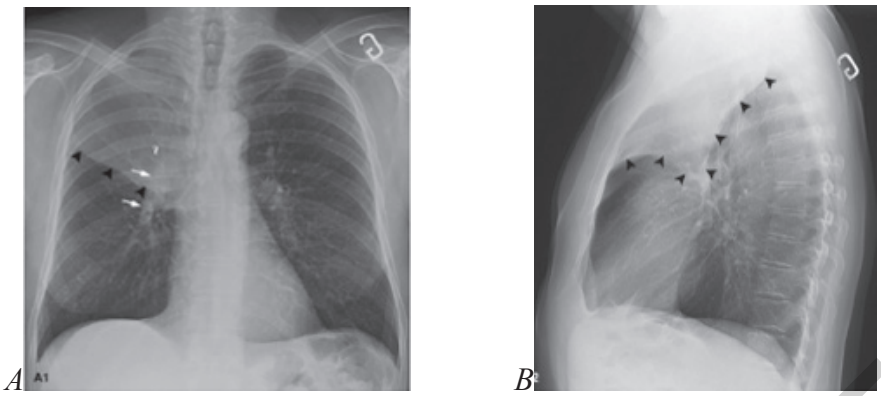


Figure 3.17 — Atelectasis of the right upper lobe (A to B) from bronchopneumonia. Increased shadowing (opacity) in the right upper zone with a clear linear border (black heads) of the horizontal fissure. The volume RUL loss is evident because of the increased opacity as well as (B) elevation of the minor fissure and elevation of right hilum (white arrows)

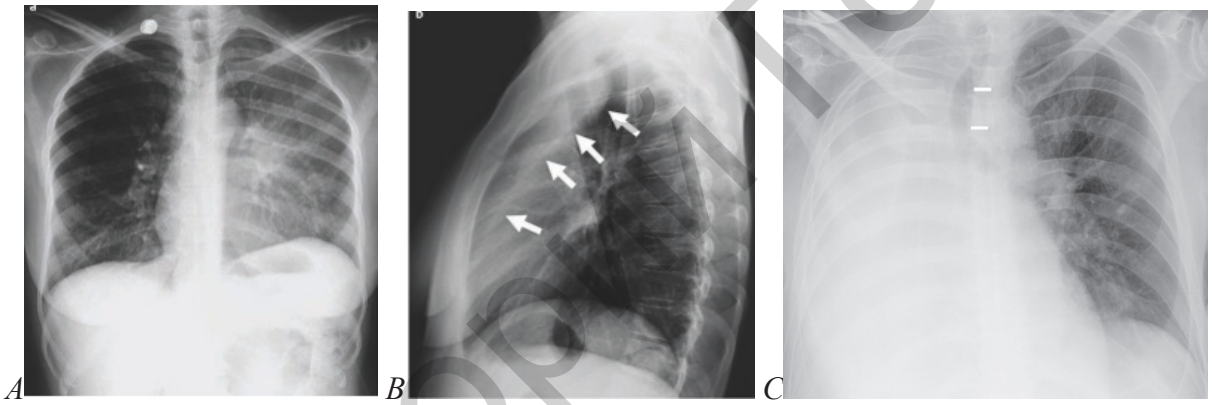


Figure 3.18 — (A) The opacity seen on the CXR obliterates the interface between the left heart and the left lung — which means that it is located in the upper lobe. It demonstrates a homogeneous internal structure indicating that it is airless and it shows associated volume loss in the affected lung (the left hemidiaphragm is elevated, decreased volume of left lung). (B) The lateral view confirms a dense stripe retrosternally (arrows) due to oblique fissure. Increased shadowing in the left upper and mid zone lung field due to left upper lobe which has collapsed upwards and anteriorly. This is compatible with left upper lobe collapse (complete lobar atelectasis). (C) Total atelectasis of the right lung. Notice the shift (white lines) of the trachea toward the affected side, loss of the right lung volume

Lung collapse or atelectasis can affect the whole lung, a single lobe or a segmental component. The lobar collapses are important not to miss on imaging. Atelectasis literally means incomplete expansion or loss of the volume.

Abscess

Abscesses can often be well defined on chest X-rays as they have relatively thick walls (Figures 3.19–3.20). Note the presence of an air fluid level. The abscess

itself may be a result of a malignant process and so it is important to ensure that follow-up occurs. Abscess characteristics includes:

— Cavitating infective consolidation.

— Single or multiple lesions.

— Bacterial or fungal pathogens are the most common causative organisms.

— Associated with aspiration and/or impaired local or systemic immune response (epileptics, diabetics, ets.).

Radiological features includes:

— Most commonly occur in the apicoposterior aspect of the upper lobes.

— A cavitating spherical area of consolidation an air-fluid level present.

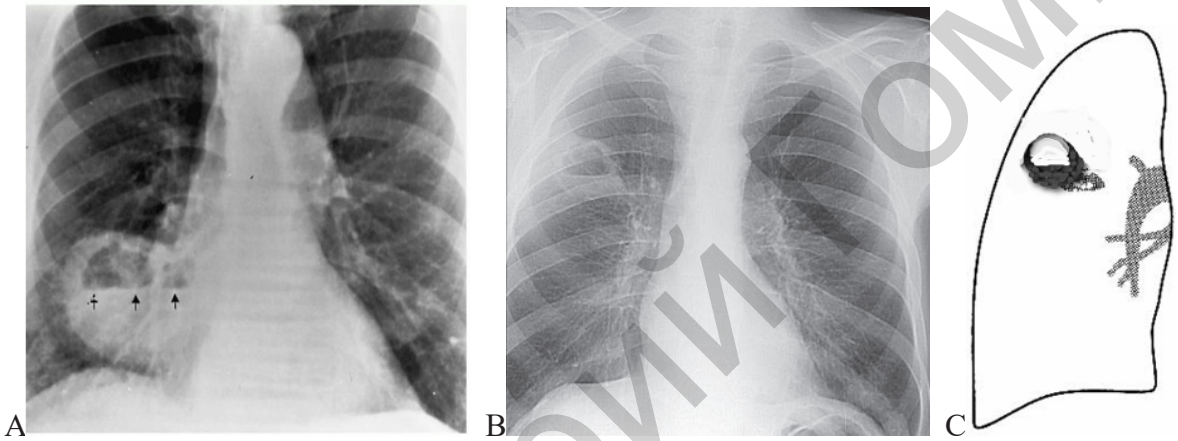


Figure 3.19 — (A) Acute lung abscess. Large right middle lobe abscess containing an air-fluid level (arrows) in an intravenous drug abuser. (B) Abscess right lung. (C) Scheme to B

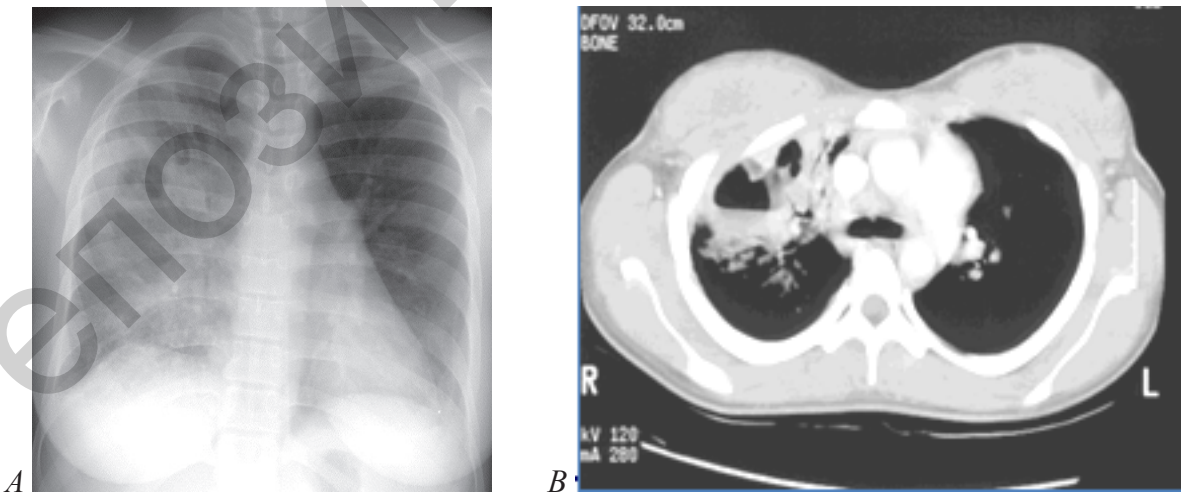


Figure 3.20 — Klebsiella pneumonia complicated by an abscesses. (A) Frontal chest radiograph with air-space consolidation involving much of the right upper lobe. (B) Progression of the necrotizing infection produces a large abscess cavities with an air-fluid level within the upper zone of the right lung field

Cavities form when a pulmonary mass undergoes necrosis and communicates with an airway, leading to gas within its center. The wall of a cavity is usually irregular or lobulated and, by definition, is greater than 1 mm thick. Lung abscess and necrotic neoplasm are the most common cavitary pulmonary lesions.

Pleural abnormalities

Pleural abnormalities are a common finding on chest X-ray, the significance of which varies from trivial to marked. Typical areas to identify pleural abnormalities are at the costophrenic and cardiophrenic angles, the apices, and the peripheral outline of both lungs. Abnormalities involving the pleura include pathologic processes (masses, calcifications, infections, thickening) of the pleura, in addition to fluid and air collections within the pleural space. Three main categories of pleural abnormalities are seen: effusions, pleural thickening or calcification, and pneumothoraces. Fluid in space between the lung and the chest wall is termed a pleural effusion. There needs to be at least 75 ml of pleural fluid in order to blunt the costophrenic angle on the lateral chest radiograph, and 200 ml on the posteroanterior chest radiograph. On a lateral decubitus, amounts as small as 5 ml of fluid are possible.

Pleural effusion definition: fluid in the potential space between the parietal and visceral pleura. The radiographic appearance of pleural effusions depends upon the amount of the fluid present, the patient's position during the radiographic examination, and the presence or absence of adhesions between the visceral and parietal pleura. Small amounts of the pleural fluid initially collect between the lower lobe and the diaphragm in a subpulmonic location. As more fluid accumulates, it spills into the posterior and lateral costophrenic sulci. A moderate amount of the pleural fluid (> 175 ml) in the erect patient will have a characteristic appearance on the frontal radiograph, with a homogeneous lower zone opacity seen in the lateral costophrenic sulcus with a concave interface toward the lung. This concave margin, known as a pleural meniscus, appears higher laterally than medially on frontal radiographs because the lateral aspect of the effusion, which surrounds the costal surface of the lung, is tangent to the frontal x-ray beam. Similarly, the meniscus of the pleural fluid as seen on lateral radiographs peaks anteriorly and posteriorly. This usually results in obliteration part or all of the hemidiaphragms (silhouette sign), blunting of the costophrenic angles both peripherally on the frontal projection and posteriorly on the lateral. Radiological characteristics includes:

— Loss of costophrenic angle.
— Loss of diaphragmatic shadow.
— Homogenous opacification.
— Shift of mediastinum to the opposite side with large effusions.
— Ellips line (meniscus high in axilla).

Pleural effusions typically have a meniscus visible on an erect chest radiograph, but loculated effusions (as occur with an empyema) may have a lenticular shape (the fluid making an obtuse angle with the chest wall) (Figures 3.21–3.22).

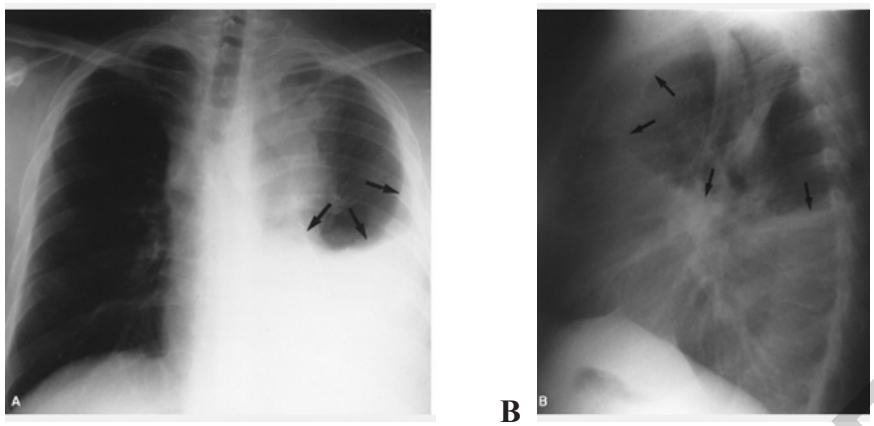


Figure 3.21 — Right pleural effusion on frontal chest radiographs.
(A) Posteroanterior and lateral (B) chest radiographs demonstrate the typical homogenous shadow, non-visualization of left hemidiaphragm and costophrenic angle, and meniscoid appearance (arrows) in a patient with a left moderate pleural effusion.
There is opacification of the lower right hemithorax with a fluid level, and the mediastinum is pushed to the left side. Note the a laterally placed meniscus, and loss of clarity of the lung and outline of the hemi-diaphragm

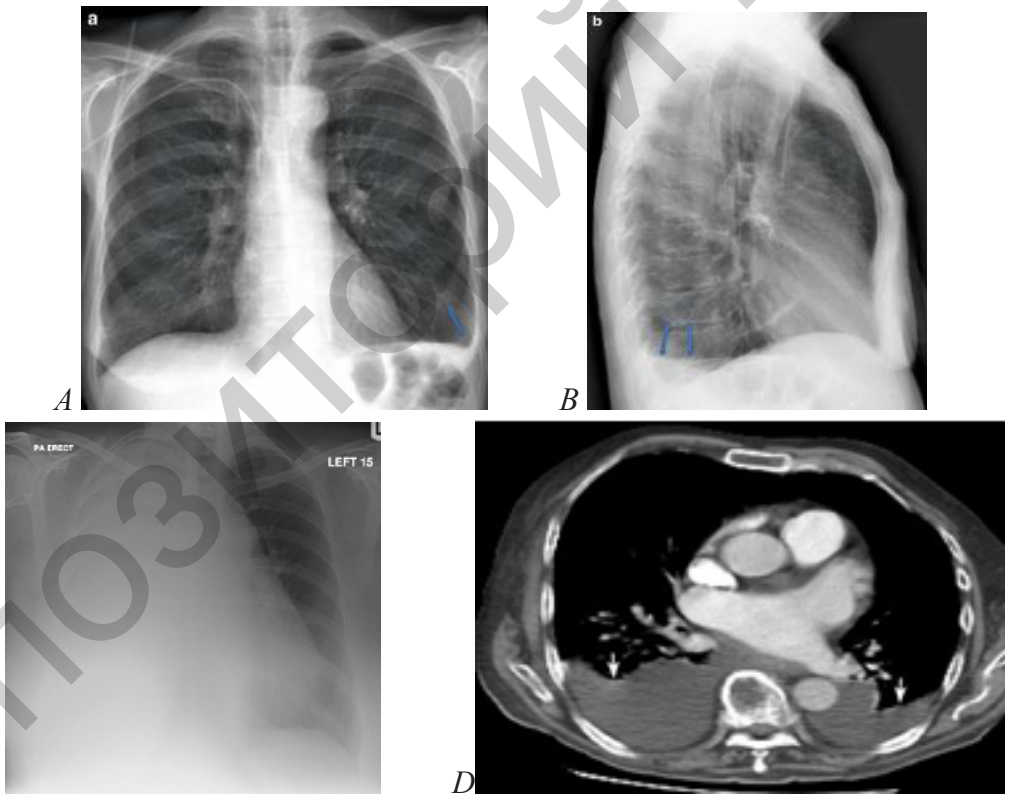


Figure 3.22 — PA (A) and lateral (B) erect projections of the chest demonstrate blunting of left costophrenic angle with a meniscus peripherally on the PA and posteriorly on the lateral (arrows) at limited exudative pleurisy.
(C) Radiograph of chest frontal projection, large right pleural effusion. Note the mediastinal shift away from the effusion. (D) Pleural effusion on CT. CT is done in the supine position. Fluid settles in the dependent portion in the back of chest.
The white arrows point to bilateral pleural effusions

Pleural thickening may cause blunting of the costophrenic angle, but is distinguished from pleural fluid by the fact that it occurs as a linear shadow ascending vertically and clinging to the ribs.

Pneumothorax

Pneumothorax results from air entering the pleural space and may be traumatic or spontaneous. Spontaneous pneumothorax is further subdivided into a primary form, which has no identifiable etiology, and a secondary form, which is associated with underlying parenchymal lung disease. Radiological characteristics includes: a) dark field with no vascular markings in the pleural space; b) visible collapsed lung, c) may be larger hemithorax (Figures 3.23–3.24).

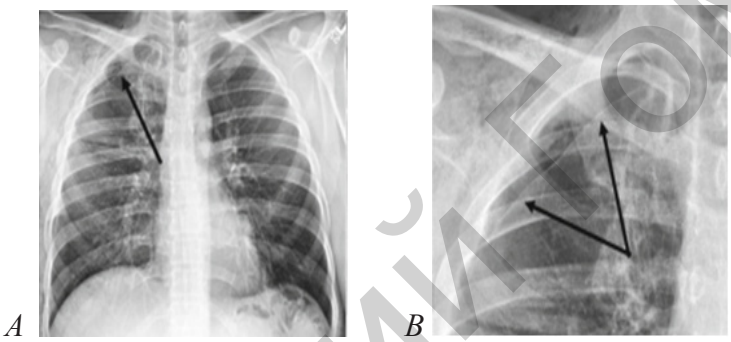


Figure 3.23 — Pneumothorax. (A) Frontal chest radiograph. (B) Spot film of right side chest. Note how the edge of the collapsed right lung is delineated by a sharply demarcated thin white line (arrows), the visceral pleura, beyond which no pulmonary markings are identified (best seen on close up image on the right)

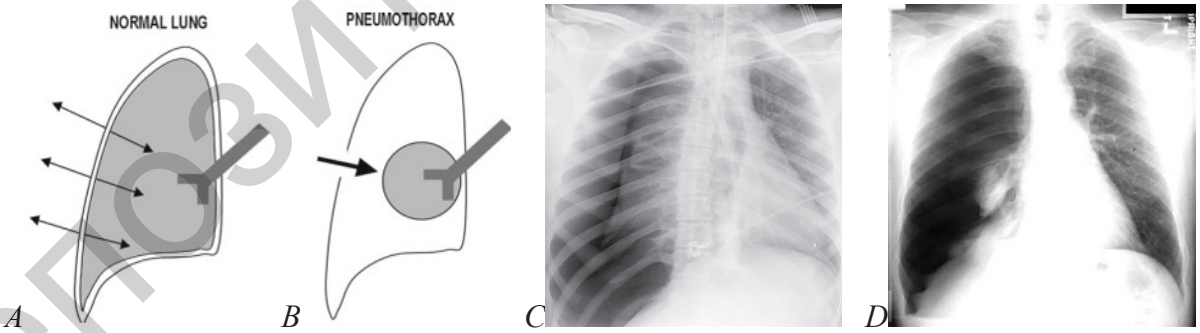


Figure 3.24 — Diagrams (A) the normal elastic forces between the chest wall and the lung oppose each other, (B) resulting in a certain equilibrium as noted in the picture on the pneumothorax. With a pneumothorax, air enters the thorax, allowing the lung to collapse. (C) Radiograph show very large pneumothorax on the right side. Increased lucency of the right hemithorax with leftward mediastinal shift, widening of the right intercostal spaces and inferior displacement of the right hemidiaphragm, consistent with a right pneumothorax. The right side of the lung is blacker, and the lung edge is seen. Right pneumothorax pushing mediastinum to the left. (D) This frontal chest radiograph reveals complete collapse of the right lung due to a massive right pneumothorax. The right lung is almost completely compressed

Hydropneumothorax

Hydropneumothorax (or hemopneumothorax) is a combination of pleural fluid and pneumothorax. A straight air-fluid level, differentiates this entity from pleural effusion without pneumothorax (Figure 3.25). Effusions without pneumothorax have a meniscus as we have seen.

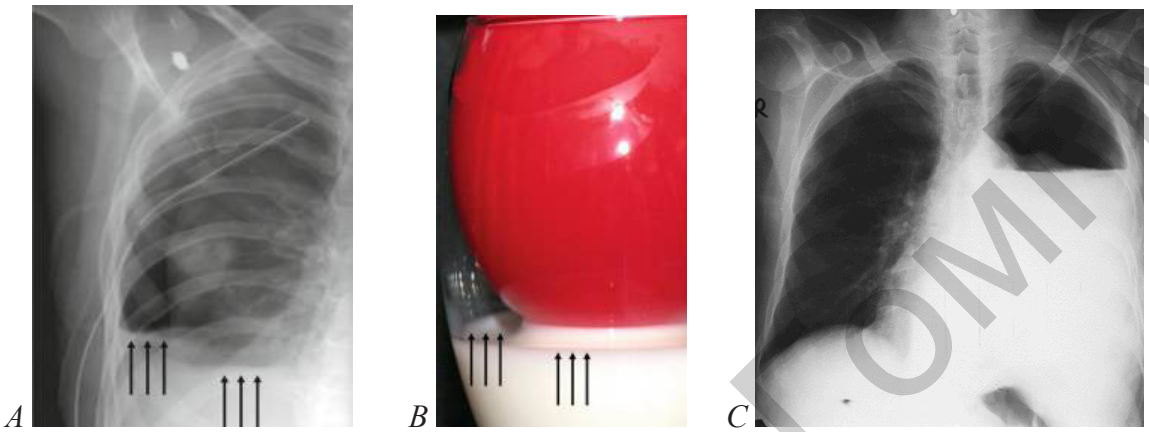


Figure 3.25 — (A) Note similarity with actual hydropneumothorax. The arrows demonstrate how fluid level can be perceived in several layers. (B) Balloon analog showing milk layer and partially filled balloon (lung) (representing an erect projection). (C) Frontal chestradiograph, the left side large hydropneumothorax pushing mediastinum to the right

Emphysema

Chronic obstructive pulmonary disease is not truly a disease but a group of diseases — chronic bronchitis, small airways disease (obstructive bronchiolitis), and destruction of the lung parenchyma (emphysema). Pulmonary emphysema is defined as abnormal, permanent enlargement of airspaces distal to terminal bronchioles, accompanied by the destruction of airspace walls without obvious fibrosis. The most prominent radiographic findings result from lung overinflation (dark lungs), manifesting as:

— Avascularity of the lung fields.

— Increased pulmonary radiolucency and a bilaterally flat.

— Increased AP diameter of the chest and lung field.

— Depressed hemidiaphragm (below the anterior portion of the seventh rib or the posterior portion of the tenth rib), low flat diaphragms.

— Increased retrosternal space (> 4,5 cm on the lateral film measured from a point 3 cm below the sternal angle).

— Increased infracardial space.

— Vertical heart.

— Accentuated kyphosis.
— Increased intercostal spaces.

The number of vessels is decreased in emphysemic tissue. The central pulmonary arteries are more prominent and appear truncated peripherally. Increased prominence of the interstitial markings is often present. Bullae may appear as radiolucent air sacs in the periphery of the apex or base of the lungs. Only moderate to severe forms of emphysema are detectable on plain film radiography (Figure 3.26).

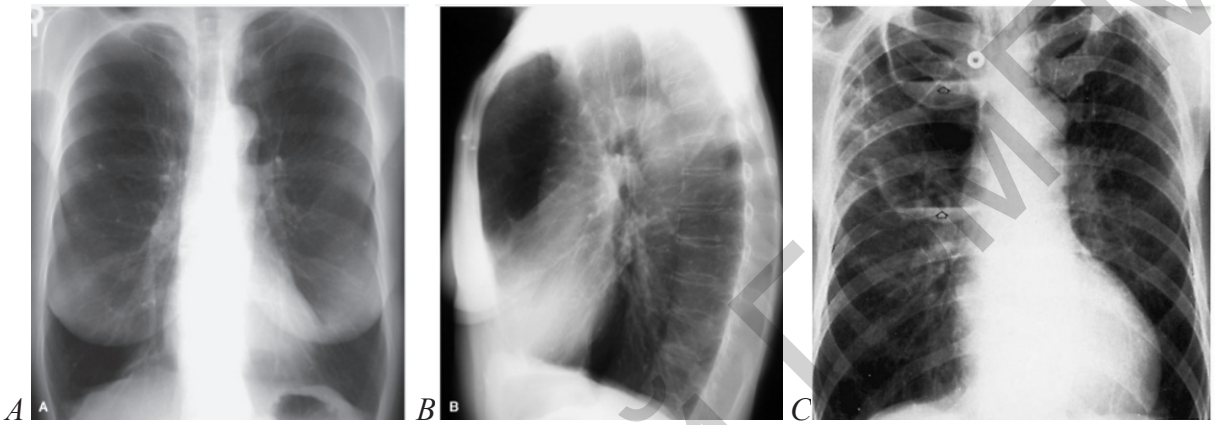


Figure 3.26 — (A) Posteroanterior and (B) lateral chest radiographs with emphysema shows hyperinflation with hyperlucency, overexpanded lungs, narrow mediastinum, upper lobe vascular attenuation, flattening of the diaphragms, and an increased retrosternal airspace, reflecting severe bilateral lungs emphysema. (C) Pulmonary emphysema. Large bullae in the right upper lung. The presence of air-fluid levels (arrows) in the cystic spaces indicates superimposed infection

A bulla is a gas collection within the pulmonary parenchyma that is >1 cm in diameter and has a thin wall < 1 mm thick. It represents a focal area of parenchymal destruction (emphysema) and may contain fibrous strands, residual blood vessels, or alveolar septa. An air cyst is any well-circumscribed intrapulmonary gas collection with a smooth thin wall > 1 mm thick. While some of these lesions will have a true epithelial lining (bronchogenic cyst that communicates with a bronchus), most do not and likely represent postinflammatory or posttraumatic lesions. A bleb is a collection of gas < 1 cm in size within the layers of the visceral pleura. It is usually found in the apical portion of the lung. These small gas collections are not seen on plain radiographs but may be visualized on chest CT, where they are indistinguishable from paraseptal emphysema. Rupture of an apical bleb can lead to spontaneous pneumothorax. Pneumatoceles are thin-walled, gas-containing structures that represent distended airspaces distal to a check-valve obstruction of a bronchus or bronchiole, most commonly secondary to staphylococcal pneumonia. A traumatic air cyst results from pulmonary laceration following blunt trauma. These lesions generally resolve within 4 to 6 months.

Bronchiectatic cysts are usually multiple, rounded, thin-walled lucencies found in clusters in the lower lobes, and represent saccular dilatations of the airways in varicose or cystic bronchiectasis.

Abnormal lucency of the lung may be localized or diffuse. Focal radiolucent lesions of the lung include cavities, cysts, bullae, blebs, and pneumatoceles. These lesions are usually recognized by identification of the wall that marginates the lucent lesion.

Tuberculosis of lung

Tuberculosis has various manifestations in the lung. In primary tuberculosis there is a peripheral lung mass (Ghon's focus) with enlarged hilar lymph nodes.

Consolidation can also occur. In secondary tuberculosis there is patchy consolidation especially in the upper lobes. This can cavitate. Other manifestations include pleural effusions and miliary tuberculosis (TB). Mediastinal lymphadenopathy does not occur in secondary TB. Other infections can cavitate, including pneumonias due to staphylococcus, klebsiella, and cryptococcus. Pneumocystis carinii, as the name suggests, can form cysts which are airfilled and have a similar appearance on an x ray film to cavities.

Tuberculosis (characteristics):

— Mycobacterium tuberculosis is an aerobic bacillus.

— High cause of morbidity and mortality worldwide.

— Susceptible groups include immunocompromised, elderly, alcoholics and immigrants from third world countries.

— TB predominately affects the lungs but spread via lymphatics and blood vessels allows dissemination to other organs (pericardium, gastrointestinal and genitourinary tracts, bone and the CNS).

— Three main types of pulmonary tuberculous infection:

▫ Primary.

▫ Post primary or reactivation.

▫ Miliary.

▫ A tuberculoma represents a focal mass lesion of uncertain tuberculous infective activity.

Radiological features (chest x-ray) includes:

— Primary.

▫ May be active or inactive infection.

▫ Scarring and calcification (lung and lymph nodes) suggest inactive disease.

▫ Consolidation, small focal nodularity, lymphadenopathy and effusions suggest active infection.

▫ A Ghon's focus is a peripheral area of lung consolidation.

— Post primary.

▫ Again may be active or inactive.

▫ Focal scarring and lung distortion ± cavitation. Usually in upper lobes.

▫ Adenopathy and effusions are much less common.

— Miliary infection.

▫ Multiple small discrete widespread pulmonary nodules.

— Reactivation of TB can be difficult to diagnose. Comparison with old films for changes in appearance is helpful. Increased soft tissue and cavitation suggest active infection (Figures 3.27–3.29).

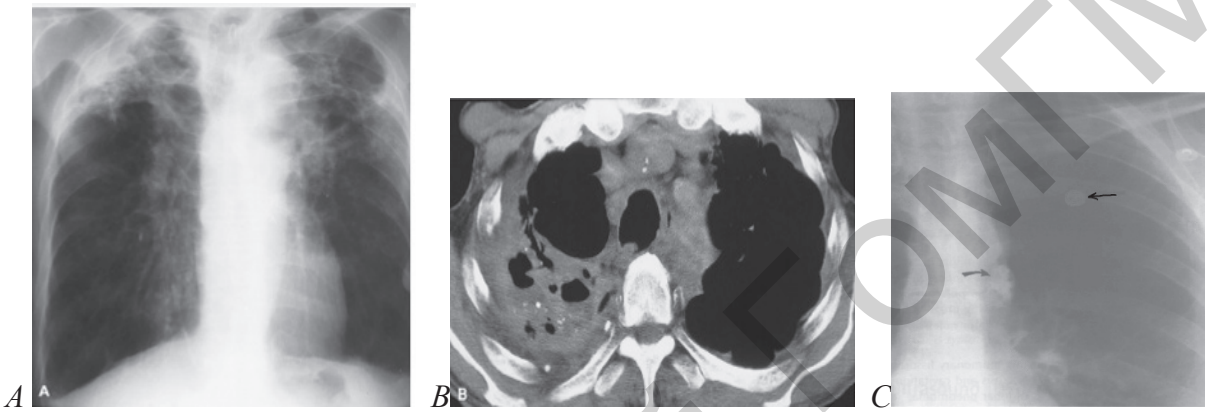


Figure 3.27— Postprimary (reactivation) tuberculosis. (A) Frontal chest film reveals hyperinflation with marked fibrotic and cavitary disease in the upper lobes with severe volume loss. In general, thin-walled cavities (<5 mm) tend to be infective and, when thick-walled (<10 mm), squamous cell carcinoma of the lung enters into the differential diagnosis. (B) A CT scan through the lung apices demonstrates consolidative and cavitary changes with air and fluid levels and pleural and parenchymal calcifications. (C) Primary tuberculosis of the lungs: Ghon complex. There is a calcified granuloma in the parenchyma left upper lobe (straight arrow), with a calcified lymph node in the hilar region (curved arrow). The combination of a focal parenchymal lesion (arrows) and enlarged right hilar lymph nodes produces the classic primary complex

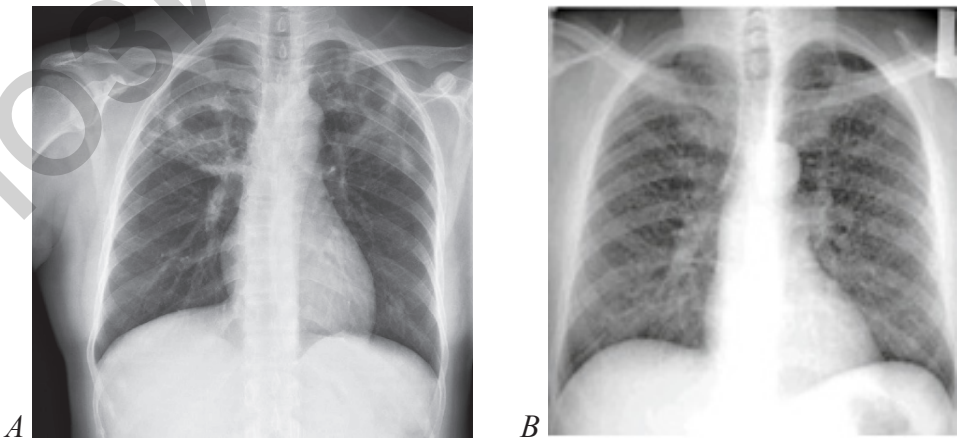


Figure 3.28 — (A) This frontal chest radiograph demonstrates multiple cavitary lesions with relatively thick walls in the upper lobes. The patient suffered from reactivation tuberculosis. (B) This frontal chest radiograph has innumerable tiny opacities throughout both lungs, secondary to miliary tuberculosis

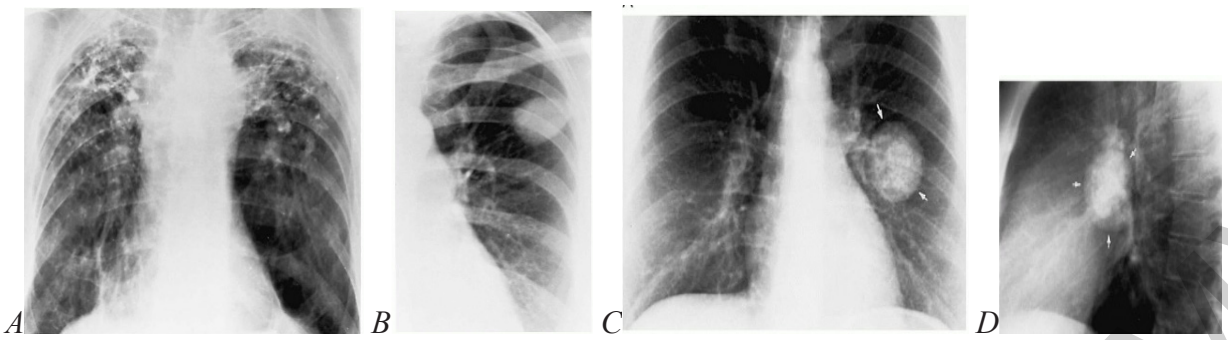


Figure 3.29 — (A) Tuberculosis. Bilateral fibrocalcific changes at the apices. There is upward retraction of the hila. (B) Tuberculoma. Single smooth, well-defined pulmonary nodule in the left upper lobe. In the absence of a central of calcification, this appearance is indistinguishable from that of a malignancy. Calcified tuberculoma. (C) Frontal and (D) lateral views of the chest show a large left lung soft-tissue mass (arrows) containing dense central calcification

Lung masses

Hamartoma (Figure 3.30, A to B)

Hamartomas grow at the same rate as their parent organ and therefore do not exhibit neoplastic pressure erosion of adjacent tissues. Hamartomas are typically peripheral, presenting as well-defined pulmonary nodules. Peripheral lesions are distributed equally among the lobes. Hamartomas may appear large but are typically less than 4 cm in diameter; an average diameter of 2 cm has been reported. Calcification is demonstrated in 30% of patients, with rates as high as 75% reported. When present, the pattern of calcification often has a pathognomonic “popcorn” or “comma-shaped” appearance. Approximately 8 % of hamartomas are in an endobronchial location, possibly leading to airway obstruction.

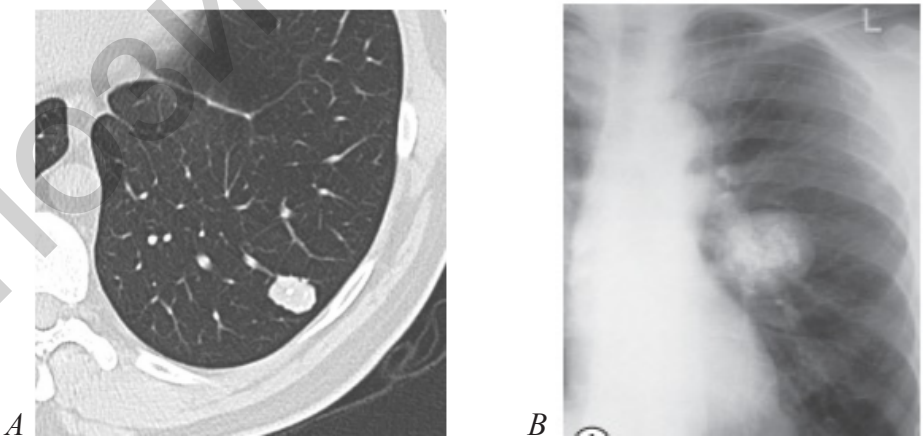


Figure 3.30 — (A) CT chest tomogram demonstrates a mildly lobulated nodule with calcification in the left lower lobe which corresponds to a hamartoma. (B) Hamartoma of the lung. Round, completely smooth, hamartoma in a 57-year-old asymptomatic man. There is typical coarse popcorn calcification in this lesion, which is unusually large

Bronchogenic carcinoma

Bronchogenic carcinoma is one of several neoplasms that may arise within the lung. It is now the leading cause of death from malignancy in the United States and most industrialized countries for both men and women. Radiographic findings in bronchogenic carcinoma depend on the subtype of cancer and the stage of the disease at the time of diagnosis. The two most common findings are an a solitary pulmonary nodule or mass (peripheral location) and a hilar mass (central location, Figure 3.31) with or without bronchial obstruction.

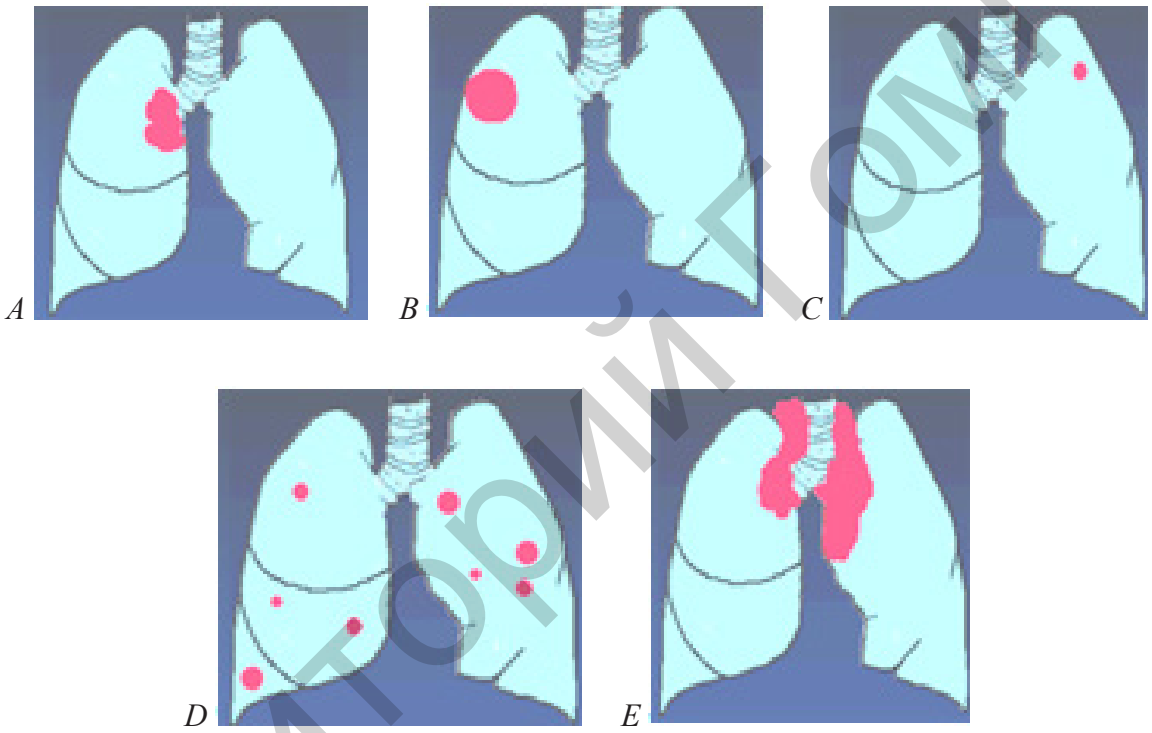


Figure 3.31 — (A to E) Diagrams main variants of bronchogenic carcinoma. (A) Central mass, (B) peripheral mass, (C) peripheral nodule, (D) multiple nodules, (E) adenopathy

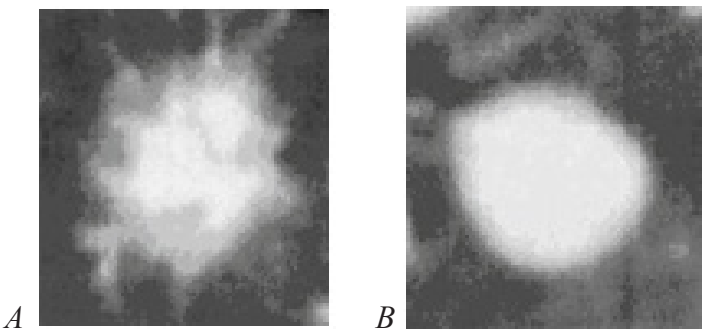


Figure 3.32 — Primary lung carcinoma (spot films). (A) The malignant mass is speculated and (B) the benign mass has smooth margins

All cell types can present with a pulmonary nodule (Figures 3.31–3.34). Because squamous and small cell carcinoma arise from the central bronchi, the majority of these types of bronchogenic carcinoma produce a hilar mass. The hilar mass represents either the extraluminal portion of the bronchial tumor or hilar lymph node enlargement from the metastatic disease. Extension of the hilar lesion into the mediastinum or the presence of mediastinal nodal metastases can produce a smooth or lobulated mediastinal mass. Marked mediastinal nodal enlargement producing a lobulated mediastinal contour is characteristic of small cell carcinoma. Extensive replacement of the mediastinal fat by either primary tumor or extracapsular nodal extension may produce diffuse mediastinal widening, with loss of the mediastinal fat planes and compression or invasion of the trachea or central bronchi, esophagus, and mediastinal vascular structures, as seen on contrast-enhanced CT or MR.

Obstruction of the bronchial lumen by the endobronchial component of a tumor can result in several different radiographic findings. The most common finding is resorptive atelectasis or obstructive pneumonitis of lung distal to the obstructing lesion. Resorptive atelectasis is recognized by the classic findings of lobar or whole lung collapse, whereas obstructive pneumonitis results in minimal or no atelectasis or occasionally an increase in the volume of the affected portion of lung. An abnormal increase in lobar or whole lung volume is recognized radiographically by a bulging interlobar fissure marginating the obstructed lobe or by mediastinal shift, respectively, and is termed drowned lung. Occasionally, the mass producing the lobar atelectasis creates a central convexity in the normally concave contour of the collapsed lobe, producing the S-sign of Golden. Most commonly, the opacity of the obstructed lung obscures the underlying central lesion.

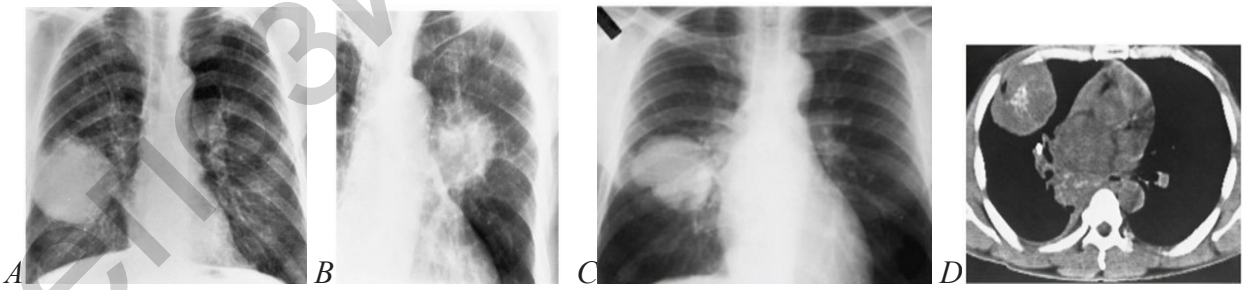


Figure 3.33 — Bronchogenic carcinoma. (A) Relatively well-defined mass periferal localization. (B) Ill-defined solitary nodule central localization. (C) Chest radiograph shows a large mass in the middle lobe. A second large lesion is evident in the azygoesophageal recess. (D) CT scan demonstrates dystrophic central calcification within the lesion and scattered calcifications in the mediastinal mass

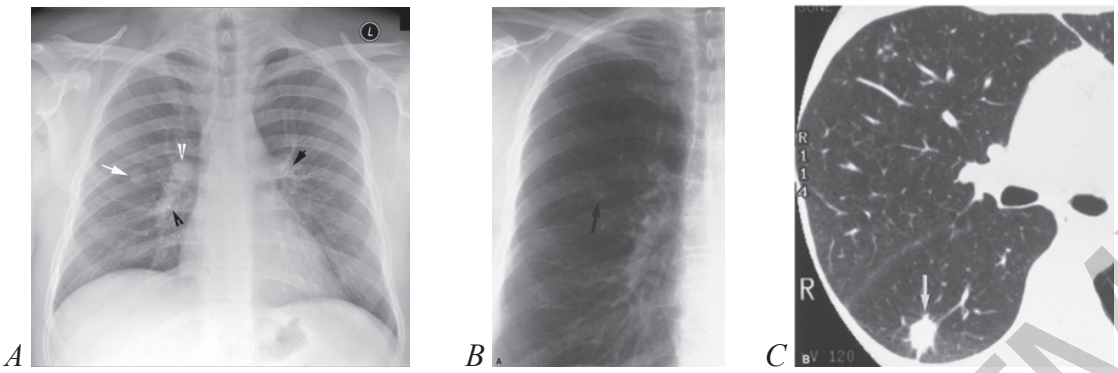


Figure 3.34 — Adenocarcinoma right lung. (A) Frontal chest radiograph. Note the solitary pulmonary nodule. White arrow points to the solitary pulmonary nodule. White arrowhead points to the right hilum which is full and dense. Black arrowheads point to calcification, evident in both hilum. Adenocarcinoma presenting as solitary pulmonary nodule. (B) Cone-down view of posteroanterior radiograph shows nodule in the right mid-lung (arrow). (C) Thin-section CT shows 12-mm nodule with spiculated margins (arrow) in the superior segment of the right lower lobe

The central mass is readily distinguished from vascular structures, with narrowing or occlusion of the bronchial lumen best seen on images viewed at lung windows. The central tumor is usually distinguished from atelectatic lung by the contrast between the perfused but nonventilated enhancing lung and the low-attenuation, nonenhancing central mass.

Tumors that arise from the bronchiolar or alveolar epithelium namely, adenocarcinoma and large cell carcinoma commonly produce a solitary pulmonary nodule or mass on chest radiography. The radiographic evaluation of the solitary pulmonary nodule, in particular the size, growth rate, shape, margins, and internal density, has been reviewed in detail earlier in this chapter. A notched, lobulated, or spiculated margin to the nodule is common in bronchogenic carcinoma. The edge characteristics of an solitary pulmonary nodule are best appreciated on thin-section HRCT images through lesion.

The size and growth pattern of an a solitary pulmonary nodule are important characteristics. Masses > 3 cm in diameter seen in adults over 35 years of age are overwhelmingly malignant. The volume-doubling time (equivalent to a 25% increase in diameter) for a malignant nodule usually ranges from 1 month (some squamous cell and large cell carcinomas) to 4 years (certain bronchioloalveolar cell carcinomas).

Primary lung cancer. Histologic types

Bronchogenic carcinoma is the more appropriate term, because most of them arise from the epithelium of the airways and not the lung per se. Because early recognition and surgical resection offer the patient the best chance for cure, it is im-

portant to be familiar with the variety of radiographic appearances of lung cancer. For therapeutic purposes, lung cancer is divided into small-cell and non-small-cell carcinoma. This distinction is necessary because small-cell bronchogenic carcinoma is almost always widespread at the time of diagnosis and is best treated by chemotherapy and radiation therapy. Non-small-cell bronchogenic carcinoma, on the other hand, is best treated by surgical resection when the tumor is confined to one lung and regional lymph nodes. The typical radiographic appearance of small-cell carcinoma is bulky hilar or mediastinal lymph nodes or both; and the primary tumor sometimes is visible as a nodule within the lung.

Non-small-cell bronchogenic carcinoma includes adenocarcinoma, squamous cell carcinoma, and large-cell carcinoma. Four major cell types account for almost 90% of all lung cancers.

The most common primary pulmonary malignancy, adenocarcinoma, is increasing most rapidly in incidence, and now accounts for nearly 50 % of lung cancers. Radiologically, three quarters of these lesions present peripherally in the lung, most often as a solitary nodule or mass, and often in the upper lobes. A variant of adenocarcinoma, bronchoalveolar carcinoma, disseminates along the tracheobronchial tree. It characteristically presents as a small peripheral nodule or as persistent air-space opacities (a “pneumonia” that fails to respond radiographically to antibiotics). It has a much better prognosis if removed before it reaches 3 cm in size. Adenocarcinoma frequently shows hilar and mediastinal adenopathy, though the nodal enlargement is not as massive as it is with small cell and large cell undifferentiated tumours. A mass in, or adjacent to, the hilum is a particular characteristic of small cell carcinoma, seen in 78% of cases. Pleural effusion (with dyspnoea) is a feature of adenocarcinoma.

Alveolar cell carcinoma is also known as bronchiolar or bronchioloalveolar carcinoma, and is a subtype of adenocarcinoma with certain special features. The second most frequent form, accounting for approximately one third of cases, is squamous cell carcinoma, so named because it exhibits the keratinization and intercellular bridges one expects in squamous epithelium. Squamous cell carcinoma typically arises centrally within a bronchus, spreading by endobronchial growth. On radiographs, it often appears as a hilar or perihilar mass, and produces segmental or lobar atelectasis and/or consolidation secondary to bronchial obstruction; however, up to one third of lesions may present peripherally. It is the most common type to cavitate and also constitutes the most common etiology of Pancoast’s syndrome. It has the best overall prognosis, with significant potential for cure if tumors are removed prior to metastatic spread.

Squamous cell cancers may attain great size and they cavitate more frequently than the other cell types; in one series cavitation was seen in 12% of squamous cell carcinomas presenting as a peripheral mass, compared with only 4–6% of peripheral large cell and peripheral adenocarcinomas. Collapse / consolidation of the lung beyond the tumour is the most frequent feature seen with squamous cell carcinoma, in keeping with the predominantly central origin of this form of neoplasm.

The third most common cell type is small cell carcinoma, including the so-called oat cell variety. It is the most strongly associated with cigarette smoking. Small cell carcinoma most often presents as a large, central mass and is very likely to be metastatic at the time of detection, with 80% of patients demonstrating extrathoracic metastatic disease. It is associated with significant degrees of mediastinal and hilar adenopathy in most cases.

Large cell lung carcinoma most often presents as a large, peripheral mass. Unfortunately, it exhibits the worst combination of biological behaviors, growing rapidly and metastasizing early. However, its prognosis remains more favorable than that of small cell carcinoma.

A peripheral nodule is very common in adenocarcinoma (72% of cases) and large cell tumours (63% of cases); it occurs approximately twice as often as with squamous or small cell carcinomas. The largest peripheral masses are seen with squamous and large cell tumours, whereas most adenocarcinomas and small cell carcinomas are less than 4 cm in diameter.

Lung carcinomas can also cavitate, squamous cell carcinomas are the typical histological subtype to do so (Figure 3.35, A to C). Apart from cavitation, other features of lung carcinomas can occur in the periphery of the lung or centrally (in or near the mediastinum). The outline of the tumour may be spiculated. Look for associated pleural effusion or hilar lymphadenopathy.

Proximal tumours can cause distal consolidation or collapse. Local rib destruction or multiple bony metastases can also occur, so look for these.

Pancoast tumour (characteristics):

— This is a primary lung tumour located in the lung apex.
— The majority are squamous cell carcinomas.
— They represent 3% of all primary lung tumours.
— Strong association with cigarette smoking.
— Usual age at presentation > 40 years.

Radiological features: (chest x-ray) unilateral apical pleural thickening/mass. The mass lesion may cavitate. Hilar enlargement secondary to lymphadenopathy. May be rib destruction and extrathoracic soft tissue mass lesion.

Metastatic lung disease

Bloodborne metastasis presents as multiple well-defined nodules ranging from 1 to 5 cm in size located in the peripheral lung fields. Nodules tend to involve the basal portions of lungs, possibly related to preferential blood flow (Figure 3.35, D). Larger lesions are termed cannonball metastasis. Lymphangitic spread of metastasis presents with Kerley lines, discrete nodules, and linear shadows, denoting a reticulonodular interstitial pattern of pulmonary disease.

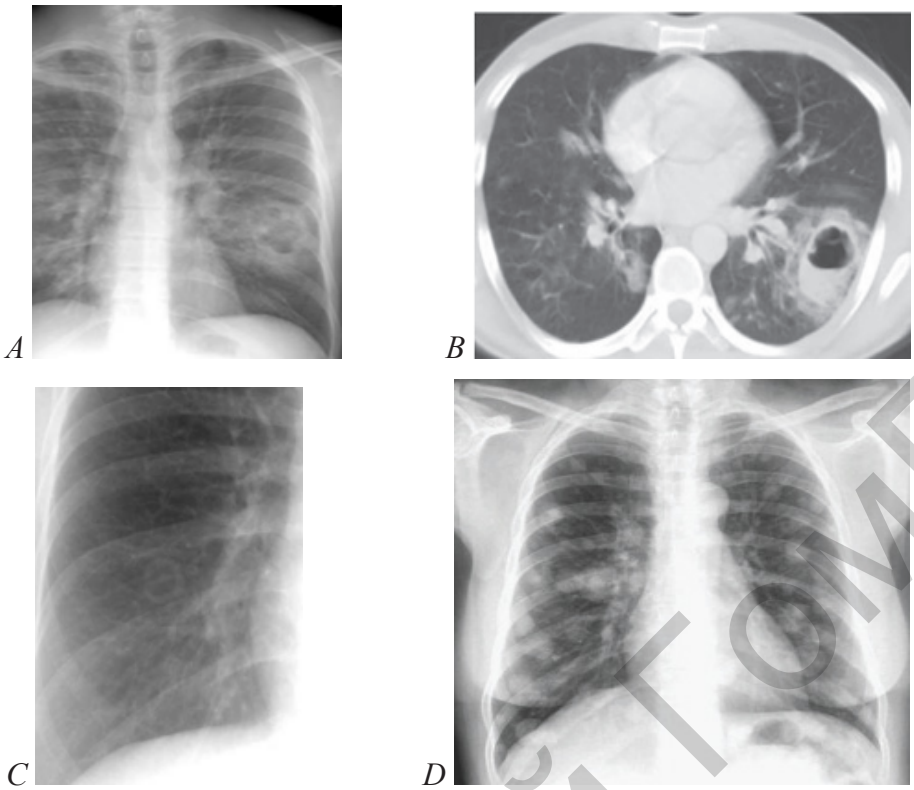


Figure 3.35 — (A to C) Examples images of the chest for a differential diagnosis: — carcinoma; — abscess-fungal/bacterial/TB; — vascular-septic emboli (black arrow). (D) Metastases. This frontal chest radiograph in a woman with cervical carcinoma demonstrates multiple bilateral pulmonary well-circumscribed nodules scattered diffusely throughout both lung fields, indicating metastases lungs

The pattern is typically bilateral. A unilateral solitary presentation suggests a primary lesion, such as bronchogenic carcinoma (Table 3.1). Cavitation is present in 6% to 7% and is more common with squamous cell carcinoma than adenocarcinoma. The uterus, cervix, colon, head, and neck are common sites of origin.

Table 3.1 — Symptoms of chest x-ray to differential diagnosis

"Mass" + ipsilateral adenopathy	*Lung mass (radiological characteristics)*
1. Bronchogenic ca. 2. Lymphoma. 3. TB	1. Homogenous liquid density. 2. > 5 cm in diameter (less than 5 cm is called solitary pulmonary nodule). 3. Sharp margins (no respect for segments or fissures)
Solitary pulmonary nodule	*Solitary pulmonary nodule*
1. Bronchogenic ca. 2. Benign tumor. 3. Round pneumonia. 5. Rounded atelectasis. 6. TB granuloma. 7. Solitary met	Radiological criteria. 1. Liquid density. 2. Distinct margin. 3. Between 2–5 cm in diameter. 4. Oval or round

Lung disease & rib destruction	*Multiple lung nodules*
1. Bronchogenic ca, i.e. Pancoast tumor. 2. Multiple myeloma	1. Mets. 2. Rheumatoid nodules. 3. Septic emboli
Cavitary lung lesions	*Metastases*
1. Carcinoma of the lung. 2. TB. 3. Abscess	1. Usually well defined. 2. Nodules of varying size. 3. More common peripherally and in the lower lobes
Hilar adenopathy	*Micronodular lung disease*
1. TB. 2. Lymphoma. 3. Bronchogenic cancer	1. Mets. 2. Pneumoconiosis. 3. Miliary TB

Mediastinal mass

Radiological characteristic of the mediastinal mass (Table 3.2).

Mass because:

— Homogeneous liquid density.

— Distinct margin.

Mediastinal because (Figures 3.36–3.37):

— Has extrapleural sign (peripheral, absence of one of the margins both in PA and lateral view)

— Location is suggested by silhouette sign and lateral chest x-rays.

Table 3.2 — Common localization of the mediastinal mass

Anterior mediastinum	Middle mediastinum	Posterior mediastinum
1. Thymoma 2. Teratoma 3. Thyroid 4. Testicular metastasis 5. Lymphoma	1. Lymph node disease 2. Bronchial cysts	1. Neural lesions 2. Esophageal disease 3. Vertebral lesions

It should be noted here that the only difference between a lung “nodule” and a lung “mass” is that of size. Traditionally, nodules are soft tissue lesions in the lung that are smaller than 3cm, while masses are lesions that are 3 cm or greater. The size does matter. The larger the nodule, the more the suspicion for malignancy. Is it smooth? This generally favours a benign cause, but it is not a fail safe. A spiculated appearance is highly suspicious for carcinoma.

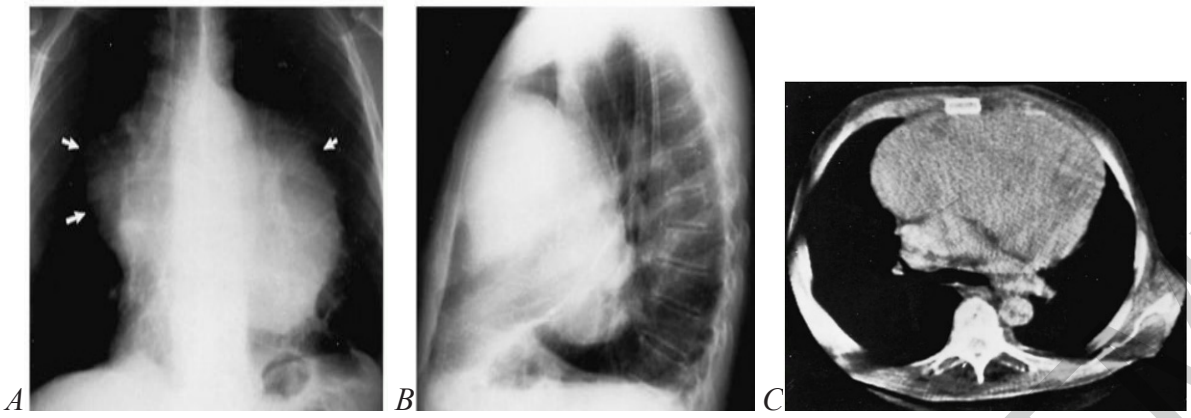


Figure 3.36 — Thymoma. (A) Frontal radiograph shows a large bilateral lobulated mass (arrows) extending to both sides of the mediastinum. (B) Lateral view shows filling of the anterior precardiac space by a mass and posterior displacement of the left side of the heart.
(C) On CT axial tomogram enormous soft-tissue mass in the anterior mediastinum with posterior displacement of other mediastinal structures. No difference in density can be seen between the mass and the heart behind it

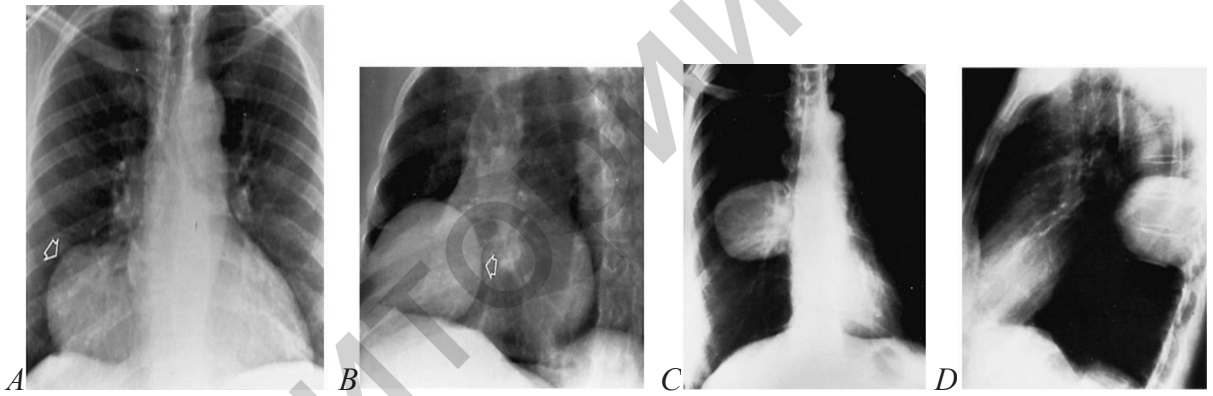


Figure 3.37 — Pericardial cyst. (A) Frontal and (B) oblique radiographs demonstrate a smooth mass (arrows) in the right cardiophrenic angle.
Neurogenic tumor. (C) Frontal and (D) lateral radiographs of the chest demonstrate a large right posterior mediastinal mass

Leiomyoma, fibroma, neurofibroma (solitary pulmonary nodule, benign tumors)

Arising from the smooth muscle of the airways or pulmonary vessels, leiomyomas are rare neoplasms that present as endobronchial or intrapulmonary lesions with equal frequency. Radiographically, the parenchymal lesions are sharply marginated, smooth or lobulated nodules or masses. The histologic distinction of benign from malignant lesions is difficult. Similarly, fibromas and neurofibromas appearing as lack distinguishing radiographic features.

Fluoroscopy (roentgenoscopy)

Roentgenoscopy is the second main method of chest examination of the chest. Fluoroscopy involves an increased dose of irradiation to the patient compared with a simple chest X-ray. In practice it is now carried out only for the elucidation of specific problems. Thus it may be used to determine whether the diaphragm is moving normally or is paralysed; to assess the relationship of an opacity to other structures more accurately by observing it with different degrees of rotation on the screen; or to confirm valve or other intracardiac calcification since this is much better visualised by screening with an image intensifier than on a simple film. Sometimes it can be used for performing some surgical manipulations such as catheterization. While the ana-lysis of an X-ray film could be done by any doctor, the roentgenoscopy is to be performed only by a radiologist.

X-ray linear tomography

This is an old method used for the clearer demonstration of doubtful opacities in the lung field; for the better visualization of masses or apparent masses at the lung hilus; for the study of the margins of opacities in the lung — whether they are clear-cut or infiltrating surrounding lung; and for the better demonstration of cavities or suspected cavities within a lung lesion, or of calcification in an opacity.

Fluorography

Fluorography it is one of additional methods of chest examination. Most frequently, it is applied to preventive researches instead of for diagnostics of diseases. It is because of a lower opportunity of this method to reveal small details on the image. In some cases fluorography can be applied to an estimation of dynamic changes of pathological process, but not for a primary research.

Bronchography

This procedure is now little used and mainly for the demonstration of bronchiectasis. It is also sometimes used for the demonstration of an obstructed or stenosed bronchus in suspected carcinoma. Bronchography is performed in the X-ray department by the surgeon and radiologist. The contrast medium, propyliodine or iodolipolum, is usually injected, through a catheter, involved to a main bronchus. Once the contrast medium has been injected, the patient is tilled into the various positions necessary for filling the appropriate lobes of the lung with contrast.

Pulmonary angiography

Pulmonary angiography is performed by passing a catheter from a peripheral vein through the right atrium and right ventricle into the main pulmonary artery and

then if necessary into the right or left pulmonary artery. Contrast medium is injected so as to opacity the blood supply of the area under examination. The main use of the method is to confirm a suspected diagnosis of pulmonary embolus. Pulmonary angiography is also occasionally used for the elucidation of opacities in the lung fields; for example to confirm a diagnosis of arteriovenous fistula or angiomatous malformation in the lung.

Radionuclide scanning

Scintigraphy of the lungs is widely practised to confirm or refute a clinical diagnosis or suspicion of pulmonary embolus. Lung scans can be performed following intravenous injection of technetium (^{99m}Tc) labelled macroaggregates or microspheres. This is known as the perfusion scan. It can also be performed by inhalation of radioactive xenon (^{133}Xe) or krypton (^{81m}Kr) or albumin aerosol labelled with technetium (^{99m}Tc). This is known as the ventilation scans. The ventilation scans are usually performed for the evaluation of low aerated areas of the lung.

Scintigraphy of respiratory system

Example indications: diagnosis of pulmonary embolism, split lung function/ preoperative assessment for lung resection.

Limitations: perfusion scintigrams are highly sensitive for the detection of small defects. However, this high sensitivity is not matched by a high specificity for the diagnosis of pulmonary embolism. Various conditions can cause mismatched defects on ventilation-perfusion scintigram including emphysema, tuberculosis, previous irradiation, etc.

Perfusion imaging agents

Technetium-99m (^{99m}Tc) + macroaggregated albumin (MAA) is the radiopharmaceutical used for pulmonary perfusion imaging. It is localized by the mechanism of capillary blockade. In general, fewer than 1 in 1000 (< 0,1%) of the capillaries are blocked. 95% of the particles are removed from the circulation on the first pass through the pulmonary capillary bed. The normal administered activity in adults is 5 mCi (185 MBq).

Ventilation imaging agents: radioactive inert gases.

The use of radioactive inert gases to evaluate ventilation permits sequential imaging of both lung ventilation and perfusion in conjunction with ^{99m}Tc-MAA because of the rapid clearance of the gases from the lungs.

Xenon-133 (^{133}Xe) is the primary isotope used for assessment of ventilation. It is relatively inexpensive and has a half-life of 5,3 days and a principal gamma ray energy of 81 keV. Xenon-133 allows for the assessment of all phases of regional ventilation: initial single breath, washin, equilibrium, and washout. This complete characterization of ventilation renders ^{l33}Xe imaging the most sensitive ventilation study for detection and assessment of airways disease.

Ventilation examinations are generally performed either to assess regional ventilation or to improve the specificity of a perfusion scintigram. Inhale 10 mCi (370 MBq) of ^{133}Xe.

Normal perfusion scintigram

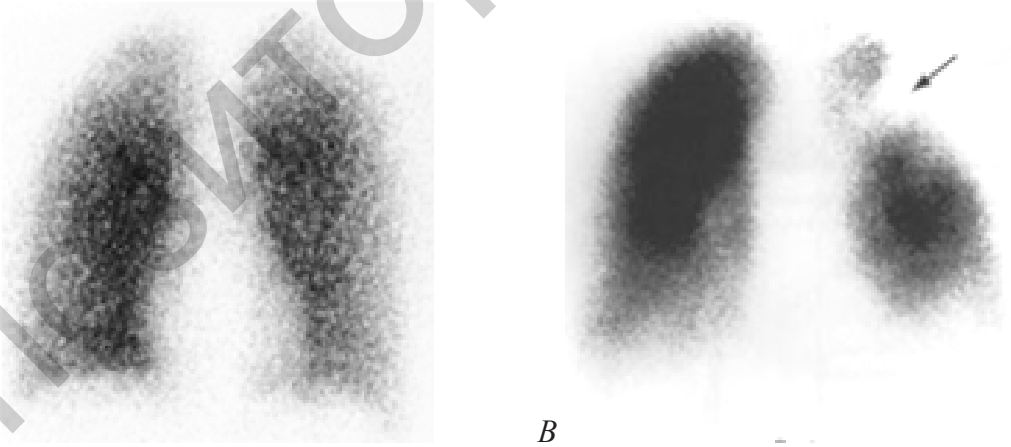
In the anterior view, the cardiac silhouette and the aortic knob are commonly identified (Figure 3.38, A). The left lateral view may show a substantial anterior defect due to the heart. Oblique projections are often helpful but may be confusing to the uninitiated observer and frequently demonstrate prominent hilar defects. In general, defects suspected on the oblique projections should be confirmed on one of the four standard views.

Normal ventilation scintigram

A relatively homogeneous distribution of activity should be seen throughout both lungs; the initial breath image reflects regional ventilatory rate if there is maximum inspiratory effort.

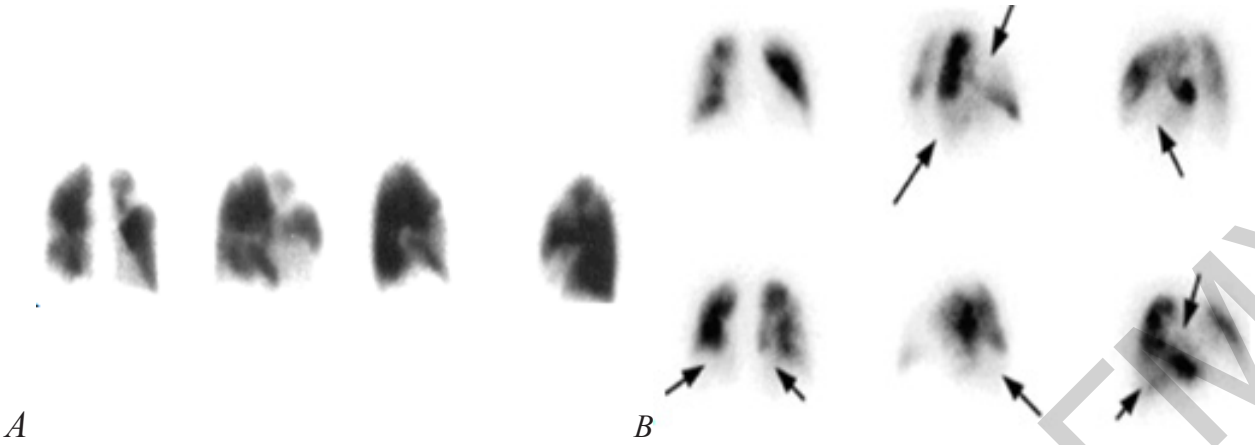
Pulmonary thromboembolism

Pulmonary thromboembolism (Figure 3.39) is a potentially fatal complication of deep vein thrombosis. Although anticoagulation and thrombolytic therapies are effective, they are without potential morbidity. Thus, before the institution of treatment, determination of the reasonable likelihood of the presence or absence of pulmonary emboli is needed.



A *B*

Figure 3.38 — (A) Normal perfusion study. A ^{99m}Tc-MAA perfusion scintigram (anterior view). The perfusion study reveals uniform perfusion throughout both lungs with no defects. Note the nonuniform uptake with homogeneous distribution of radiopharmaceutical and the sharp delineation of the costophrenic angles. In the anterior view, the cardiac silhouette and the aortic knob are commonly identified.
(B) Tuberculosis (for comparison B to A). A posterior image from the perfusion lung scan shows decreased perfusion (arrow) in the upper area left lung (a matched defect)



A *B*

Figure 3.39 — (A) Perfusion MAA polipositions scans. Perfusion study shows multiple perfusion defects equivalent to more than two segments with no matching abnormalities on ventilation study and no corresponding changes in the chest X-ray, which was normal. This illustrates a typical pattern of high probability of pulmonary emboli.
(B) ^{99m}Tc-MAA perfusion images demonstrate multiple segmental and subsegmental perfusion defects (arrows) in regions which are ventilated normally (V/Q mismatch). The findings indicate a high probability of acute pulmonary embolism

The clinical diagnosis of pulmonary embolism is often difficult. Chest radiographic findings alone are nonspecific for the diagnosis of pulmonary embolism. Radionuclide ventilation-perfusion imaging, when properly performed and interpreted, is an effective noninvasive procedure for the detection of pulmonary embolus. In addition, a normal scintigram essentially excludes the diagnosis. Lungs scintigrams are often preferred over CT-angiography for patients who have contrast allergies, are in renal failure, or who are too large for the CT-gantry.

Diagnostic ultrasound

The scope of application of chest sonography has been significantly widened for the last few years. Portable ultrasound systems are used to an increasing extent in preclinical sonography, at the site of trauma, in the ambulance of the emergency physician or in ambulance helicopters. Chest sonography has proved its worth as a strategic instrument to be used directly after the clinical investigation. Ultrasound has proven to be more sensitive than flat anteroposterior chest radiography in the diagnosis of trauma-induced pneumothorax. Ultrasound provides added benefit by allowing sonologists to differentiate between small, medium, and large pneumothoraces, with good agreement with CT results. Sonography provides very significant information about the cause of a sudden chest pain in the presence of a tension pneumothorax, in cases of pulmonary embolism. Pulmonary consolidations are detected if they reach the visceral pleura, or if they are located behind an acoustic window. Sonography control investigations are particularly valuable in the course of pleural and pericardial effusions.

The high resolution of the sonographic image and the real-time examination make a major contribution to the diagnosis of diseases of the chest. Structures of the chest wall and pleural lesions are visualized by ultrasound.

Computed tomography

The main use of CT in the chest is in assessing mediastinal disease and in staging of lung cancer and other malignant lesions. It is also more sensitive than simple X-ray in identifying small pulmonary metastases and in detecting pulmonary fibrosis and bronchiectasis. CT is commonly employed to better evaluate lesions detected on plain radiography. Cross-sectional images eliminate the superimposition of structures that characterizes chest radiographs. High resolution thin section CT is invaluable in elucidating interstitial pulmonary disease.

Magnetic resonance imaging

MRI of the chest has proved most valuable in the assessment and characterization of mediastinal and pleural masses. Its ability to show sections in the sagittal and coronal as well as the axial plane and its ability to show vascular structures without contrast injections give it an advantage over CT.

While MRI is an imaging method of first choice in almost all parts of the human body its acceptance for thoracic imaging is rather ow even today. However, appropriate instructions of the patient remain the key to high image quality without respiratory motion artifacts. It is also useful in the diagnosis of hilar and mediastinal lymphadenopathy in the staging of malignant tumours. MRI has the advantage of not using ionizing radiation.

IV. BASIC IMAGING CARDIOVASCULAR SYSTEM

Cardiovascular imaging is different from that for all other organs because the dimension of time has to be included in the subsecond acquisition and analysis of images. The chest film remains the entry-level examination for most cardiac problems. Although daunting economic and scheduling constraints remain, the cross-sectional methods — echocardiography, computed tomography, and magnetic resonance imaging are becoming the primary imaging choices to diagnose cardiac diseases because the millisecond temporal resolution and the millimeter special resolution can follow the beating heart and the moving blood.

The anatomic and physiologic effects of heart disease have many common imaging features. Chamber dilatation, valve calcification, and anomalous connections are morphologic signs of cardiac abnormalities. Increased or decreased blood flow and segmental wall motion disorders are physiologic signs of a heart disease. The analysis for a cardiovascular disease on the chest film, echocardiogram, CT scan, and MRI begins with a search for these common elements. Diagnostic imaging has a great role in the examination of patients with various cardiac and vessels diseases. Among all the methods of medical visualization the first which are applied to patients are X-ray plain films and ultrasound examination which are available nowdays in the majority of clinics and hospitals. For more precise and deeper functional examinations are used CT, MRI, nuclear medical examinations and angiography. The task of the general practitioner is to be able to differentiate normal and pathologic image and to distinguish the most common diseases of the cardiovascular system.

Chest plain radiography

The chest film is often the first imaging procedure performed when a heart disease is suspected, and more commonly, it is used to assess and follow the severity of a cardiac disease. Because the chest film forms images by projection, this technique detects only those cardiopulmonary abnormalities that change the shape of the heart, mediastinum, and lungs and those that alter the structure of the pulmonary vasculature. Clinically a silent heart disease may also be detected on a chest film taken for other reasons. Extracardial structures, particularly in the abdomen and the thoracic cage, may produce additional clues indicating a heart disease. Calcification in the aortic valve, for example, identifies the abnormal structure and directs the differential diagnosis toward a particular pathologic lesion.

The complete X-ray examination at cardiac diseases imply the performance of four X-ray films — in anteroposterior (AP) direct view, left lateral view (LL), right and left oblique (RO, LO) views. The main among them would be the direct AP view.

Plain X-ray film of examination

1. Position of heart (oblique, vertical, horizontal).

2. Arcs of a cardiovascular shadow.

Cardiac chambers and borders of great vessels prominent on cardiac borders create the shape of convexities or the so-called cardiac arcs. In all the views only certain arcs can be seen.

3. X-ray cardiometry.

To reveal the sizes of the heart and enlargement of its chambers and dilatation of the great vessels (aorta and pulmonary artery) are to be measured special sizes (Figure 4.1).

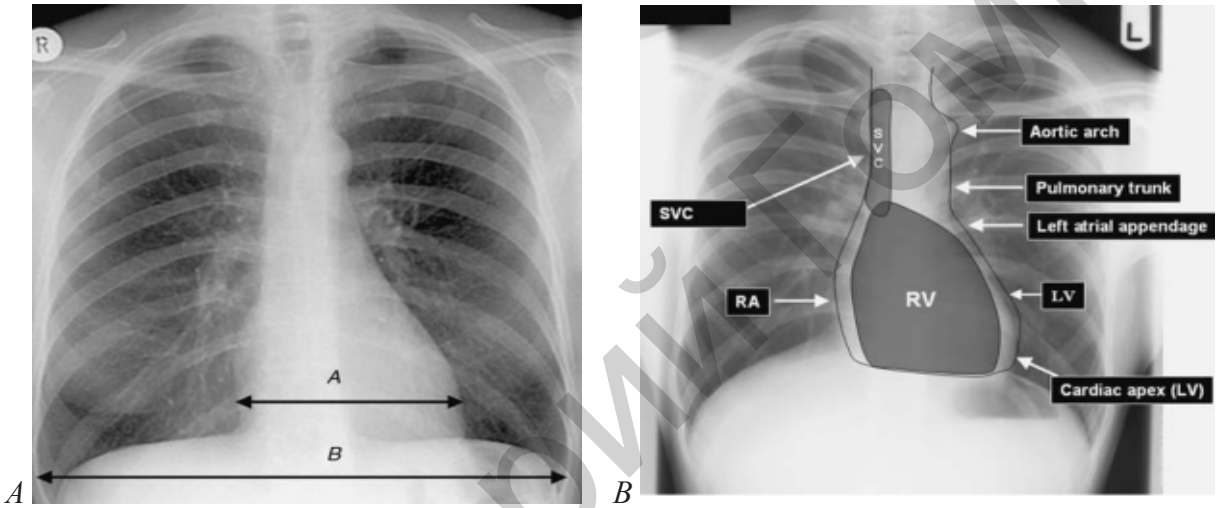


Figure 4.1 — Heart and mediastinum. (A) Assessment of heart size: the cardiothoracic ratio should be less than 0.5, i.e. A/B < 0.5; a cardiothoracic ratio of greater than 0.5 in a good quality film) suggests cardiomegaly. (B) Assessment of cardiomediastinal contour: right side: SVC, RA; anterior aspect: RV; cardiac apex: LV; left side: LV, left atrial appendage, pulmonary trunk, aortic arch

4. The shape of the heart is defined by constitutional features and the size of heart chambers. The X-ray sign of the heart shape has a diagnostic value only by comparison to other signs, in particular, with the exact sizes of heart chambers.

The *normal shape* of the heart is detected most frequently at the persons of a normostenic body build. It is characterized by smooth and clear contours of the arcs; the second and third arc on the left contour are often merge a among themselves and the border between them can be poorly differentiated.

The *mitral shape* of the heart is characterized by smoothing or protrusion and elongation of the arcs of a pulmonary artery and left atrium. The degree of a protrusion can be various. This shape is detected at diseases with a hypertension in a small blood circle (mitral valve disease, pulmonary heart, unclosed arterial duct, defects of septum, etc.). It can be accompanied by the enlargement of ventricles, changes of a heart position and sizes, changes of a lung pattern and lung hila.

The *aortal shape* of the heart is characterized by projection shortening of the second and third arcs on the left contour of the heart with formation of their concavity ("the underlined waist of the heart"). Enlargement of aortic arches and left ventricle is detected. Heart widely adjoins to a diaphragm and its apex is uplifted. This shape is detected at a high position of a diaphragm (at an ascites or pregnancy), at aortal valve failures and some other diseases.

The *round shape* of the heart is characterized by greater rounding of the right and left lower arcs, absence of clear angles between arcs on the left contour of the heart with a total magnification of all the heart sizes. This shape is detected at some congenital heart failures (defects of chambers septum, stenosis of a pulmonary artery), and at the pericardial effusion.

Triangular (trapezoidal) shape of the heart is characterized by smoothing and lining of all the arcs with absence of visual borders between them; the heart widely adjoins to a diaphragm, the cardio-diaphragm angles are often blunt. Most frequently blunt is detected at a myocarditis.

5. The structure of a heart shadow is examined at all the views and implies the detection of homogenity or if there are depositions of a calcium, foreign bodies.

6. Condition of all the chambers of the heart is examined the next. On the basis of cardiometry the doctor makes the conclusion if the ventricles and atriums are enlarged or normal.

7. Condition of an aorta. Aorta might be not changed, elongated, dilated, it sometimes can contain calcifications.

8. Condition of lung hila. This X-ray sign is very important at various cardiac diseases with the hypertension or congestion of blood in a pulmonary circle. The hila can be dilated or not dilated.

9. Condition of a lung pattern. This sign is also important at changes of blood flow in a lung circus. The lung pattern can be normal, increased, decreased. Sometimes on a background of a changed lung pattern the presence of a hemosiderosis can be detected.

After all these X-ray signs and measurements are taken into account the general conclusion is done by a doctor.

X-ray diagnostics most common diseases of the heart

X-ray diagnostics of a mitral stenosis

There are two variants of stenosis of the left atrioventricular valve:

1. Stenosis due to rheumatic endocarditis.

2. Stenosis caused by atherosclerotic process (seldom).

The mitral stenosis constitutes 54 % from all valve failures of a rheumatic origin (Figure 4.2). Isolated stenosis — 48–68 % from all mitral lesions.

Pathologic mechanism of the disease: at narrowing of the left atrioventricular hole the inflow of blood from the left atrium to the left ventricle is labored; this leads

to the left atrium which becomes hypertrophied and dilated. In a left atrium the blood can accumulated sometimes ten times more than normal. The left ventricle receives less amount of the blood, than under normal conditions and remains unchanged. The blood, collected in the left atrium, leads to the extent congestive process in the small circle of a blood circulation, increases the strain of a right ventricle, which has to overcome the resistance which has arisen in a small circle. A right ventricle is hypertrophied and later dilated. In late stages appears the functional failure of thricuspid valve with a dilatation of the right atrium and associated congestion in the major circle of a circulation.

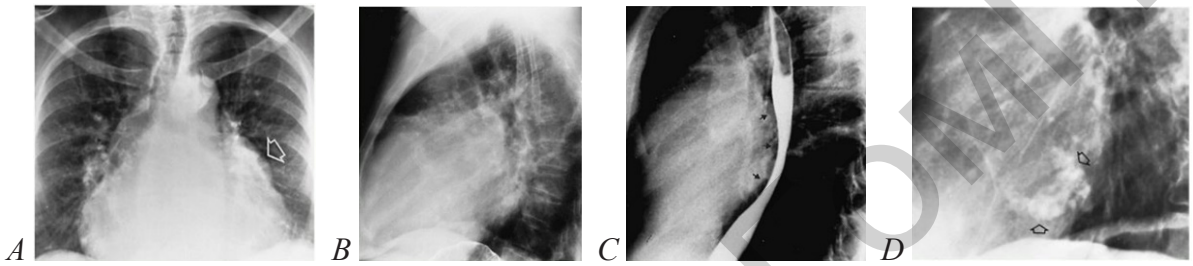


Figure 4.2 — Mitral stenosis. (A) Frontal and (B) lateral radiographs of the chest de-monstrate cardiomegaly with enlargement of the right ventricle and left atrium. Left atrial enlargement produces a convexity of the upper left border of the heart (arrow, A).
Mitral stenosis. (C) On a lateral radiograph, the enlarged chamber produces a discrete posterior indentation (arrows) on the barium-filled esophagus. (D) In another patient, there is associated calcification of the mitral valve annulus (arrows, left oblique view)

X-ray diagnostic:

1st stage — X-ray signs of a mitral configuration of the heart with enlargement of a pulmonary artery arc, hypertrophy of the left atrium and enlargement of its arc; the waist of the heart is smoothed and flattened or slightly convex. The left ventricle is not changed or it looks diminished. Rising of pressure in pulmonary veins leads to their visibility on roentgenograms as horizontally located vessels; lung congestion and dilatation of hila.

2nd stage — On the right contour of the heart a high position of an atriovasal corner is detected. Because of a hypertrophy of a right ventricle there is a rotation of the heart and the shift of its apex to the left and backwards; the left atrium comes to a contour on the right in the area of the atriovasal corner so on the right contour three arcs are formed.

Because of the enlargement of the left atrium there's detected the shift of contrasted esophagus on an arc of small or medial radius (4–6 cm) and widening of a bifurcation angle of a trachea. Due to the congestion appears the transuding of a blood through the veins walls and formation of the hemosiderosis (nodules 1–2 mm size) in the lower and medial parts of the lungs. The edema of an interstitial tissue results in an unclearness of a lung pattern. Reaction of a pleura as the under line interlobar

pleura or even exudate because of congestion. Sometimes is the reflective spasm of veins possible, then it are poorly visible on a roentgenogram, and arteries begin to extend, especially in the upper parts of the lungs.

3rd stage — Dilatation of a right ventricle, over-dilatation of the right atrioventricular hole with functional tricuspidal failure, the right atrium is enlarged, the enlargement of the heart borders to the right. The sclerosis of walls of vessels results in deformation of a lung pattern and decrease in peripheral parts of the lungs because of an obliteration of small vessels. The lungs hila look "chopped off" because of weakened lung pattern.

X-ray diagnostics of the mitral valve incompetence (Figure 4.3)

There are two forms of a mitral incompetence:

1. Organic failure — at a lesion of the valve leaflets, chords or papillary muscles.
2. The functional failure — appears secondary at dilation of the left atrioventricular hole.

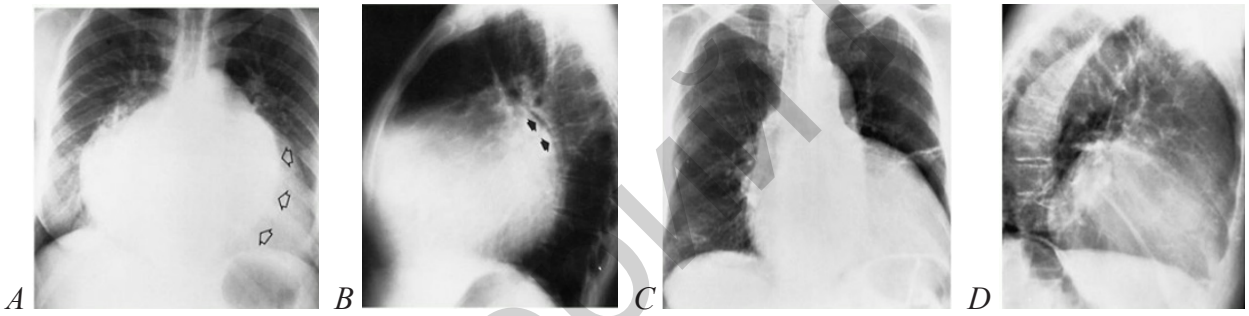


Figure 4.3 — Mitral insufficiency. (A) Frontal and (B) lateral radiographs of the chest demonstrate gross cardiomegaly with enlargement of the left atrium and left ventricle. Note the striking double-contour configuration (open arrows, A) and elevation of the left main bronchus (closed arrows, B). Arteriosclerotic heart disease. (C) Frontal and (D) lateral radiographs of the chest show marked enlargement of the left ventricle

Pathologic mechanism of a failure: at incomplete closing of the mitral valve a blood at a systole of the left ventricles is not thrown out to an aorta completely, and partially reverted from a left ventricle in the left atrium. Thus, an atrium at a phase of its diastole accumulates more blood, than under normal conditions and this additional amount of a blood gets to a left ventricle. The excessive amount of a blood in a left ventricle results in its dilatation and hypertrophy of its walls. In far late stages of the disease, the excessive amount of a blood in the left atrium results in rising a pressure in pulmonary veins and congestion in a pulmonary circle of blood circulation. The pressure in a right ventricle raises, there comes its hypertrophy and dilatation, with the subsequent development of functional failure of a tricuspidal valve, rising a strain for the right atrium and congestion in a major circle of a circulation.

X-ray diagnostics:

1st stage — Mitral configuration of the heart with enlargement of an arc of the left atrium and left ventricle, the waist of the heart is flattened. The transverse size of the heart is enlarged. The right parts of the heart are not changed. No changes of the lung pattern and of the lung hila. At a roentgenoscopy there's detected the sign of a "pendulum".

2nd stage — A hypertrophy of a left ventricle, dilatation of the left atrium and hypertrophy of a right ventricle. The enlargement of the third and fourth arcs on the left heart contour; the heart is located horizontally. Because of enlargement of the left atrium there's detected the shift of a contrasted esophagus by the arc of major radius (more than 6 cm) and enlargement of an angle of a tracheal bifurcation sometimes up to blunt. The left atrium can come on the right contour of the heart, forming an additional arc.

3rd stage — Severe expansion of the left atrium (sometimes atriomegaly) and left ventricle, enlargement of the right parts of the heart. There is an increased lung pattern due to the veins, enlargement and loss of lung hila. On a background of the heart there might be seen the additional shadow caused by enlargement of the left atrium. Contrasted esophagus is displaced to the right ("slipping" of an esophagus from an enlarged left atrium).

X-ray diagnostics of the aortal valve incompetence

Etiology: a rheumatic lesion of leaflets of the aortal valve, atherosclerosis, lues. Pathologic mechanism of a lesion: Owing to incomplete closing of leaflets of the aortal valve, the blood during a diastole of a left ventricle returns back from the aorta. As a result of this, the left ventricle dilates. For ejecting a greater amount of a blood necessary greater effort and there develops a hypertrophy of a myocardium of a left ventricle, but the dilatation prevails above the hypertrophy. The excessive amount of a ejected blood in a phase of a systole results in a uniform aortectasia. At the severe dilatation of a left ventricle there arises the dilation of the left atrioventricular hole up to the development of the functional failure of the mitral valve.

X-ray image

In a period of compensation and at minor valvular lesion the heart is not enlarged or the left ventricle a little bit enlarged. In a direct AP projection the minor enlargement of the fourth arc on the left contour of the heart is detected (on the chart — the signs of enlargement of a left ventricle).

In patients with the severe aortal failure the cardiac shadow acquires a typical aortal configuration, the heart is considerably enlarged, mainly due to a left ventricle, the waist of the heart is sharply marked and becomes concave; an apex of the heart is displaced to the left and rounded, and is usually located above a dome of a diaphragm. The heart widely lays on a diaphragm ("laying heart"). An enlarged left

ventricle in the second oblique view prominent backward. The shadow of an aorta is usually uniformly dilated. At a fluoroscopy in the area of an apex of the heart and the aortic arch the very intensive and high amplitude pulsation is detected. In a direct AP view the considerable enlargement and protuberance of an arc of a left ventricle on the left contour (1 arc), elongation and protuberance of an arc of a uprising aorta on the right contour (2 arc) are detected. In oblique projections — the enlargement of an arc of a left ventricle and the aortic arc occur.

At the addition of the functional failure of the mitral valve, there would be the signs of a pulmonary venous hypertension, the contrasted esophagus is shifted on an arc of major radius owing to enlargement of the left atrium. Later there is possible the enlargement of the right ventricle.

X-ray diagnostics of stenosis of an aortal ostium

Etiology: the main reasons are the atherosclerosis, rheumatic disease. The isolated aortic stenosis is seldom, more often it is combined with incompetence.

Pathologic mechanism of a lesion: owing to an aortic stenosis the ejection of a blood from left ventricle is impeded. The excessive amount of a blood in a left ventricle results in its dilatation and hypertrophy of its myocardium, with prevailing of a hypertrophy. The high flow rate of a blood which is coming out through a narrow hole results in major the rising of pressure in the aorta and its dilatation. At a decompensation of a stenosis the functional failure of the mitral valve appears because of dilation of its lumen.

X-ray image

In a period of compensation the heart is of a normal size, in some cases the minor enlargement of a left ventricle is detected. In a direct AP projection the small enlargement of the fourth arc on the left contour of the heart is detected. (On the chart there are signs of enlargement of a left ventricle).

In patients with the severe stenosis the shape of the heart is aortal: the arc of a left ventricle is enlarged and rounded, in a direct AP view the waist of the heart is well expressed and concave, the apex of the heart is rounded, shifted downwards and visualized as if under a diaphragm, sometimes on a background of a gas bubble of a stomach. In the second oblique view the enlargement of an arc of a left ventricle (1) backward is detected. The pulsation of a left ventricle (at a roentgenoscopy) is slow, deep and strong, weakened at a decompensation. The dilation of an initial part of the aorta (2) and intensifying of its pulsation in this arc. The revealing of the aortal valves calcification is possible.

At a reduced function of a left ventricle and decompensation of a valve lesion the functional failure of the mitral valve is possible, there would be the signs of a pulmonary venous hypertension (Figure 4.4); the contrasted esophagus is shifted on an arc of major radius owing to enlargement of the left atrium. Later the enlargement of a right ventricle is possible.

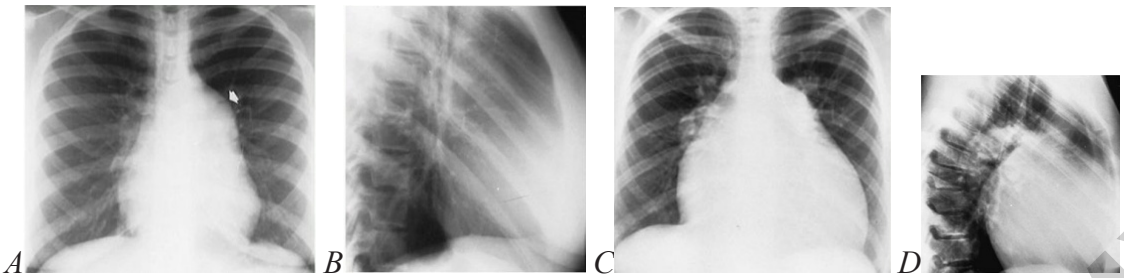


Figure 4.4 — Pulmonary stenosis. (A) Frontal and (B) lateral radiographs show striking poststenotic dilatation of the pulmonary artery (arrow).
Cor pulmonale (primary pulmonary hypertension). (C) Frontal and (D) lateral views of the chest in a patient with primary pulmonary hypertension show marked globular cardiomegaly with prominence of the pulmonary trunk and central pulmonary arteries.
Clinical examples of radiographs of heart diseases and great vessels (Figures 4.5–4.8)

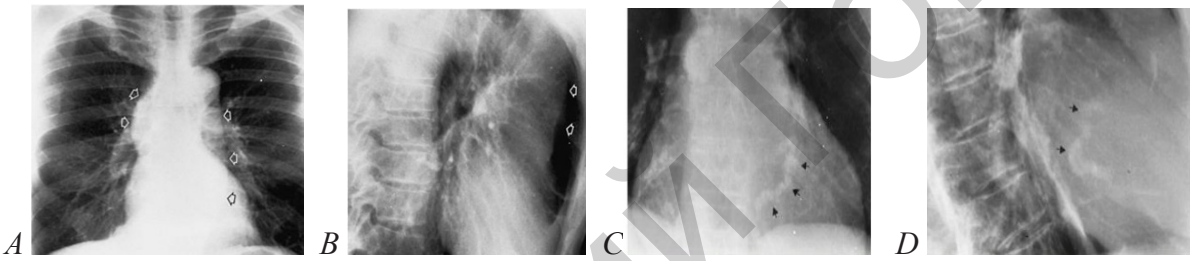


Figure 4.5 — Essential (idiopathic) hypertension. (A) Frontal and (B) lateral radiographs of the chest demonstrate characteristic tortuosity of the aorta (arrows), especially the ascending portion. Coronary artery calcification (arrows) in ischemic heart disease.
(C) Frontal and (D) lateral radiographs of the chest

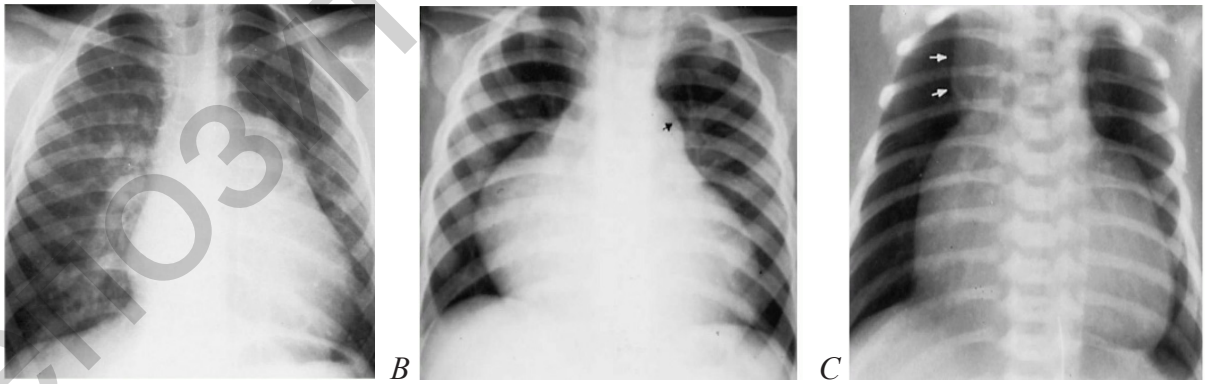


Figure 4.6 — (A) Ventricular septal defect. The heart is enlarged and somewhat triangular, and there is an increase in pulmonary vascular volume. The pulmonary trunk is very large. (B) Trilogy of Fallot. Decreased pulmonary vascularity with prominent poststenotic dilatation (arrow) of the pulmonary artery. There is enormous right atrial and moderate right ventricular enlargement. (C) Ebstein's anomaly. In addition to decreased pulmonary vascularity, there is enlargement of the right atrium. Widening of the right side of the superior portion of the mediastinum (arrows) reflects marked dilatation of the superior vena cava due to right ventricular failure

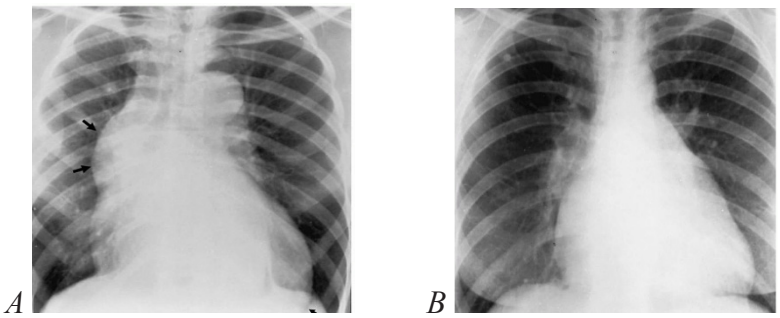


Figure 4.7 — (A) Aortic insufficiency. Marked dilatation of the ascending aorta (arrows), suggesting some underlying aortic stenosis. The left ventricle is enlarged. Note that the cardiac shadow extends below the dome of the left hemidiaphragm (small arrow). (B) Congenital aortic stenosis. Small aortic arch with enlargement of the left ventricle

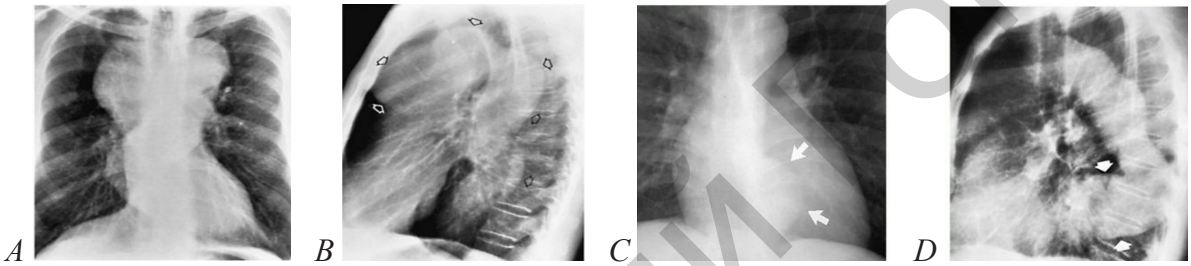


Figure 4.8 — Aneurysm of the thoracic aorta. (A) Frontal and (B) lateral radiographs of the chest demonstrate marked dilatation of both the ascending and descending portions of the thoracic aorta (arrows, B). Aneurysm of the descending aorta. (C) Frontal view of the chest demonstrates a localized bulging of the descending aorta (arrows). (D) Left oblique view in another patient shows aneurismal dilatation of the lower thoracic aorta (arrows). Note the marked tortuosity of the remainder of the descending aorta

Chest radiography is widely available, inexpensive, and carries low risk to the patient being examined. Therefore it is often the first test to image the heart and great vessels in patients with suspected cardiovascular disease, although much of the information about the cardiovascular system obtained from a chest x-ray is indirect and non-specific.

Ultrasound examination of heart

Echocardiography remains the most commonly used cardiac imaging technique. Despite the existence of other methods to image the heart, echocardiography continues to be the “bread and butter” imaging modality of cardiologists worldwide. Echocardiography has become so central to our care of patients precisely because it is almost universally available, it can be performed in the outpatient setting or the intensive care unit, provides usable clinical information on the vast majority of pa-

tients, it is relatively inexpensive, and has significant clinical and prognostic value. Echocardiography allows to estimate the size of the heart chambers, the thickness of myocardium, to estimate morphology and motions of valves, character of a blood motion in the heart and the large vessels (B – mode, Doppler techniques); to determine a minor amount of a fluid in a pericardial cavity (Figure 4.9 – C, with comparison to A – B).

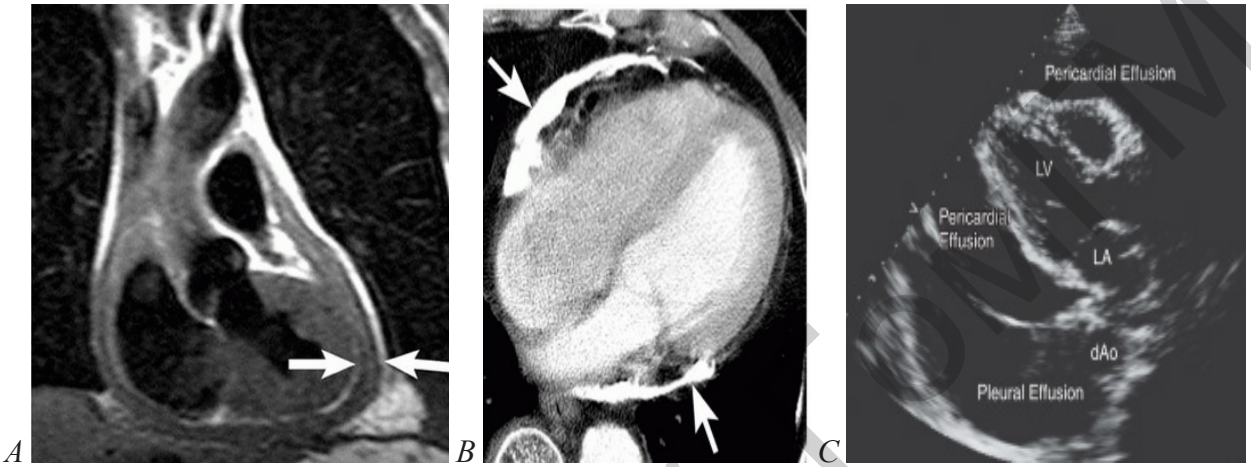


Figure 4.9 — Constrictive pericarditis. (A) Coronal T1-weighted MR tomogram shows abnormally thickened pericardium (arrows) outlined by epicardial and mediastinal fat. (B) Contrast CT shows dense pericardial calcification (arrows) in a patient with a history of hemopericardium. (C) Two-dimensional echocardiogram in a patient with both a pleural and pericardial effusion. The echo-free space anterior and immediately posterior to the heart is pericardial fluid. The parietal pericardial layer divides the posterior pericardial fluid from the pleural fluid. Pericardial fluid lies between the heart and the aorta while pleural fluid is seen posterior to both the heart and the aorta. Ao, aorta; dAo, descending aorta; LA, left atrium; LV, left ventricle

Even as we embrace other emerging cardiac imaging technologies, advances in ultrasound technology in general and cardiac ultrasound in particular are leading to continued improvements in the image quality and new techniques and applications of cardiac ultrasound. These advances will ensure that echocardiography will continue to remain the leading cardiac imaging modality for some time to come.

Cardio-vascular radiologic examination

Despite the fact that it usually provides an indirect (inferential) information, and that other more specific imaging techniques for noninvasive cardiovascular imaging have now become available, the chest radiograph remains a widely available, economical and often the first examination performed in a patient with suspected cardiac or a vascular disease.

Noninvasive cardiac imaging includes a combination of different modalities that can be used to evaluate both a cardiac structure and a function. Advances in

cardiac imaging have been spectacular over the past several decades. As a result of technological advances, the number of available noninvasive cardiac tests in the physician's armamentarium has increased substantially over the last decade. The anatomic and functional detail offered by echocardiography, nuclear medicine, cardiac magnetic resonance and computed tomographic modalities allows precise delineation of the pathophysiology of both congenital and acquired cardiac and vascular diseases. Recent years, cardiac imaging with echocardiography, cardiac magnetic resonance and multidetector CT technology has evolved extensively.

Computed tomography is however increasingly used, as important adjunct to plain films for detection, diagnosis, and characterization of cardiovascular disease. Cardiac multi spiral CT can demonstrate ventricular function and some myocardial features. But cardiac MR is now considered the 'in vivo' gold standard imaging modality for the diagnosis and treatment monitoring. It provides high-resolution images of the heart in any desired plane without any radiation.

The peripheral vasculature is a common site for vascular diseases. Advances in imaging technology have had a significant impact on vascular imaging, resulting in a shift from invasive to noninvasive imaging. The modalities currently available to evaluate peripheral vasculature include:

1. Ultrasound and Doppler flow imaging.
2. CT angiography and venography.
3. MR angiography and venography.
4. Digital subtraction angiography.

In the past decade or so, the diagnostic work-up of patients with peripheral arterial and venous diseases has undergone a sea change. Advances in noninvasive imaging modalities like Doppler sonography, CT angiography and MR angiography have greatly reduced the role of invasive arteriography/venography. Arteriography and venography though invasive allow percutaneous interventions to be performed in the same sitting and remain the gold standard of vascular imaging.

In the difficulties cases many modalities of the diagnostic radiology may be used in complex for same patient for maximal clinical information. All special diagnostic radiology knowledge has a big volume and fine details and present in additional special of the materials cardio-vascular examinations.

Vascular radiographic examination

Angiographic imaging is frequently required to analyze the extent and the location of thrombotic occlusions arteries. An ipsilateral antegrade approach is recommended if the ipsilateral arterial pulse is present and normal. An antegrade puncture is preferred so as to continue with a percutaneous intervention if possible. A contralateral retrograde approach is performed if the ipsilateral arterial pulse is abnormal. The diagnostic catheter is introduced into the priximal artery via a cross-over maneuver if the proximal artery is patent. If involvement, for example, of the common

or profound femoral arteries is suspected, sonography or duplex sonography may be added as a simple diagnostic tool.

To date, other imaging modalities such as MR angiography (MRA) or CT angiography do not play a major role in the diagnosis of acute ischemia as the potential combination of the diagnostic and interventional procedure in one step favors direct transarterial imaging.

Imaging and diagnosis embolization

Diagnosis based on the clinical and angiographic findings is usually easy to make. It is more difficult to detect the underlying source of acute occlusion, the extent of the thrombosed arterial segment, and the best appropriate therapeutic approach (Figure 4.10).

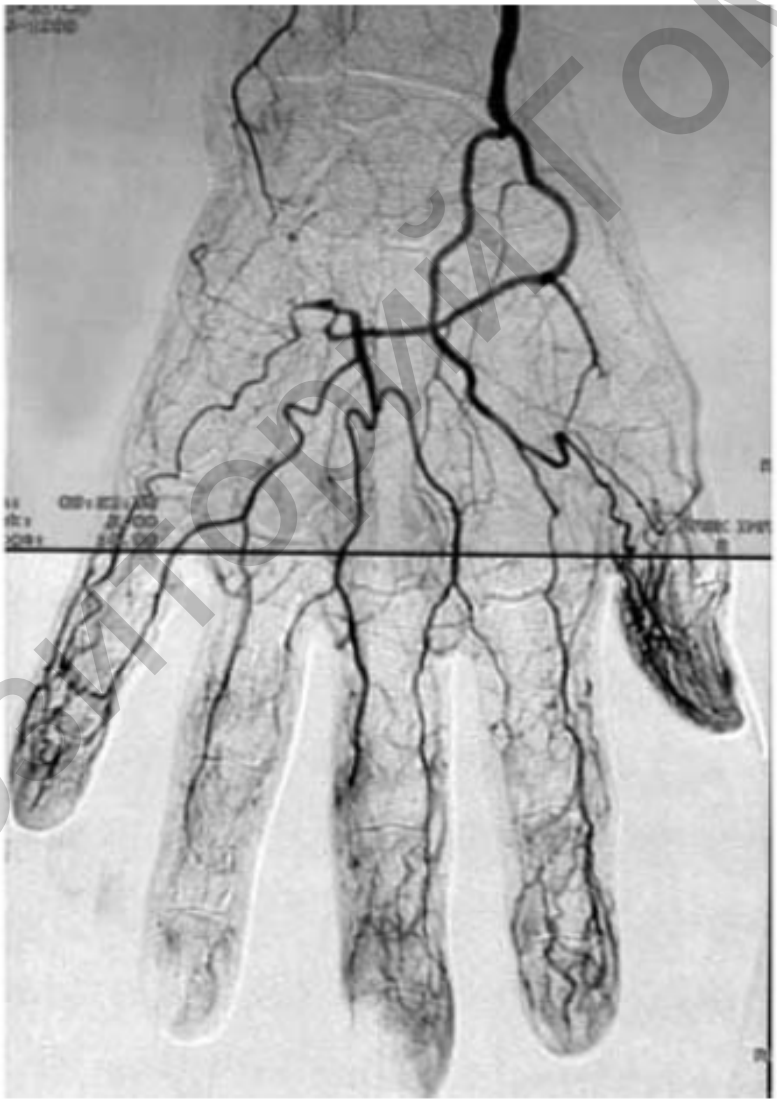


Figure 4.10 — Brachial ischemia. Hand digital subtractive angiogram (DSA) in a patient with acute onset of left-hand ischemia depicts atherosclerotic disease of the hand arteries, absence of the ulnar artery and the deep palmar arch, and filling defects of the digital arteries suggestive of peripheral embolization

If embolization is suspected, color Doppler sonography or other noninvasive imaging modalities can evaluate large arteries, but may fail to provide detailed information, for example, on the hand arterial pathology (Figure 4.10).

Angiography is recommended to rule out proximal arterial embolic source. Imaging from the arch to the digits should be performed. The proximal arteries should be evaluated for aneurysm containing thrombus or atherosclerotic lesions. With digital embolization, luminal defects are depicted in the involved vessels. In non-iatrogenic trauma the diagnosis is obvious in the presence of active arterial hemorrhage, expanding hematoma, ischemia, or absence of pulses. Sometimes the patient has to go immediately to surgery. Imaging is mandatory to rule out subclinical vascular injury. Angiography is the recommended imaging modality as it can be used in the same session for interventional treatment.

Common etiology acute upper extremity ischemia includes:

1. Iatrogenic injury (axillary, brachial, radial artery cannulation).
2. Non iatrogenic trauma.
3. Embolization.
   a. Cardiac origin.
   b. Proximal artery ulcerated plaque.
   c. Aneurysms (ascending aorta, innominate, subclavian, axillary, brachial, ulnar).
   d. Thoracic outlet syndrome.
   e. Fibromuscular disease.
4. Steal phenomenon after arteriovenous fistula formation.
5. Aortic dissection.

Findings digital subtraction angiography in case of arterial embolization may include spasm, intimal flaps, thrombosis, laceration, frank exsanguination, and pseudoaneurysm.

Imaging and diagnosis vascular occlusion

Many imaging modalities allow physician to diagnose arterial obstruction. Color-coded duplex sonography as well as magnetic resonance angiography, computed tomography, computed tomography angiography, and intra-arterial angiography are useful tools for detecting the location and extent, for example, of an femoral obstruction (Figure 4.11).

Diagnosis is reliably achieved by angiography or MRA. Detection by duplex sonography is a reliable tool for the femoropopliteal segment but it is sometimes limited for detection and exact lesion description in the lower limbs. In stage IV (Fontaine) disease, MRA may be limited because of low arterial flow, movement artifacts, or artifacts due to a superimposed venous flow.

Particularly in femoral occlusions, the degree of organization of the occluding thrombus or the composition of the lesion with the original stenosis at the proximal and distal ends or in the middle are the factors that are not very predictable but may influence the technical outcome of the intervention or its complication rate (for instance, distal embolization might aggravate symptoms).

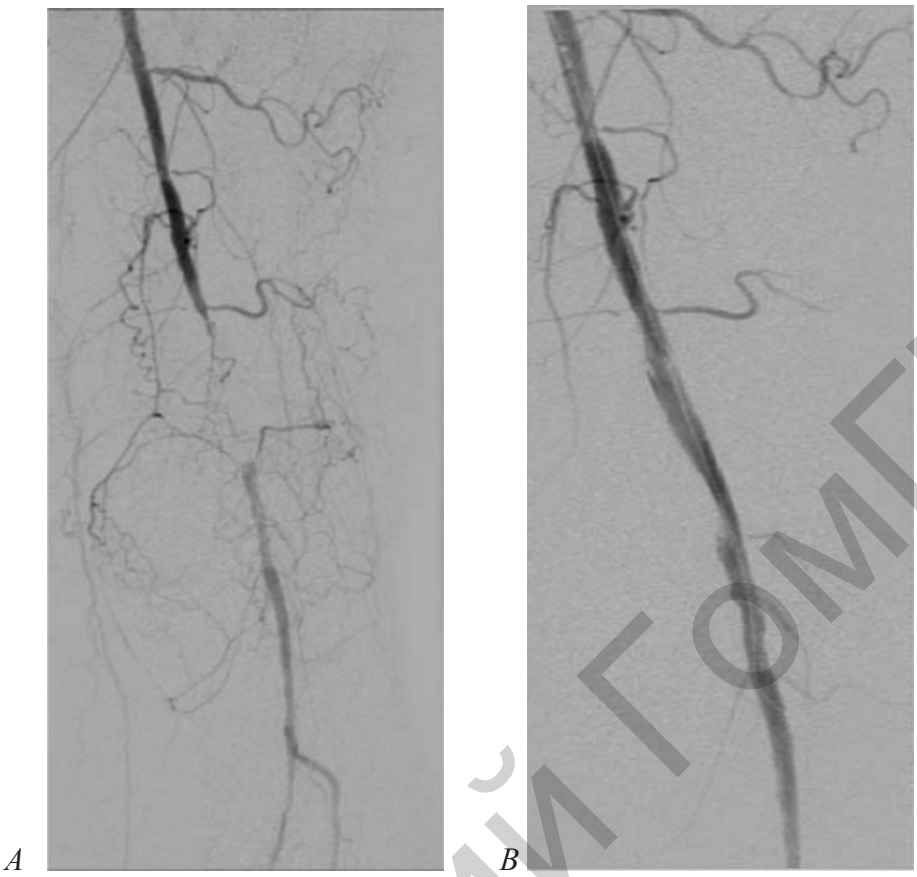


Figure 4.11 — Occlusion femoral artery. (A) A 7 cm-long occlusion of the popliteal artery in a patient with stage IV disease. (B) After subintimal recanalization and percutaneous transluminal angioplasty, sufficient reopening with stent placement

Most pathological processes affecting the lower extremity arteries cause stenosis, occlusion or dilatation, i.e. aneurysm formation. Atherosclerosis may affect the arteries at any level, from the iliac arteries to the small vessels of the foot. While it is true that a stenosis or occlusion is almost always due to atherosclerosis, it is important to consider other possible causes.

Vascular diagnostic ultrasound examination

Color Doppler ultrasound

Color Doppler ultrasound displays blood flow information in real time over the entire image or a selected area. Doppler spectral analysis by rapidly identifying areas of flow abnormalities. The highest velocities in the region of and immediately distal to a stenosis are seen as aliasing high-velocity jets of color. Color Doppler ultrasound facilitates placing the pulsed Doppler range gate in the region of these most striking color abnormalities for pulsed Doppler spectral analysis. The presence of a stenosis can be determined by color Doppler changes in the vessel lumen as well as by visible luminal narrowing.

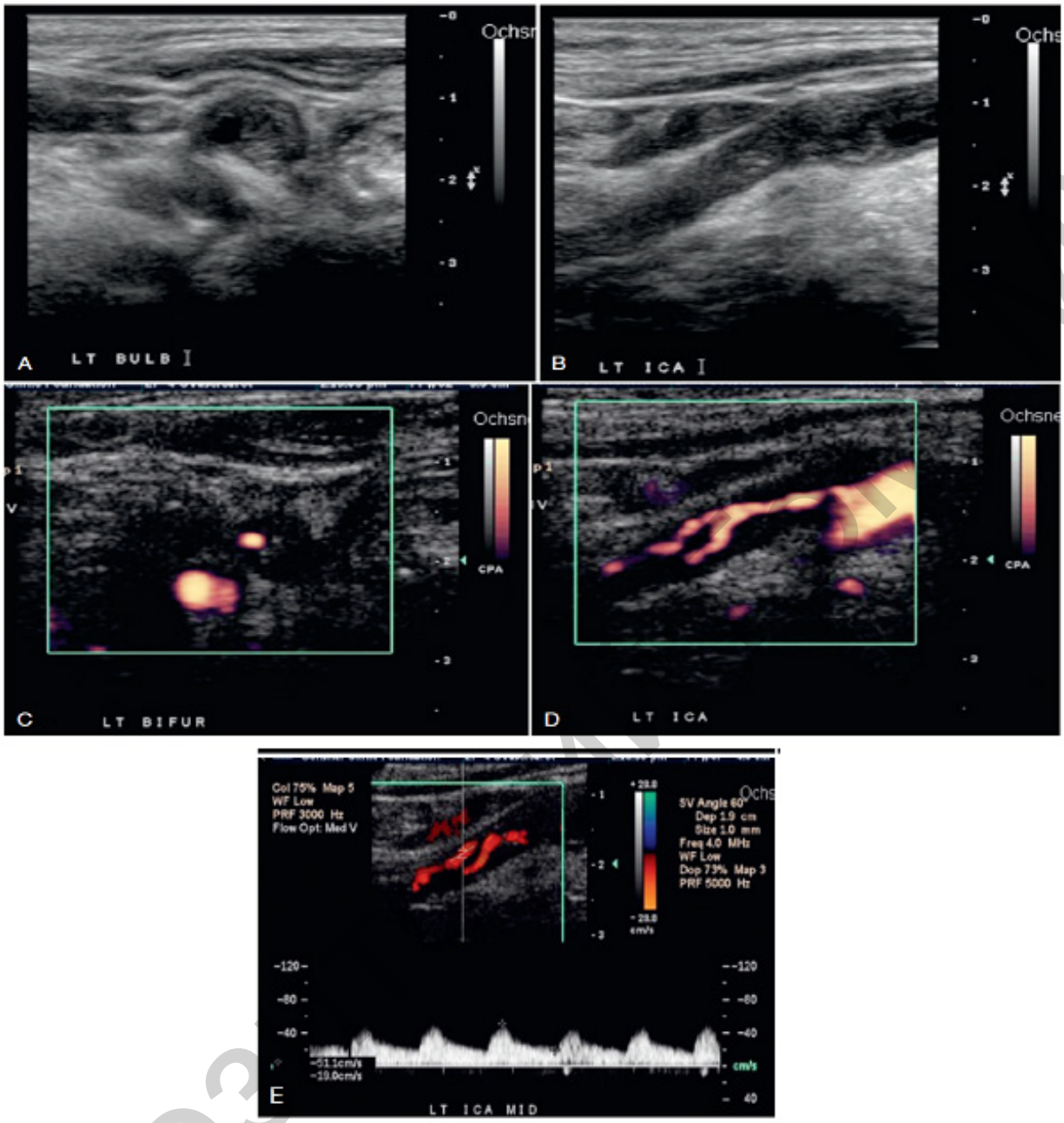


Figure 4.12 — Near arterial occlusion (95% –99% stenosis) with homogeneous plaque. (A) Transverse and (B) sagittal gray-scale sonograms of the left ICA demonstrate homogeneous (type 3) plaque. (C) Transverse and (D) sagittal power Doppler images demonstrate extremely narrowed residual lumen. (E) Velocity measurements for the ICA(internal carotid artery) were peak systolic velocity, 51 cm/sec; acoustic Doppler velocity, 19 cm/sec; systolic velocity ratio, 51/64=0,8; diastolic velocity ratio, 19/12=1,5. The combination of visual images and Doppler spectral analysis findings indicates a 95% to 99% stenosis

Branches of the ECA (external carotid artery) are readily detected, facilitating differentiation from the ICA. The real-time flow information over a large cross sectional area provides a global overview of flow abnormalities and allows ready determination of the course of a vessel (Figure 4.12).

Gray-scale assessment, power Doppler, or B-flow imaging should be used to assess the diameter/area of the patent carotid lumen. If a stenosis produces a bruit or thrill, the resultant perivascular tissue vibrations may be seen as transient vein and the presence of abundant collateral circulation. Internal jugular thrombosis most often results from complications of central venous catheterization.

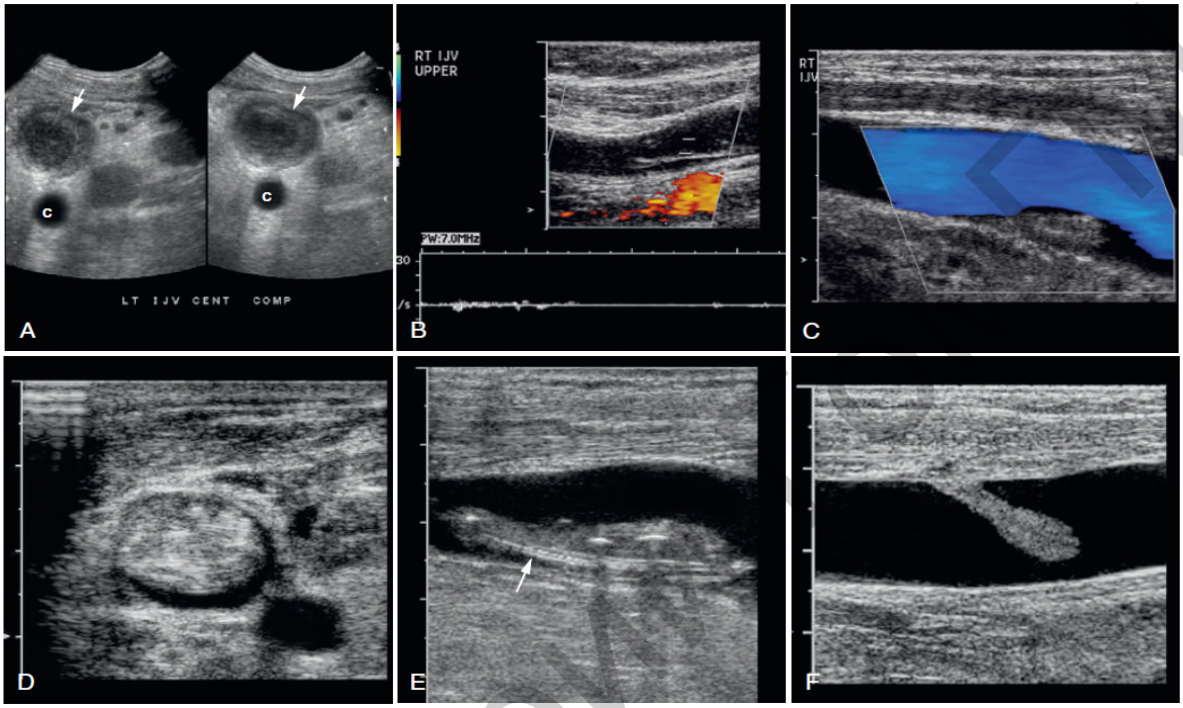


Figure 4.13 — Internal jugular vein (IJV) thrombosis: spectrum of appearances. (A) Transverse sonogram of an acute left internal jugular vein thrombus (arrow). The vein is distended and noncompressible. C, Common carotid artery. (B) Longitudinal image of a different patient demonstrates a hypoechoic thrombus and no Doppler signal. (C) Longitudinal color Doppler image shows a small amount of thrombus arising from the posterior wall of the IJV. (D) Transverse image shows an echogenic thrombus, indicating chronic thrombus in IJV. (E) Longitudinal image demonstrates a thrombus (arrow) around jugular vein catheter. (F) Longitudinal images show a thrombus arising from anterior wall. This thrombus probably results from previous catheter placement in this region

Other causes include intravenous drug abuse, mediastinal tumor, hypercoagulable states, neck surgery, and local inflammation or adenopathy. Some cases are idiopathic or spontaneous. Possible complications of jugular venous thrombosis include suppurative thrombophlebitis, clot propagation, and pulmonary embolism.

Real-time examination reveals an enlarged, noncompressible vein, which may contain a visible echogenic intraluminal thrombus. An acute thrombus may be anechoic and indistinguishable from flowing blood; however, the characteristic anywhere along the course of the vein (Figure 4.13).

Characteristic lack of compressibility and absent Doppler or color Doppler flow in the region of a thrombus quickly lead to the correct diagnosis. Collateral veins

may be identified, particularly in cases of chronic internal jugular vein thrombosis. Central liquefaction or other heterogeneity of the thrombus also suggests chronicity. The absence of cardiorespiratory plasticity in a patient jugular or subclavian vein can indicate a more central, nonocclusive thrombus. The confirmation of bilateral loss of venous pulsations strongly supports a more central thrombus.

A thrombus related to catheter insertion is often demonstrated at the tip of the catheter, although it may be seen anywhere along the course of the vien. The catheter can be visualized as two parallel echogenic lines separated by an anechoic region. The flow is not usually demonstrated in the catheter, even if the catheter itself is a patient.

Serial sonographic examination to evaluate response to therapy after the initial assessment can be performed safely and inexpensively. Sonography can also document venous patency before vascular line placement, facilitating safer and more successful catheter insertion.

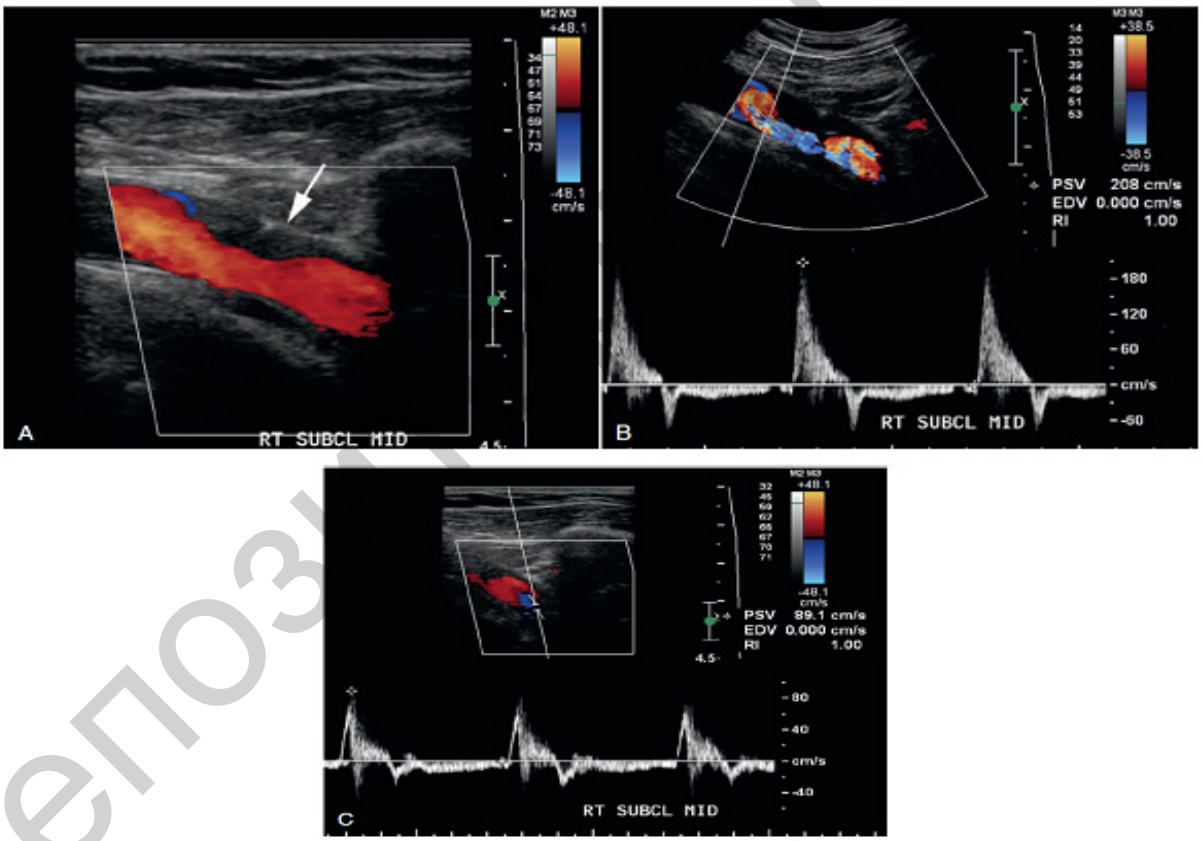


Figure 4.14 — Subclavian artery stenosis due to atherosclerotic disease. (A) Focal hypoechoic approximately 50 % stenosis (arrow) in the proximal subclavian artery, outlined by color Doppler. (B) Peak systolic velocity (PSV) elevation at 208 cm/sec at stenosis. (C) Triplex scan shows upstream (proximal) to stenosis is 89 cm/sec

Subclavian stenosis

Subclavian stenosis (Figure 4.14) most commonly occurs proximal to the origin of the left vertebral artery. In a subset of patients, flow to the arm is provided by filling through the vertebral artery via retrograde flow. If this reversed flow is significant, there can be a steal phenomenon ("subclavian steal") from the brain, leading to dizziness with certain arm movements as an additional flow is diverted to the arm. In these patients, the vertebral artery waveform should be insonated. Transient early systolic deceleration with resultant transient cessation of antegrade flow or transient reversal of flow correlated with subclavian artery mean diameter stenosis of 72% and 78%, respectively.

Acute deep venous thrombosis

There are four findings of acute venous thrombosis: (1) intraluminal material that is deformable during compression, (2) dilation of the vein, (3) smooth intraluminal material, and (4) free tail floating proximally from the attachment of the clot on the vein wall (Figure 4.15).

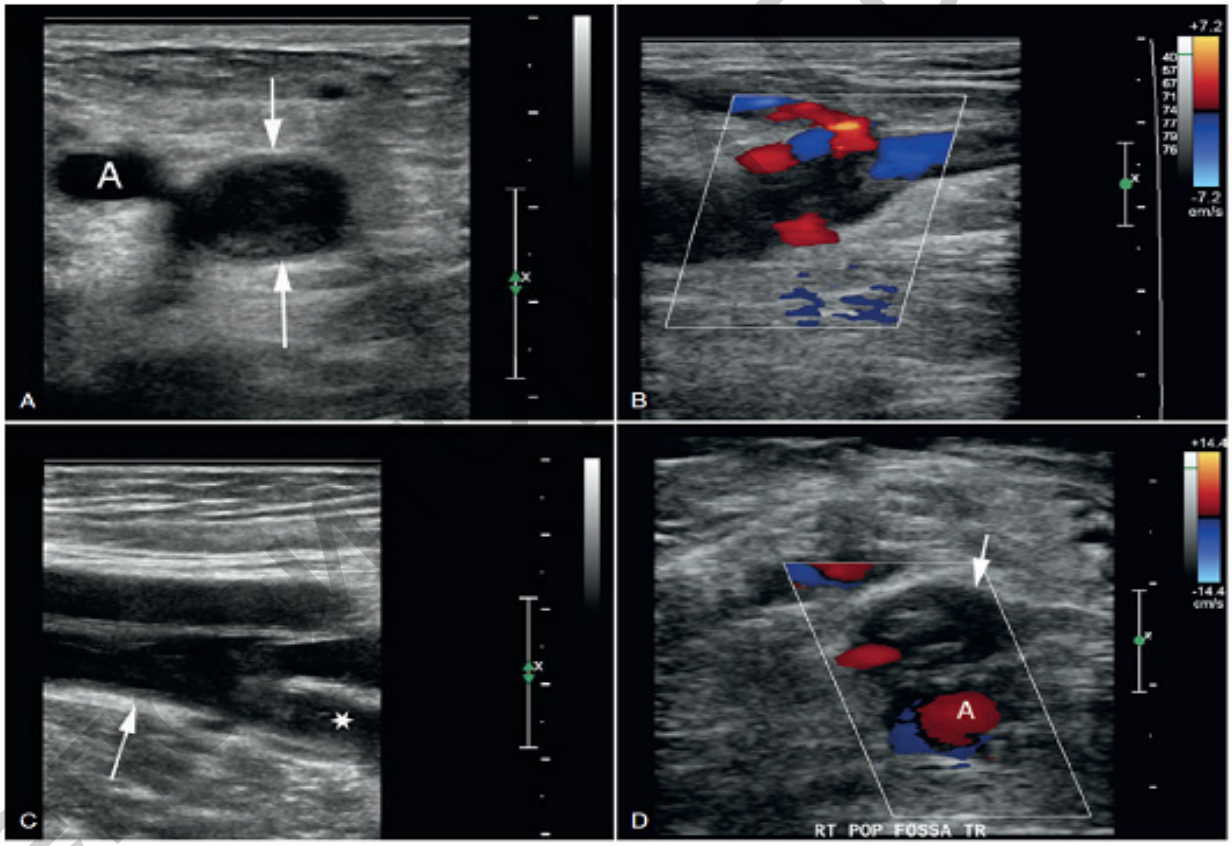


Figure 4.15 — Acute deep venous thrombosis (DVT). (A) Acute common femoral vein (CFV) thrombus: Compression image in the transverse plane shows acute CFV thrombus. Note that the vein (arrows) is larger than the adjacent artery (A). (B) Longitudinal color Doppler image in the same patient shows acute nearly occlusive common femoral vein thrombus with little flow. (C) Longitudinal image of acute DVT in the profunda femoris vein (*), with nonocclusive extension into the CFV (arrow), and a small amount of thrombus in the femoral vein as well. (D) Transverse color image of acute popliteal vein DVT, with expansion of the vein (arrow) relative to the popliteal artery (A)

The classic gray-scale findings of acute DVT are noncompressibility of the vessel with direct visualization of the thrombus (Figure 4.15). With complete acute vein thrombosis, the vein will typically enlarge. Thrombi may completely or partially occlude the lumen, may be adherent to the wall, or may be free floating. Compression ultrasound for DVT has been shown to have 95% accuracy with 98% specificity.

Arterial stenosis

An atherosclerotic disease can cause upper extremity stenosis but is a less common problem in the arm than encountered in the lower extremities. Gray-scale findings are similar to the lower extremities and include intimal plaques and/or visible irregularity of the vessel lumen. Color Doppler may show aliasing with turbulent flow similar to those findings seen in lower extremity arterial stenosis. On spectral Doppler, velocity criteria are not well defined for the upper extremity arteries. However, for a stenosis in most nonbranching arteries, a greater than 2 : 1 peak systolic velocity (PSV) ratio of the stenosis relative to the upstream artery within 2 to 4 cm is consistent with at least 50% diameter stenosis. Depending on the timing and whether collaterals have formed, this degree of stenosis may or may not be symptomatic or clinically significance.

Conclusion

Ultrasound plays an important role in evaluating the peripheral vasculature. Although peripheral artery ultrasound is commonly considered for its uses in peripheral artery atherosclerotic disease, the technique can be applied in numerous clinical scenarios. For evaluation of stenosis in native or bypassed vessels, the concepts are similar, although threshold values may differ. For evaluation of aneurysm, pseudoaneurysm, or AVF, the examination can be more localized in its scope to determine the size of the abnormality by gray-scale and the use of Doppler to focus on the inflow and outflow characteristics.

For the upper and lower extremity deep venous system, ultrasound is the initial imaging modality of choice. In the occasional case where sonographic findings are equivocal or nondiagnostic, especially when there is concern for central thrombosis, correlation with MRI, CT, or catheter venography may be helpful. Ultrasound can provide an accurate, rapid, portable, low-cost, noninvasive method for screening, mapping, and surveillance of the upper and lower extremity venous system.

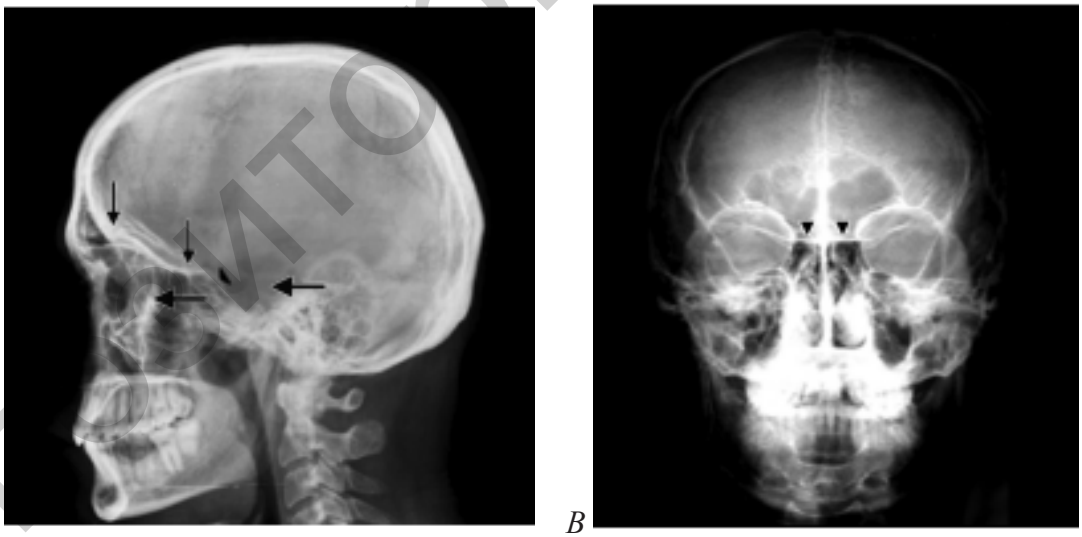
Preoperative ultrasound evaluation of the veins and arteries before both upper extremity and thigh hemodialysis access placement may decrease complications related to access procedures and improve overall access utility. After access placement, ultrasound is useful in the assessment of complications including stenosis, pseudoaneurysm, steal, and AVF nonmaturation.

V. BASIC NEUROIMAGING

Cranial radiology

Advances in neuroimaging have had a remarkable impact on the diagnosis and treatment of neurologic diseases ranging from earlier detection and treatment of stroke to a more timely diagnosis of dementia and from the rapid detection and treatment of cerebral aneurysms to the ability to diagnose multiple sclerosis after a single attack. Both computed tomography and magnetic resonance imaging are utilized for studying the brain and spinal cord, but MRI is the study of the first choice for most clinical scenarios. Conventional radiography has no significant role in imaging intracranial abnormalities.

In the past, skull radiograph was considered an essential step in the investigative protocol of a patient suspected to have a neurological disease (Figure 5.1). With the introduction of computed tomography and magnetic resonance imaging, there has been a tremendous decline in the usage of plain films and the indications for skull radiographs have been redefined. The major indication for skull radiographs is in the evaluation of skeletal dysplasia, diagnostic survey in abuse, abnormal head shapes, infections and tumors affecting the skull bones, metabolic bone disease, leukemia and multiple myeloma.



A *B*

Figure 5.1 — (A) Lateral radiograph of head demonstrates the normal structures. Arrow head marks the tuberculum sellae. Vertical arrows (anterior) show the cribriform plate and the (posterior) planum sphenoidale. Open arrow shows the greater wing of sphenoid bone forming anterior borders of middle cranial fossa. The dorsum sellae (horizontal arrow) with posterior clinoid processes above and the clivus posteriorly are well seen. (B) Posteroanterior radiograph demonstrates also normal structures, lesser wings of the sphenoid on both sides joining to form the planum sphenoidale (arrow heads). Floor of sella is faintly visualized in the midline (vertical arrows). Oblique line of the orbit is formed by the greater wing of sphenoid in its lower two-thirds and by the frontal bone in its upper one-third

Choice of modality imaging

Plain radiography plays essentially no role in evaluation of the central nervous system (CNS), although it can be very useful in evaluating bony lesions of the skull and spine, such as bone tumors and fractures. In adults, ultrasound is used to assess the carotid arteries, and angiography is used as a secondary study to assess for vascular stenosis, aneurysms, and the like. In the acute setting, however, the choice is between CT and MRI. The widespread clinical application of CT antedated that of MRI by — 25 years, and, although MRI has supplanted CT in many clinical settings, CT remains the modality of choice in several important situations. In general, the advantages of CT over MRI include speed (examinations lasting minutes rather than tens of minutes or even hours), cost, and wide availability. CT is more sensitive than MRI for the detection of small amounts of calcification, which can be helpful in diagnosing tumors that frequently contain calcifications.

Moreover, even if all other factors were equal, noncontrast CT would be the preferred modality in most acute settings because of its superior ability to detect acute hemorrhage, and because the CT scanner is a much more hospitable environment for the seriously ill patient, whose presence in the radiology department often requires a retinue of monitoring and life support equipment and personnel. Examples of settings where a noncontrast CT generally remains the examination of choice include acute trauma, acute stroke, severe acute headache, and acute coma.

In the vast majority of nonacute clinical settings, MRI is superior to CT. Although CT is generally confined to imaging in the axial plane (coronal scanning is often used in imaging osseous structures and the paranasal sinuses), MRI is capable of multiplanar imaging (axial, coronal, sagittal, and obliques), and these multiplanar capabilities can be further customized to answer specific questions about the extent of lesions and their impact on adjacent structures.

MRI provides greater differentiation of gray and white matter structures, is more sensitive for the detection of subacute and chronic bleeds, and generally provides a more detailed and precise view of anatomic structures. MRI can be used to determine the structure and patency of vascular structures with greater sensitivity than CT, and even without the use of intravascular contrast agents. CT is relatively poor at visualizing soft tissue structures surrounded by or adjacent to large amounts of bone, such as the inferior temporal lobes, whereas MRI is immune to this problem. Situations in which MRI generally represents the study of choice include suspected tumor or infection, nonacute trauma, seizures, chronic headache, and dementia.

Recent introduction of multi-detector CT have revolutionized the neuro-imaging with extensive anatomic coverage and thinner sections. Dynamic section CT, dual source CT and flat-panel detector are noninvasively demonstrating entire cranial and extracranial vasculature with high spatial and temporal resolution. Fusion imaging, i.e. metabolic images of PET superimposed on anatomical images of CT is already changing the way cancers are treated. With the recent CT scanners, visu-

alization of dynamic flow and perfusion as well as motion of an entire volume at a very short time interval is possible.

Recognizing of the abnormal findings

Understanding basic anatomy of the brain is vital to the planning and interpretation of neuroradiologic studies. Modern imaging techniques provide cross sections of the brain similar to the dissected brain. Computerized tomography provides cross-sectional anatomy of the brain in the axial plane. Magnetic resonance imaging due to its multiplanar capabilities also allows direct coronal and sagittal sections. Better tissue differentiation on MRI allows not only morphological but also histological information to some extent (Figure 5.2). The brain, at the macroscopic level, is a largely symmetric structure aiding the identification of abnormalities. Recent advances in functional imaging and diffusion tensor imaging makes understanding of brain anatomy even more important. Current MRI scanners and multidetector computerized tomography have further expanded the scope of three-dimensional conceptualization of complex brain structures through true volumetric data sets.

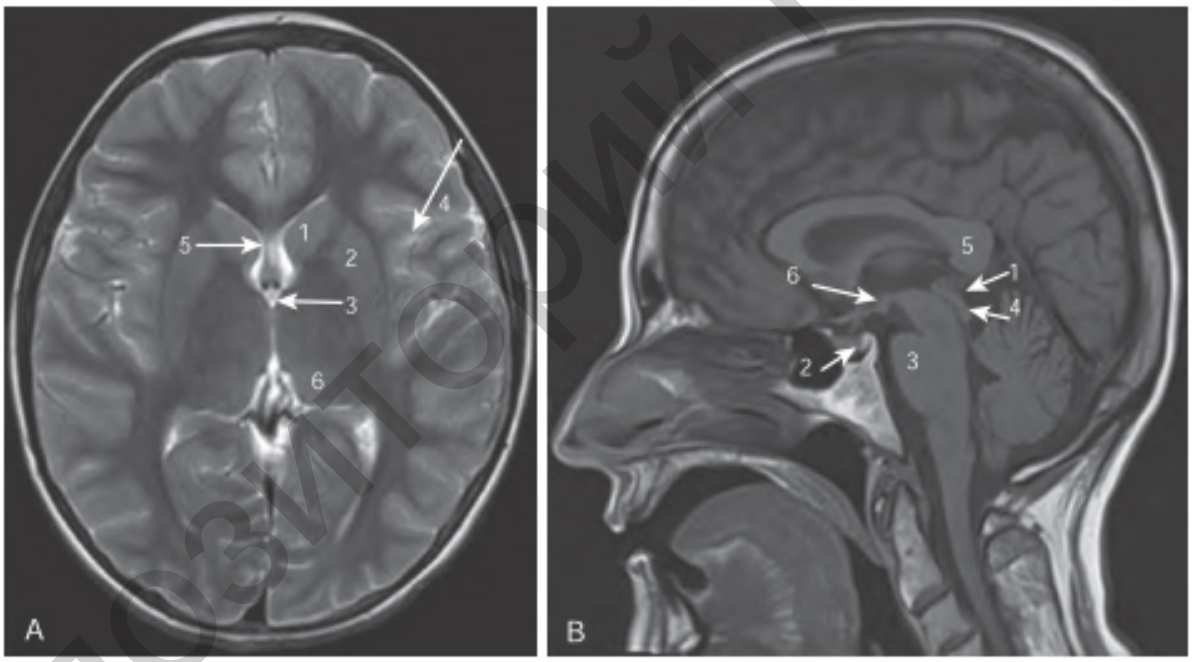


Figure 5.2 — Normal brain anatomy on MRI. (A) Axial T2-weighted MR image of brain at level of basal ganglia (1, caudate head; 2, putamen; 3, third ventricle; 4, insular cortex; 5, septum pellucidum; 6, thalamus). (B) Sagittal T1-weighted image of brain at midline (1, pineal gland; 2, posterior lobe of pituitary gland ("pituitary bright spot"); 3, pons; 4, tectal plate; 5, splenium of corpus callosum; 6, mamillary body)

The two major noninvasive cross-sectional imaging modalities used in neuroimaging are computed tomography and magnetic resonance imaging (Figures 5.2–5.7). Catheter angiography, also known as digital subtraction angiography or conventional angiography is reserved for the detection of intracranial vascular processes such

as aneurysms and intracranial vasculitis. The advantage to catheter angiography is the potential for intervention at the time of diagnosis, such as coiling of an aneurysm. Myelography involves the injection of contrast material into the subarachnoid space by lumbar puncture, allowing for visualization of the spinal cord and nerve roots which are seen as "filling defects" within the contrast-opacified cerebrospinal fluid. Myelography (usually followed by postmyelography CT) is reserved for patients with contraindications to MRI (e.g., patients with noncompatible pacemakers or severe claustrophobia), patients with surgical hardware that may cause significant artifact obscuring the spinal canal on MRI, patients with equivocal MRI findings, and obese patients who exceed weight limits for MRI scanners.

In patients of trauma, CT should be the first line of investigation except in patients who suffer from facial and orbital fractures where plain films are helpful in orientation and in medicolegal cases. Occasionally, skull X-rays may reveal linear fractures with more certainty than a CT scan. In patients suspected to have intracerebral tumors, posteroanterior and lateral view of skull may provide additional information like detection of hyperostosis in case of meningiomas, presence of lytic and sclerotic metastasis in neuroblastomas and tram-track calcification in Sturge-Weber syndrome which may compliment the diagnosis on computed tomography.

Intracranial abnormalities in head trauma can be classified as either primary or secondary. Primary lesions occur at the moment of injury and include skull fractures, extra-cerebral hemorrhage (e.g., epidural or subdural hematomas, subarachnoid hemorrhage), and intracerebral hemorrhage (e.g., brain contusion, brain stem injury, diffuse axonal injury). The secondary effects of head trauma are actually complications of the primary intracranial injury.

Epidural hematoma is usually associated with skull fractures that lacerate the middle meningeal artery or a dural sinus. Up to one-half of patients with epidural hematomas have a lucid interval after the head trauma occurs. On CT, epidural hematomas usually appear as biconvex, high-attenuation, extra-axial masses. Most are located in the temporoparietal area. Underlying skull fractures are common. Intracranial brain herniation may also be a prominent feature in this condition. One important imaging feature in epidural hematomas is that they do not cross skull sutures.

Subdural hematoma, on the other hand, is usually a crescent-shaped extra-axial collection that may cross suture lines. These lesions are more lethal than are epidural hematomas; the subdural hematoma mortality rate is greater than 50%. CT can usually, but not always, distinguish between epidural hematomas and subdural hematomas.

In addition, cerebral ischemia/infarction and multiple, complex, unexplained skull fractures may be associated findings.

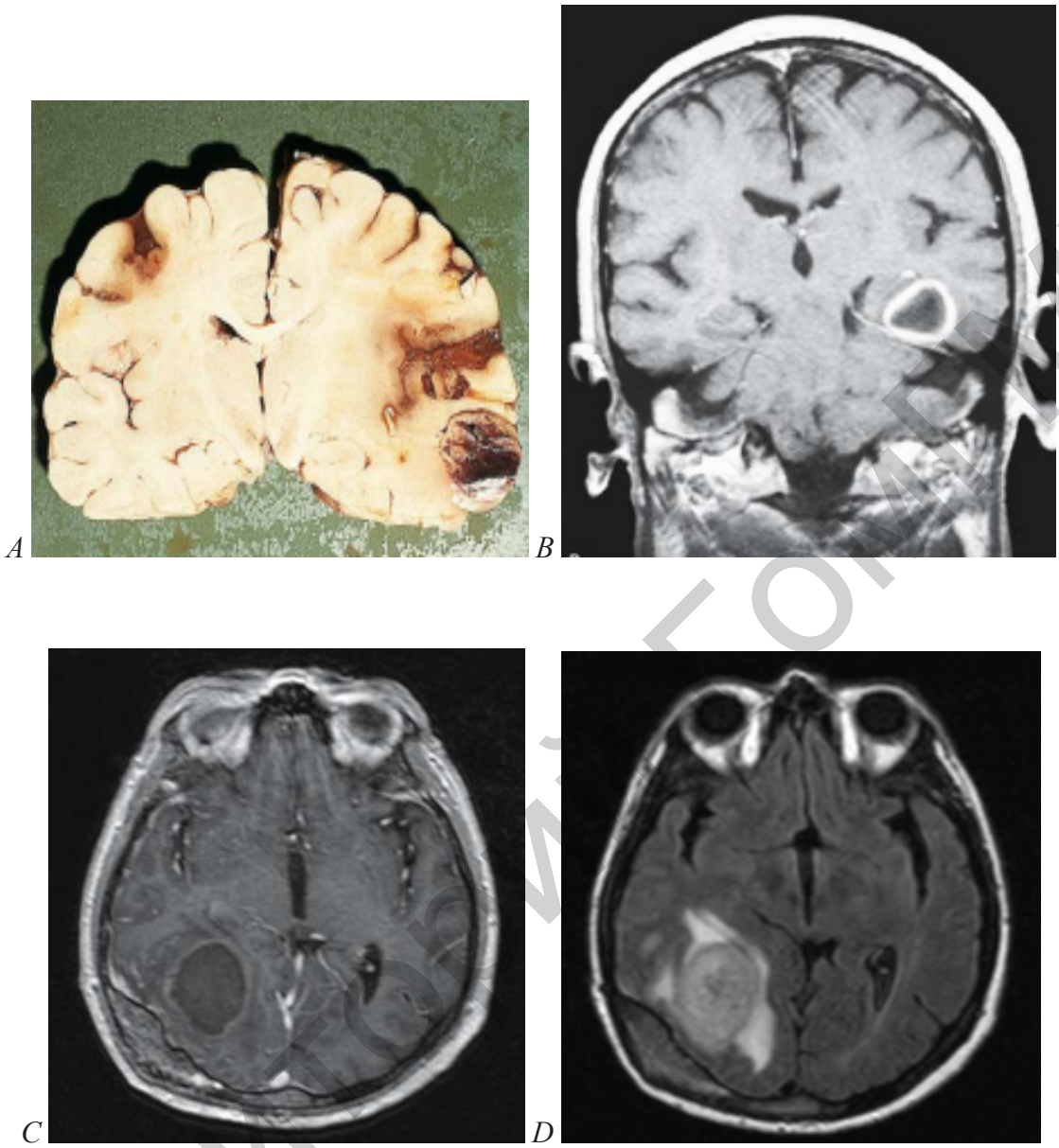


Figure 5.3 — Bacterial abscess of the brain. (A) Neuropathology: large bacterial abscess in the temporal lobe well defined by a fibrous capsule, surrounding a necrotic purulent center. (B) MRI coronal T1-weighted image (T1WI) after contrast administration: large hypointense necrotic center surrounded by a regular marked contrast enhanced ring, with smooth outer and inner borders, thicker in the part facing gray matter. (D) MRI axial T1-weighted image after contrast administration: the center remains hypointense whereas the capsule becomes ringed contrast enhanced. (E) MRI axial FLAIR: hyperintense center with the hypointense ring related to the capsule

Diffusion MRI appears to be a sensitive method for differentiating abscesses from necrotic neoplasms in doubtful lesions (Figures 5.3). Contrary findings are usual for necrotic cystic tumors, but these features are not pathognomonic.

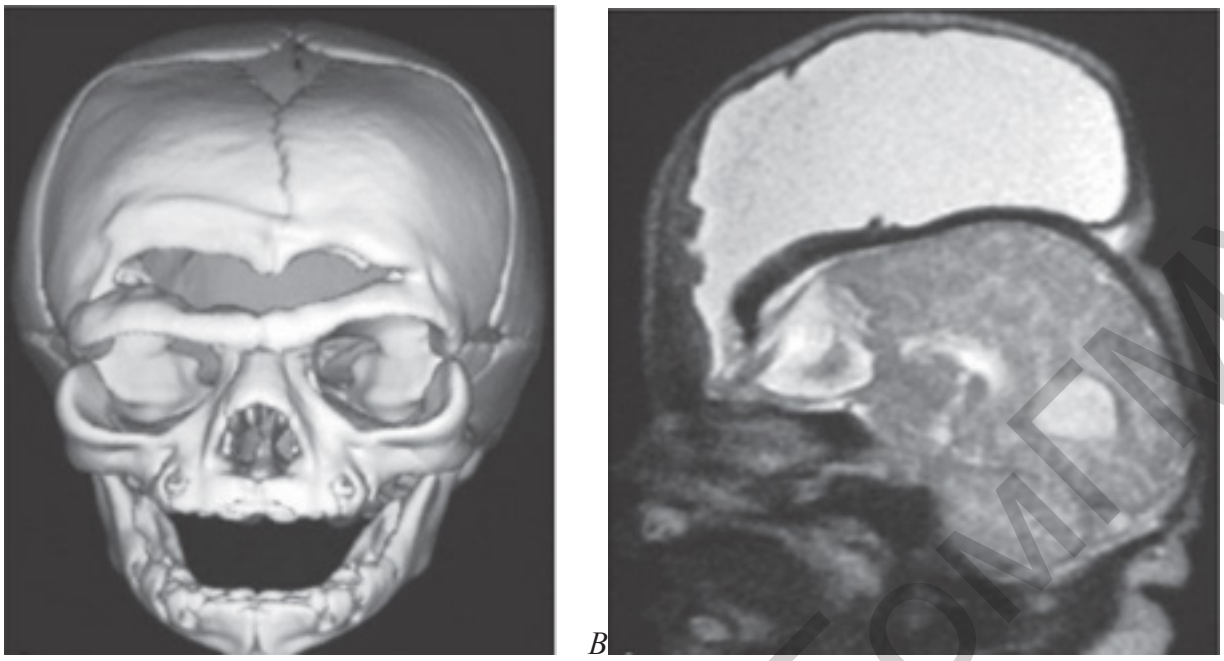


Figure 5.4 — Frontal gliocele. (A) Coronal surface-rendered CT shows a defect in the frontal bone. (B) Sagittal T2-weighted imaging (T2WI) shows damaged brain tissue and meninges extending through the skull defect. A large gliocele (glial-lined cyst) is seen overlying the upper calvarium

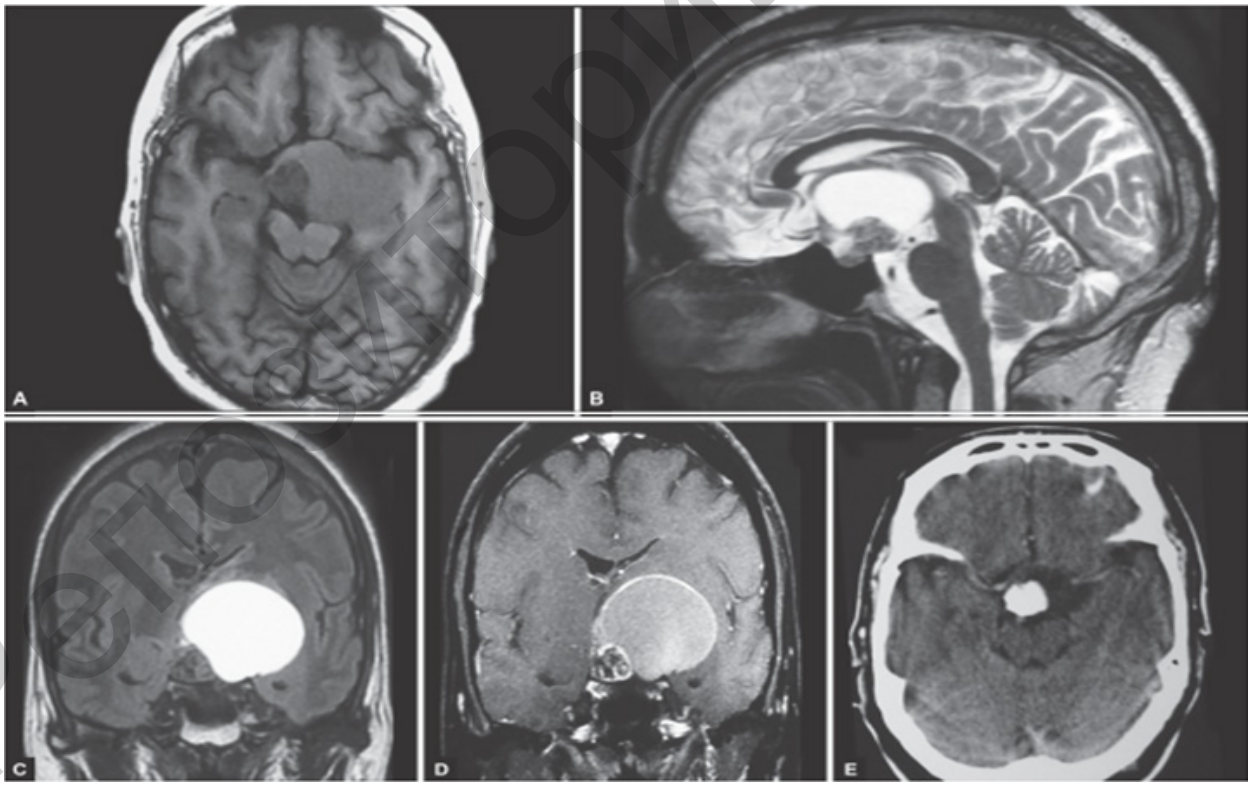


Figure 5.5 — A to E: Craniopharyngioma. (A) Axial T1WI and (B) sagittal T2WI show cystic and solid suprasellar mass. (C) Coronal plan shows high signal of the cyst compared to CSF. (D) Enhanced T1WI shows peripheral enhancement of the cyst but calcification is difficult to comment upon which is clearly shown on (E) axial CT head

Modern imaging techniques depict the tissues of body in ever more exquisite detail in different planes (Figures 5.2 – 5.6). Since neuroradiology forms an important part of radiology training and a substantial part of most radiologists daily work, familiarity with some of the intricacies of neuroanatomy becomes increasingly important; radiology remains in large part applied anatomy. Plain radiographic findings in brain tumours are of historical interest and may show signs of raised intracranial pressure (such as erosion of the lamina dura of the dorsum sellae, or a "J-shaped" sella), tumour calcification or enlargement of middle meningeal artery grooves in meningiomas.

Magnetic resonance imaging is the preferred investigation for patients with suspected intracranial tumours. It provides a better soft-tissue differentiation and tumour delineation than CT and advanced MR imaging techniques, such as diffusion-weighted and perfusion-weighted imaging and MR spectroscopy, allow the assessment of physiological and metabolic processes (Figures 5.5). Intra-arterial angiography for brain tumours is now mostly performed in conjunction with preoperative or palliative tumour embolisations.

CT and MRI allow visualization of the brain, its coverings, the extraaxial spaces, the calvarium, and skull base. Facial CT is now the primary investigative tool for evaluating facial fractures as well as sinus disease. The advantages of CT include faster scanning times, lower cost, and superior spatial resolution. The primary advantage of MRI is great contrast resolution with greater ability to characterize normal tissue structures as well as disease processes.

There are very few absolute contraindications to cerebral angiography, but since it is not without risk, it should never be carried out if it is clear that the results will not influence management. A well-documented history of untoward reactions to contrast media is a relative contraindication. Intra-arterial angiography is now increasingly used in the context of thrombolytic treatment of acute stroke. Treatment with anticoagulant drugs does not contraindicate arteriography.

Spine imaging

Choice of modality imaging

Plain films are conventional radiographs, which are commonly referred to as x-rays. They may be obtained in a frontal projection [anteroposterior (AP) or posteroanterior (PA) — the difference is insignificant in the spine], a lateral projection (side view), or an oblique projection. Plain films are most useful for the visualization of bony structures. Soft-tissue structures (everything but bone) are largely radiolucent and cannot be seen clearly on plain films unless abnormal density such as calcification is present. Although plain films depict bone anatomy quite well, certain structures may be obscured by other structures in front of or behind them. For instance, on a lateral projection, both pedicles would be superimposed on one another. For this reason, multiple views are always obtained as part of a routine examination.

Certain small bony structures, such as the cervical transverse foramen (for the vertebral artery) and the small facets for rib articulation in the thoracic spine, are not well visualized on plain radiographs. Because "soft-tissue" structures also are poorly demonstrated on plain radiographs, the intervertebral disc is not well seen with x-ray unless calcified (and therefore dense). However, the soft tissues should not be ignored. In the cervical spine, for instance, one may identify calcification in the region of the carotid artery bifurcation, which may suggest atherosclerotic vascular narrowing. In the evaluation of cervical trauma, one should always include assessment of the width of the normal soft-tissue stripe, which is anterior to the vertebral bodies. This prevertebral soft-tissue stripe may become widened in cervical spine trauma (prompting a closer search for fracture) and also in certain inflammatory conditions. When reviewing thoracic or lumbar spine films, attention to the soft tissues may facilitate diagnosis of a host of conditions ranging from pneumonia and lung cancer to retroperitoneal disea-ses and abdominal aortic aneurysms. Therefore, it is important not to focus only on the spine when interpreting spine radiographs.

Traumatic

Acute situations in which MRI is clearly superior to CT, for example, to evaluate suspected spinal cord compression. Like the brain, the spinal cord does not respond well to lesions exerting mass effect upon it, as in trauma or neoplasms involving the spine or its contents. In the case of a patient presenting with the acute onset of neurologic deficits such as lower extremity weakness, paresthesias, or the loss of bowel or bladder control, MRI is the study of choice to rule out cord compression and should be performed urgently, before sustained pressure on the cord produces an irreversible neurologic deficit.

Plain films provide the best initial examination for the evaluation of spine trauma. In a potentially unstable patient, they are obtained readily and often yield an immediate diagnosis. For further characterization of complex fractures, for conditions in which plain films would be inadequate (e.g., the cervical thoracic junction), or when additional information is required (e.g., to rule out canal compromise by a bone fragment), CT is frequently performed. CT is the best imaging study to evaluate complex spine fractures.

The most important imaging modality in suspected or known acute head/spine trauma is the noncontrast CT (Figures 5.6). CT is superior to MRI for the detection of acute blood and fractures, and it is more readily available, quicker, and more accommodating to the patient requiring close clinical monitoring.

Non-traumatic

MRI is the most sensitive modality for the detection of more subtle regions of parenchymal injury, but these need not be demonstrated emergently, because their detection does not alter therapeutic management.

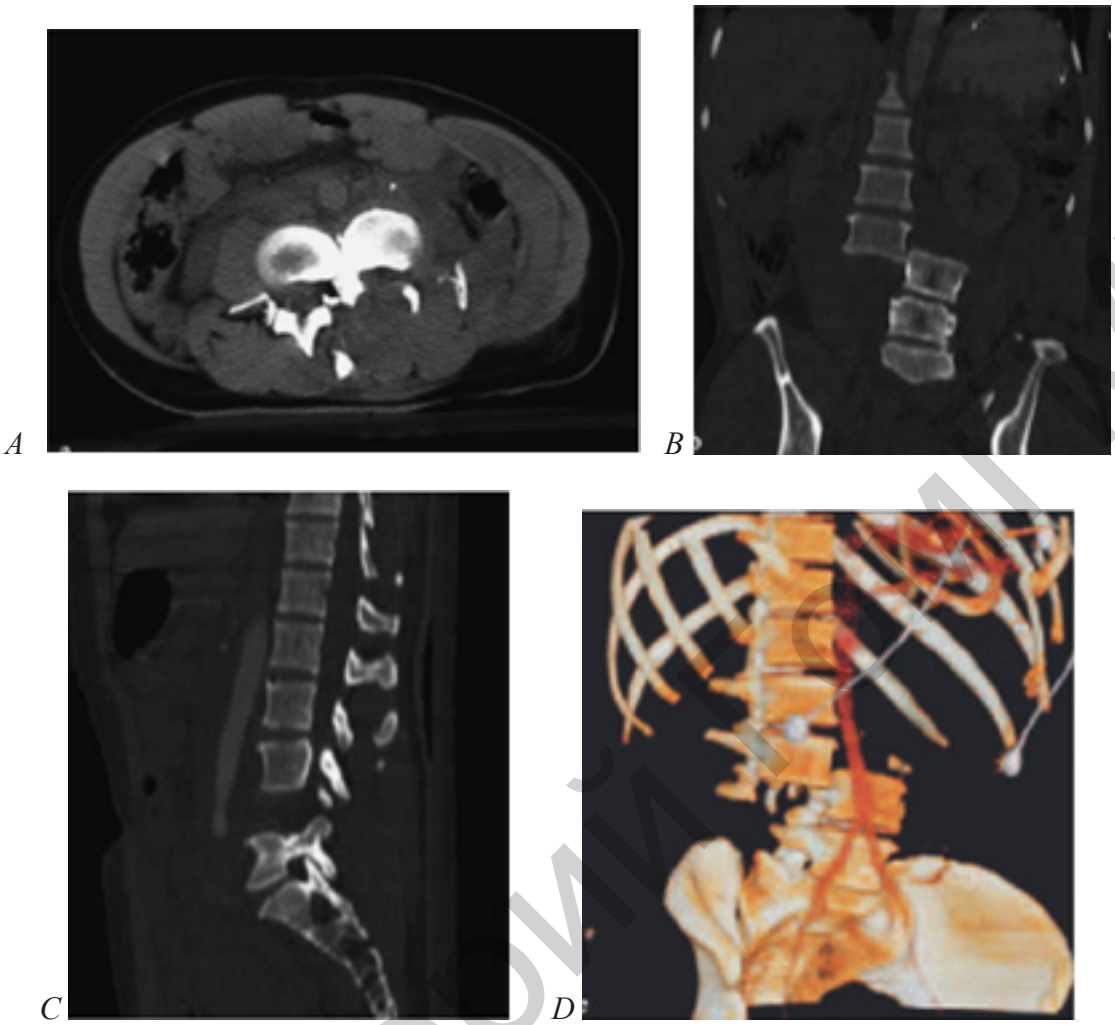


Figure 5.6 — Complete fracture dislocation/spondyloptosis and complete cauda equina injury: shear type of injury. (A) Axial, (B) frontal and (C) saggital CT with multiplanar reconstructed coronal and sagittal images demonstrate a complete fracture dislocation. (D) Volume rendered images the oblique view shows that the major vascular structures are normal, a useful piece of information for surgical planing

MRI has dramatically enhanced spine imaging, due to its superior tissue resolution, multiplanar imaging capabilities, noninvasive nature, and freedom from the artifact produced by bone in CT. T1-weighted images provide the best information about spinal anatomy, including the cord, whereas T2-weighted images (in which CSF is bright) provide a myelographic effect that is excellent for assessing both cord and nerve root compression and intrinsic cord lesions (Figures 5.5 B). Standard parameters, such as vertebral body and disk space height and vertebral alignment, should be assessed, as well as the signal of the bone marrow.

Bone scintigraphy is used as a common screening test for suspected bone metastases because of its high sensitivity, availability, low cost, and ability to scan the entire skeleton. Historical data and clinical experience has established bone scintigraphy as the reference standard in the search for skeletal metastatic disease (Figure 5.7 A).

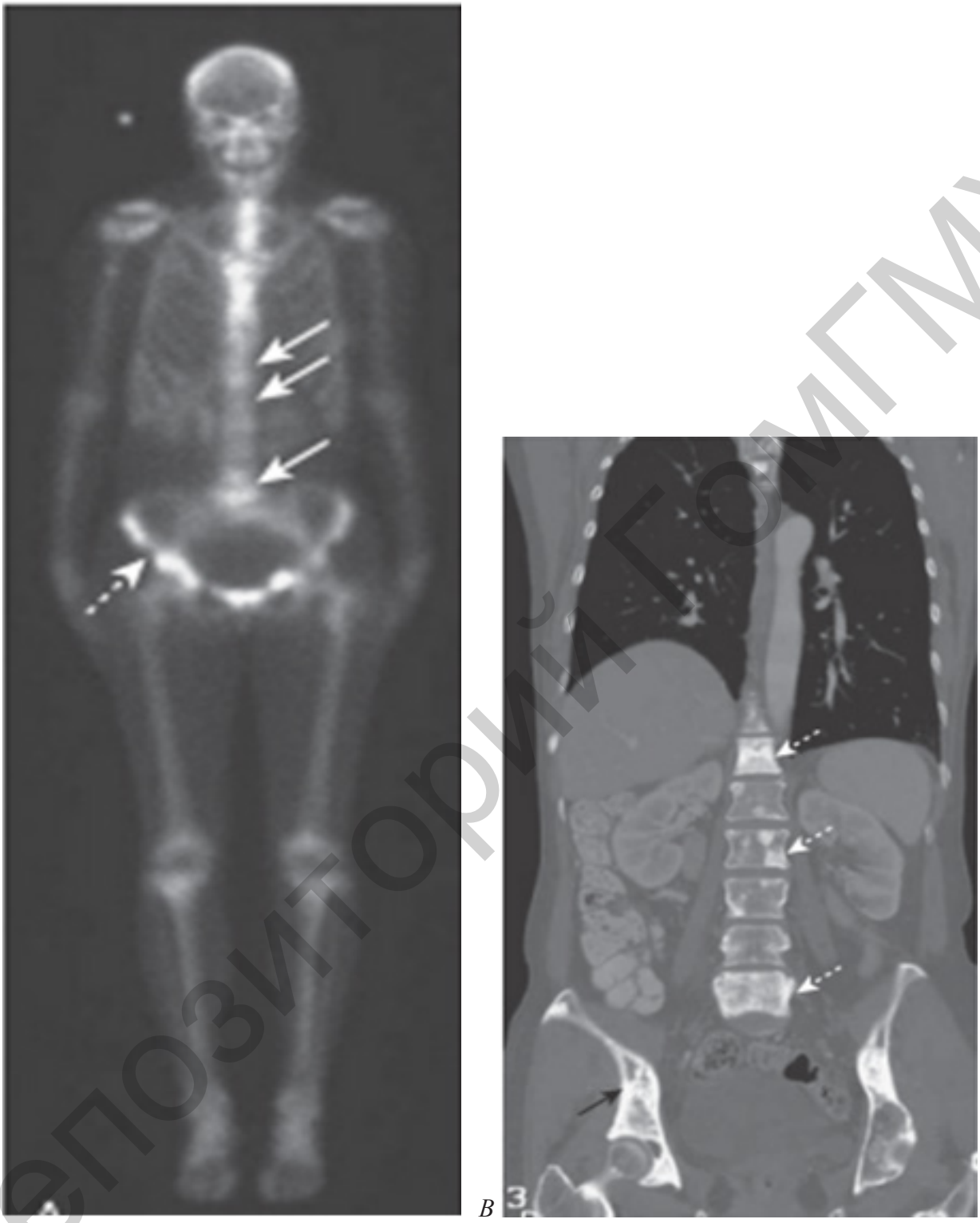


Figure 5.7 — Skeletal metastases. (A) A technetium-99m bone scan demonstrates abnormal tracer uptake in numerous areas, including the spine (solid white arrows) and pelvis (dashed white arrow). In this case the patient had undergone a CT scan (B), and the coronal reformatted image shows numerous osteoblastic lesions in the spine (dotted white arrows) and the pelvis (solid black arrow) corresponding to the lesions seen on bone scan. This patient had known breast carcinoma

Vascular neuroimaging

Angiography is a roentgenologic procedure which permits visualisation of the internal anatomy of the heart and blood vessels including arteries, veins and lymphatics through the intravascular injection of radiopaque contrast material (Figure 5.8).

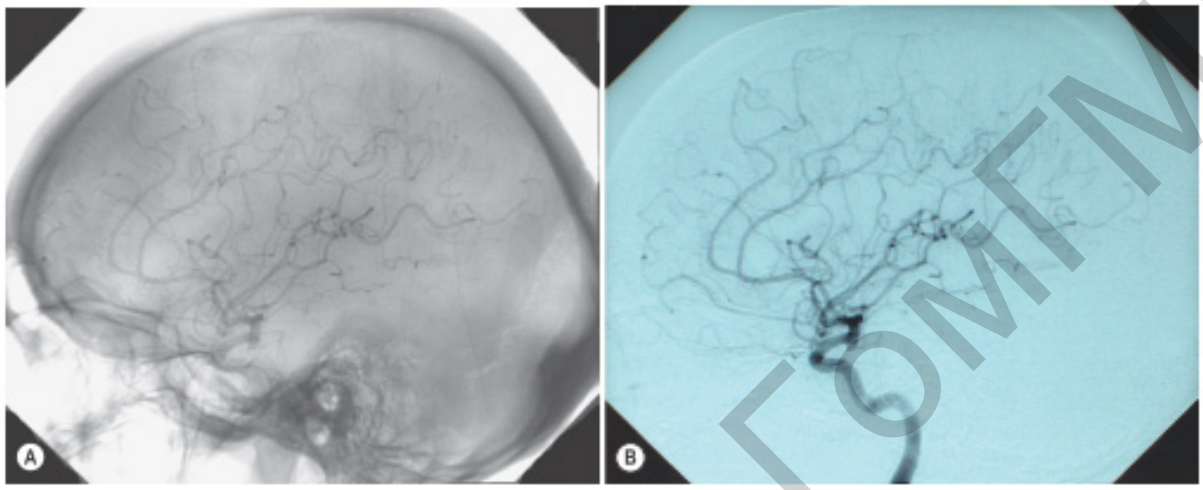


Figure 5.8 — Lateral projection following injection into normal the left internal carotid artery: (A) unsubtracted; (B) subtracted

Indications are many and varied.

Contraindications:

1. Bleeding tendencies or anticoagulant therapy leading to a prothrombin time above 30 % of the control values.
2. Pulse not palpable at the vascular access site.
3. Thrombogenic tendency.
4. Skin infections or swelling at site of entry. In case of this, alternate entry site is selected.
5. Abnormal renal function. If patient is in CRF then it is better to put the patient on dialysis after doing the angiogram.
6. Contrast injection may exacerbate cardiac failure.
7. Hepatic failure.
8. History of allergy, skin rashes or asthma.
9. Pregnancy.
10. Residual barium from previous studies.

Phlebography contraindications:

1. Allergy to iodine.
2. Local sepsis.
3. Obvious acute deep vein thrombosis.

Cerebral angiography — a primary tool to detect neovascularity (new tumor vessels) and to show displacement and encasement of vessels by intracranial masses.

It was also used to show brain compression from extracerebral masses such as subdural and epidural hematomas.

Procedure

Fully informed consent must be obtained. Patients who are acutely ill may be unable to give consent, and may be treated as an emergency. Those undergoing diagnostic investigation may later undergo interventional treatment and will need to give their consent for this separately. Preparation is as for standard peripheral angiography, with the addition of a baseline neurological observation. Studies are routinely carried out with the patient awake, or with mild sedation. General anaesthesia may be used in the case of a patient who is unwell, or unable to cooperate, or where interventional treatment is undertaken.

Arterial access is normally gained via the femoral artery. The catheter and guide wire are advanced via the aorta and each cerebral vessel is selectively catheterised. Catheters for cerebral angiography have preshaped tips to facilitate vessel access. More than one catheter type may be used if vessels are tortuous or stenosed and a different shape is required. The catheter is often connected via a three-way tap to a pressurised saline flush, which is maintained throughout the procedure to minimise the risk of thrombus formation in the catheter.

Physiological monitoring is maintained throughout the procedure, with neurological observations at 15 — minute intervals. Bed rest is necessary for 4 hours after the procedure, and during this time neurological and catheter site observations are made every 30 minutes.

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Учебное издание

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И ЛУЧЕВАЯ ТЕРАПИЯ
(на английском языке)

Учебное пособие

В двух частях

Часть 1
Основы лучевой диагностики

Редактор ***Т. Ф. Рулинская***
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