X-ray Anatomy

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X-RAY ANATOMY

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Preface

This book describes and illustrates both elementary and advanced radiological anatomy for physicians (internists), surgeons and, in particular radiologists at all stages of their training.

It has been assumed that the trainee radiologist will be familiar with general anatomy and much of this has been omitted. Such surface anatomy as is particularly relevant to the radiologist as a reminder of the basis of radiological appearances is included. Some sections of the text will be appropriate only for radiologists beginning their training while other sections will be most useful to those approaching the final stages.

Great care has been taken in planning the content of this book to ensure that most of the radiological appearances described and shown are those which will be met with in the day-to-day work of the general radiologist.

We are extremely grateful to the publishers of our earlier book, *Surface and Radiological Anatomy*, for kindly granting permission for the reproduction of certain sections and illustrations from that work.

We wish to acknowledge the generous help given by the following radiologists who either wrote or collaborated with the writing of the sections named: Peter Armstrong, Kings College Hospital. London, *the limb and abdominal vessels;* C. I. Bartram, St. Bartholomew's Hospital, London, *the stomach and duodenum;* A. S. Bligh, University Hospital of Wales, Cardiff, *myelography;* George du Boulay, National Hospital, Queen Square, London, *the skull and central nervous system;* Ian Kelsey Fry, St. Bartholomew's Hospital, London, *the urinary tract and colon*; K. E. Jefferson, National Heart Hospital, London, *coronary arteriography;* Glyn Lloyd, Moorfields Eye Hospital, London, *the orbit;* Ivan. F. Moseley, National Hospital, Queen Square, London, *the skull and central nervous system;* M. J. Simmons, St. Bartholomew's Hospital, London, *knee arthrography;* Audrey J. Tucker, St. Batholomew's Hospital, London, *mammography*; I. P. Williams, Northwick Park Hospital, London, *the alimentary tract;* J. V. Dacie, Royal Postgraduate Medical School, London, *the bone marrow;* Jonathan Levi, Northwick Park Hospital, London, *gastroscopy;*

We are much indebted to Dr W. A. P. Hamilton and Mrs Hamilton for their help with the text. We owe much to Mr A. K. Maxwell and Mr F. B. Price for the skill and care they have shown in the preparation of the illustrations, and recognize in them an indispensible contribution to the book. To them we feel deeply grateful.

G. SIMON
W. J. HAMILTON

Publishers Announcement

The authors, in their Preface, have expressed their thanks to the publishers of their earlier book *Surface and Radiological Anatomy* for permission to reproduce certain sections and illustrations.

Butterworths would like to echo these thanks to the Macmillan Press Ltd. and to express the hope that this example of publishing co-operation will enable the material to reach the widest possible audience.

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Contents

CHAPTER 1

General Anatomy and Radiological Methods

INTRODUCTION

The anatomy of the living subject can be studied by the four classical methods of inspection, palpation, percussion and auscultation.

Inspection reveals the proportions and natural posture of the body. As these influence the radiological appearances, the two methods are complimentary. The form of parts of the human skeleton can be deduced from inspection, for example, the vault of the skull. Asymmetry of the thoracic coverings such as the breasts or muscles is obvious on inspection, and may result in shadows in the radiograph which, being due to normal anatomical structures, are normal. Movements, such as those of the thoracic wall during respiration can be seen and related to the radiological findings.

Suitable instruments have been devised which now make it possible to examine the interior of all the hollow organs possessing an external opening or communication. The interior of the larynx is examined with a laryngoscope; the larger airways with a bronchoscope or fibrescope; the alimentary tract with a gastroscope, fibrescope, sigmoidoscope or colonoscope; the urethra and bladder with a cystoscope; and the rectum or vagina with the aid of a speculum.

Palpation may give information about some of the deeper structures which are invisible, for example, the shape of the shaft of the humerus, or the size of the uterus.

Percussion and auscultation may further add to the total anatomical picture by giving functional data such as the state of distension of the bladder, or whether the heart valves are opening and closing in a normal manner, or air is entering or leaving the alveoli or smaller airways (bronchioli) evenly throughout both lungs.

Further information about the form of many of the bones, the internal organs and viscera can be obtained by radiological methods.

The newer methods such as isotope studies and ultrasound echo studies all help to complete the total anatomical picture.

INDIVIDUAL VARIATION

Despite the fundamental similarity of structure in all human subjects, striking differences do occur and on these depend the recognition of an individual. Such characteristics as facial configuration, colouring, hair, height and build are usually noted, but hands, feet and other parts of the body exhibit just as much variation although this is often overlooked. The individuality of anatomical structure is very evident if a series of subjects is examined. Peculiarities of external form are characteristic of certain peoples. The Bushwoman, for example, exhibits a distinctive accumulation of fat in the buttocks which is described as steatopygia.

Surface contours are much influenced by the state of development of the musculature and the amount of fat in the superficial tissues. The prominences and depressions produced by underlying structures in a thin subject may be obscured in a fat one; an elevation produced by a bone in a thin subject may even be replaced by a depression if adjacent muscles are well developed, for example, over the spine of the scapula.

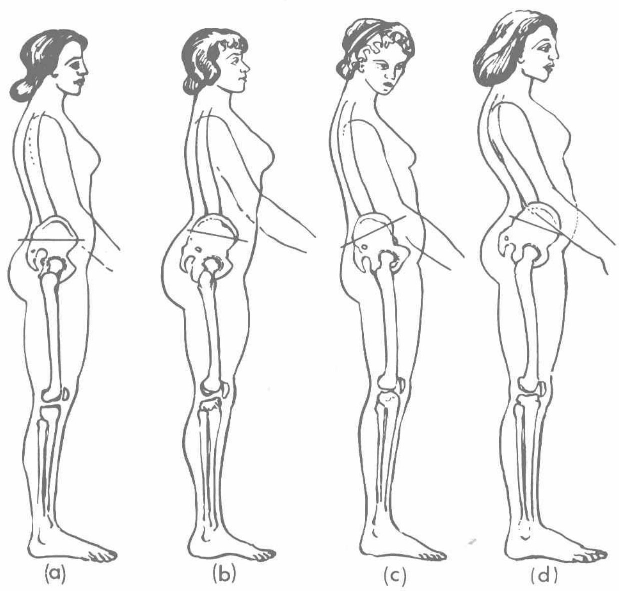


Figure 1. Diagrams illustrating variations in posture: (a) shows a good posture; in (b) there is a forward tilt of the pelvis and exaggerated posterior concavity of the lumbar region (lordosis); in (c) there is flattening of the lumbar region; and in (d) (sway-back type) there is a marked degree of lordosis. Compensatory modifications of the posture of the chest and head are seen in (b), (c) and (d)

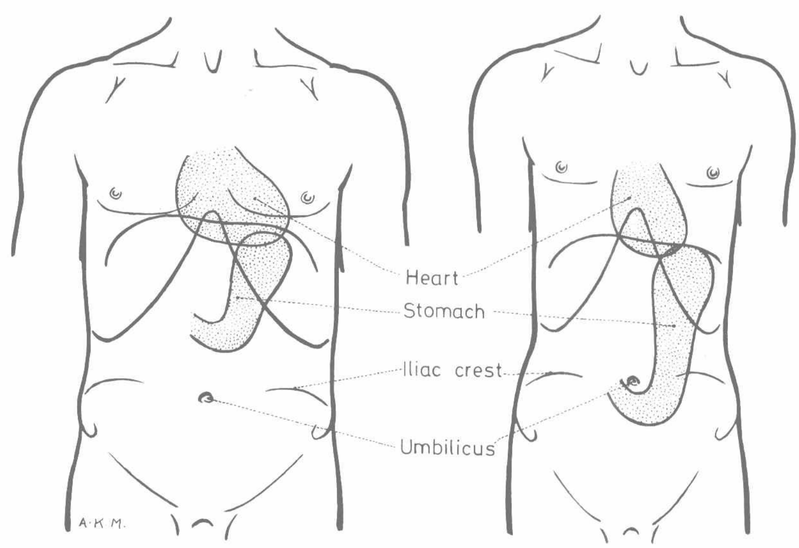


Figure 2. Diagrams of the stocky and slender body types, showing the forms of stomach and heart which characterize these types

Certain superficially placed muscles are present in some individuals but absent in others; the palmaris longus muscle is absent in many individuals; when present it varies greatly in size and the differences in the size of its tendon are evident on examination of the wrist in a number of living subjects.

Differences occur in the detailed form of bones. The peroneal tubercle of the calcaneum may be inconspicuous or it may form a salient prominence which is very evident on inspection of the foot.

The humerus may exhibit a projection, the supracondylar process, a short distance above the medial epicondyle (*Figure 57*). Occasionally, in this situation, a flange of bone is present which is perforated by an 'entepicondylar foramen' through which pass the median nerve and brachial artery.

There are individual differences of habit in what is popularly known as 'posture'. The stance, that is, the standing attitude of different people shows distinctive features which are so characteristic that they often serve for recognition of the individual. The sitting position may also show individual characteristics which depend on differences in the positions at the various joints. The movements of individuals are likewise distinctive, and recognition of a person by his gait is an everyday experience. The differences depend on variations of detail in the sequence and range of movement at different joints. The joint postures on which attitudes depend affect the relative position of parts of the skeleton; thus, the level of the scapulae relative to the vertebral column shows much variation. The general form of the trunk is greatly influenced by postural habit. If the upper ribs occupy a more oblique position than usual the upper part of the chest appears flattened; if they are more horizontal the chest becomes 'barrel-shaped'. If the lumbar convexity of the spine is pronounced (*Figure 1*), the hollow of the back is correspondingly exaggerated (lordosis). A forward bend of the upper thoracic spine, which is often combined with a lateral and forward displacement of the scapulae towards the side of the chest, produces the familiar 'round shoulders'.

Protuberance of the abdomen is usually produced by an excess of subcutaneous fat in the anterior abdominal wall. Prominence of the lower part of the abdomen may also be produced by a forward tilt of the pelvis (*Figure 1*), or may be due to a weakness of the musculature of the abdominal wall. Forward tilting of the pelvis is a normal feature in young children. Protuberance of the abdomen is sometimes due to gas in the alimentary canal, pregnancy, a pathological enlargement of some organ or an accumulation of fluid in the peritoneal cavity. It tends to modify body balance, as exemplified in the characteristic stance and gait of the pregnant woman.

Radiology shows that there are wide individual variations in the size and shape of the bones and viscera. In addition, many minor variations are seen which are invisible on inspection or palpation such as those of the pattern of branching of the segmental bronchi (page 200) or of vessels, for example, the renal artery (page 252).

BODILY TYPES

Differences in the general build of the body have a hereditary basis. Individuals may be classified into two contrasting types based primarily on the form of the trunk:—one with a short broad trunk and termed 'hypersthenic' or 'pyknic' (*Figure 2*), the other with a long narrow trunk and termed 'asthenic', 'hyposthenic' or 'leptosomatic'. Certain associations can often be recognized between the general body-form and the position of the viscera (*Figure 2*). The heart, lungs, stomach and colon exhibit considerable individual differences of form and position. The two widely contrasting types also tend to exhibit characteristic differences in temperament, in their illnesses and in the kinds of psychological disturbance to which they are liable.

The broad trunk

This type may be associated with relatively long or short lower limbs. The lumbar region tends to be short, the ribs are situated more horizontally than in the slender subject, the infrasternal (subcostal) angle is wider and the sternum lies at a higher level. In contrast with the slender subject the muscular system of the broad subject tends to be well developed, and for this reason the term hypersthenic has been frequently applied to the pyknic type. In these subjects the heart tends to lie more transversely than in the slender type; the pyloric (distal) part of the stomach tends to be situated at a relatively higher level (*Figure 2*) and the stomach is thus generally less elongated in a vertical direction and lies more transversely in the upper part of the abdomen than it does in the subject with a long narrow trunk.

The slender trunk

This type of subject tends to have a long lumbar region, the ribs are very obliquely placed; the infrasternal angle is small and the sternum lies at a low level. This type is frequently described as the hyposthenic or asthenic with reference to the frequency with which a relative weakness or deficiency of tone occurs in the muscular system, resulting in 'round' shoulders and a sagging abdominal wall (*Figure 1*). The heart is narrow and long, in a vertical direction, and is situated at a lower level than in the broad type (*see Figures 250, 251*). The pyloric part of the stomach tends to lie at a relatively low level, and the stomach is thus elongated in a vertical direction.

ASYMMETRY

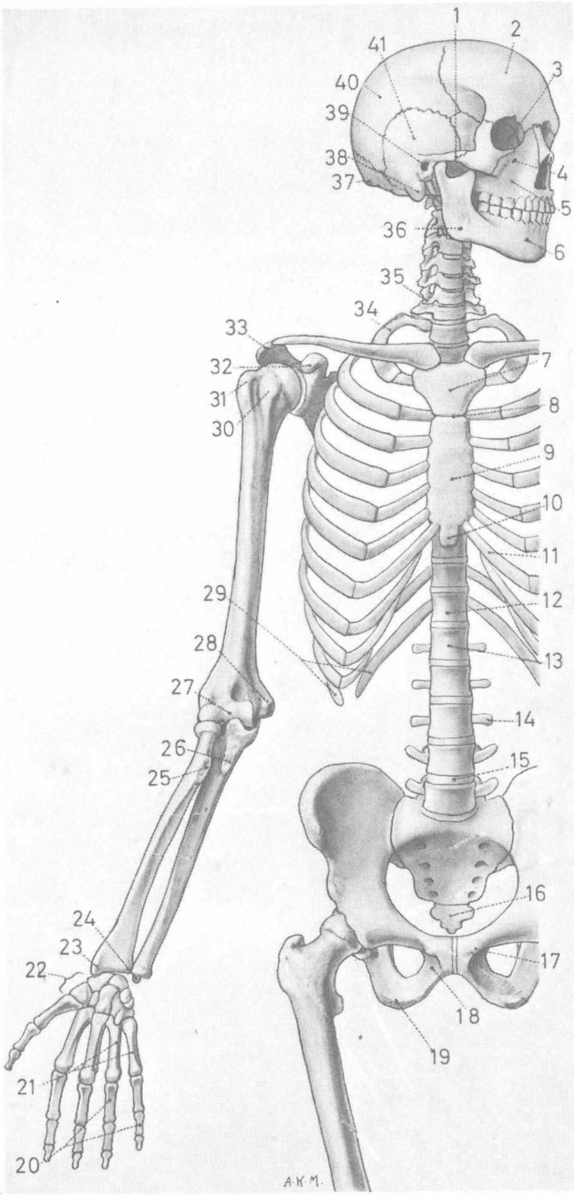
A slight asymmetry affects both the proportions and the movements of the body. Thus, one limb may be 1 cm shorter than its fellow, and breathing movements may be more extensive on one side than on the other. Such asymmetries commonly show a relationship to the right- or left-handedness of the individual. In the right-handed person the thoracic part of the vertebral column may show a slight convexity to the right (with rotation of the vertebrae), and the right clavicle tends to be shorter, stouter and more horizontally placed than the left one. In consequence of the associated rotation of the vertebrae the ribs may be more sharply curved posteriorly on the right, whilst the left side of the chest may be more prominent anteriorly. The converse asymmetry is usual in the left-handed. Muscular development also often shows marked asymmetry even though limb lengths may be similar; manual workers (carpenters) and sportsmen (tennis players) often show marked variation between left and right side.

SEX DIFFERENCES

There are physical differences between the male and female form which are independent of race and civilization and are, in the main, due to secondary sexual characteristics. Some differentiation is, however, apparent at a very early age. In the pelvic region, for example, certain of these characteristics are present during early fetal life.

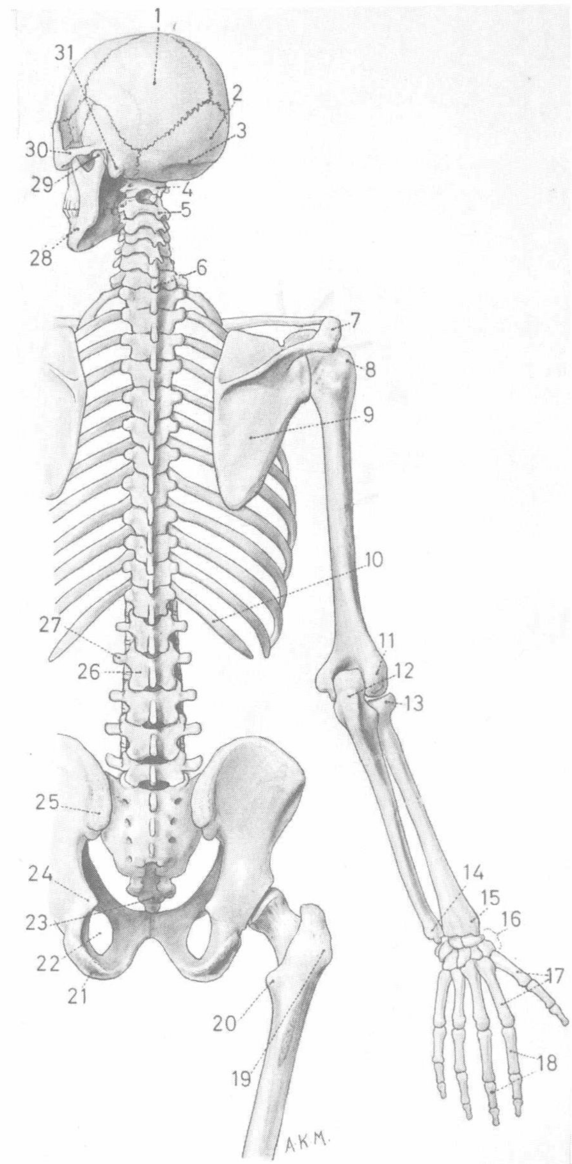
At birth and for several years there is little difference between the male and female child. Until the age of puberty the main differences are those of weight and height; there are periods of special height increase, 'stretching out', and weight increase, 'filling in', which have different distributions in the sexes during growth. Over a period of a few years, centred round puberty, girls are on the average taller and heavier than boys of the same age.

In general, the bony prominences and the superficial muscles are more clearly defined in the adult male than in the female. Owing to the presence of an abundance of subcutaneous fat in women the general contours of the body are more rounded; in particular we may notice the distinctive curves of the breasts, hips and thighs. Bony landmarks of the skull, for example, the glabella and superciliary ridges, are more conspicuous in men than in women. The facial skeleton is smaller in proportion and the jaws are narrower and less prominent in the female than in the male. Notwithstanding these differences it is not possible to determine with certainty the sex of an individual from the size or shape of the skull.



1. Zygomatic arch
2. Frontal
3. Ethmoid
4. Infraorbital foramen
5. Maxilla
6. Mental foramen
7. Manubrium of sternum
8. Sternal angle
9. Body of sternum
10. Xiphoid process
11. Seventh costal cartilage
12. Twelfth thoracic vertebrae
13. Body of lumbar vertebrae
14. Transverse process of third lumbar vertebrae
15. Fourth intervertebral disc
16. Coccyx
17. Pubic tubercle
18. Body of pubis
19. Ischium
20. Phalanges
21. Metacarpals
22. Carpus
23. Styloid process of radius
24. Styloid process of ulna
25. Radial tuberosity
26. Coronoid process
27. Trochlea
28. Medial epicondyle
29. Eleventh and twelfth ribs
30. Greater tuberosity
31. Lesser tuberosity
32. Coracoid process
33. Acromion
34. First rib
35. Carotid tubercle
36. Mandible (ramus)
37. External occipital protuberance
38. Mastoid process
39. External auditory meatus
40. Parietal

Figure 3. The skeleton (anterior view). For the lower limb see Figures 149 and 150



1. Parietal
2. Occipital
3. Superior nuchal line
4. Atlas
5. Axis
6. Seventh cervical spine
7. Acromion
8. Greater tuberosity
9. Infraspinous fossa of scapula
10. Twelfth rib
11. Lateral epicondyle
12. Olecranon
13. Head of radius
14. Lower end of ulna
15. Lower end of radius
16. Carpus
17. Metacarpals
18. Phalanges
19. Greater trochanter of femur
20. Lesser trochanter of femur
21. Ischium
22. Obturator foramen
23. Coccyx
24. Spine of ischium
25. Posterior superior iliac spine
26. Second lumbar vertebra
27. Transverse process
28. Mandible
29. Condyle of mandible
30. Zygomatic arch
31. Mastoid process

Figure 4. The skeleton (posterior view). For the lower limb see Figures 149 and 150

In both men and women the trunk is ovoid in form but in men the difference between the upper and lower parts is considerable; in men the transverse diameter at the shoulders tends to be greater than that at the hips, while in women the diameter at the hips is equal to or even greater than that at the shoulders. On the average the limbs are relatively shorter in women than in men, and this difference is more noticeable in the lower limbs. The carrying angle of the forearm is greater in the female (page 46). Owing to the relative shortness of the lower limbs in the female a larger proportion of the height is formed by the trunk. The thighs are also more obliquely placed due to the relatively greater width of the pelvis. The large amount of fat in the upper part of the thigh and the relative shortness causes the thigh to taper more rapidly in the female than in the male.

LANDMARKS

The use of carefully selected landmarks is essential for determining and describing the positions of organs and structures. Landmarks comprise conspicuous features of the skeleton, elevations produced by muscles and tendons, and cutaneous features such as the nipple and umbilicus.

In employing landmarks it must be recalled that: (1) individuals exhibit habitual differences in the relative positions of various parts of the skeleton, for example, of the scapula to the trunk; and (2) the relative positions differ in the same individual in different attitudes of the body; the position of the scapula, for example, changes with most movements of the upper limb.

The more important changes in the relative positions of landmarks on the trunk are those due to respiratory movements and those brought about by changing from the standing to the recumbent position or vice versa. In deep inspiration the sternum is elevated 2–4 cm relative to the vertebral column, the costal margin is raised somewhat less, and the umbilicus is drawn upwards through a distance 1 to 2.5 cm further from the symphysis pubis. In the recumbent position the costal margin is at a higher level with reference to the vertebral column than in the erect position.

Landmarks should be selected with reference to the particular purpose in view. A given structure may offer a more constant relation to one landmark than to another and preference should be given accordingly. For example, the lower limits of the pleural cavities maintain an approximately constant relation to the ribs during the various phases of respiration, whereas their relation to the levels of the spinous processes of the vertebrae changes. Similarly, the vertebral column and pelvis are better guides than the umbilicus to the level of the bifurcation of the abdominal aorta.

Skeletal features which can be determined in the majority of subjects, even in the obese, are preferable as landmarks. Special value is attached to landmarks which can be used both for radiological and general examination, for example, the level of the highest parts of the iliac crest.

Cutaneous landmarks such as the nipple and umbilicus undergo displacement with reference to underlying structures during movements of the body, and their position is also influenced by the amount of superficial fat. They are of value mainly as guides to the position of superficial features such as zones of segmental innervation (for example, around the umbilicus) or the distribution of lymphatic vessels (for example, around the nipple).

NATURE OF X-RAYS

X-rays, like light, are electromagnetic radiation. They are of shorter wavelength than light, and can pass through all substances of low atomic weight (including human tissues). As they traverse the tissues they are absorbed in varying amounts depending on the thickness of the tissues and their different densities which, in turn, are dependent on the atomic weight of their constituents. This differential absorption results in shadows which can be recorded on a film or other recording device placed opposite the x-ray source with the subject interposed (*Figures 5* and *6*).

FLUOROSCOPY

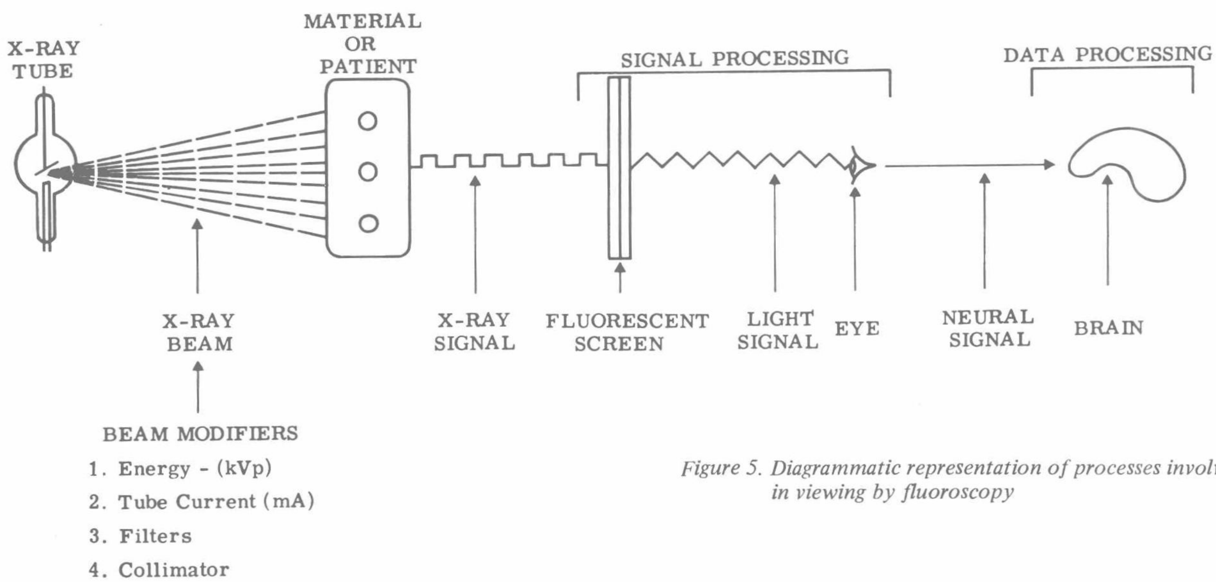


Figure 5. Diagrammatic representation of processes involved in viewing by fluoroscopy

CINE RADIOGRAPHY WITH TV MONITORING

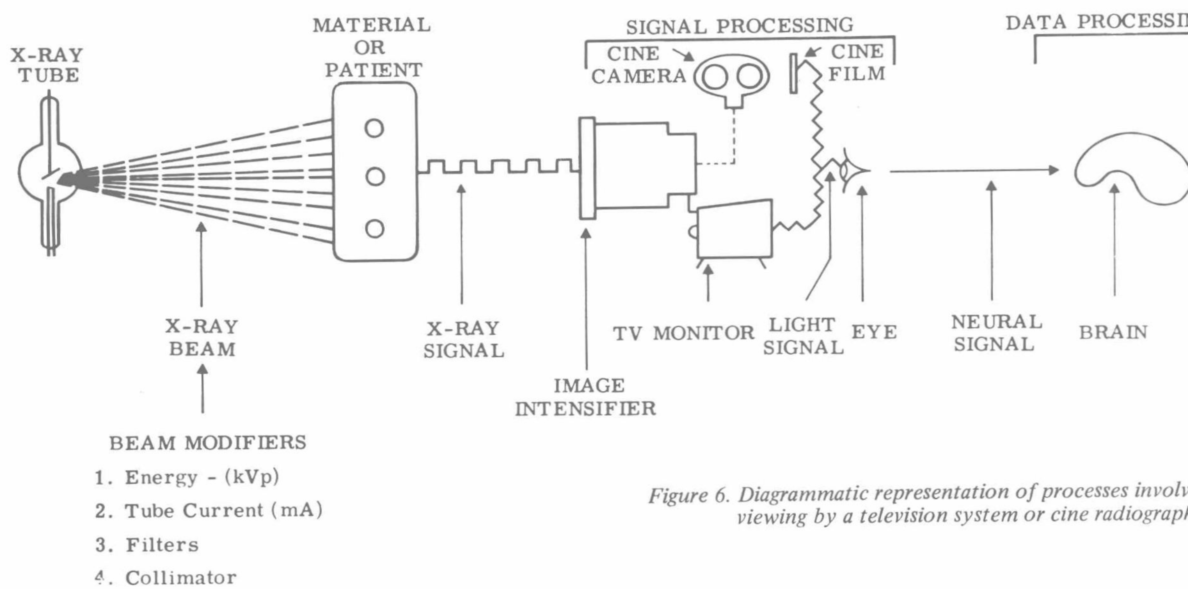


Figure 6. Diagrammatic representation of processes involved in viewing by a television system or cine radiography

PRODUCTION OF X-RAYS

The x-ray tube and generator

Figure 7 is a diagrammatic representation of an x-ray tube (hot cathode type) with its usual type of electric circuit. The diagram shows a cylindrical glass bulb (B) from which all the air has been extracted. Sealed within this tube at one end are two wires joined together inside the bulb by a spiral of wire of high resistance (F). It can be heated to incandescence by passing a current through it, as in an ordinary electric light bulb. The current is supplied by a transformer (G). The spiral of wire is called the filament and when red hot it emits electrons.

Sealed in at the opposite end of the glass bulb is a block of copper, on the end of which a piece of tungsten is mounted directly opposite the filament (F); this is the target (T) which is inclined at a suitable angle. Lead shields (L) prevent the x-rays emerging from the tube except through the gap in the shield, sometimes called the window (W). There is little absorption of the useful beam of emerging rays at the window due to the particular nature of the glass at (B).

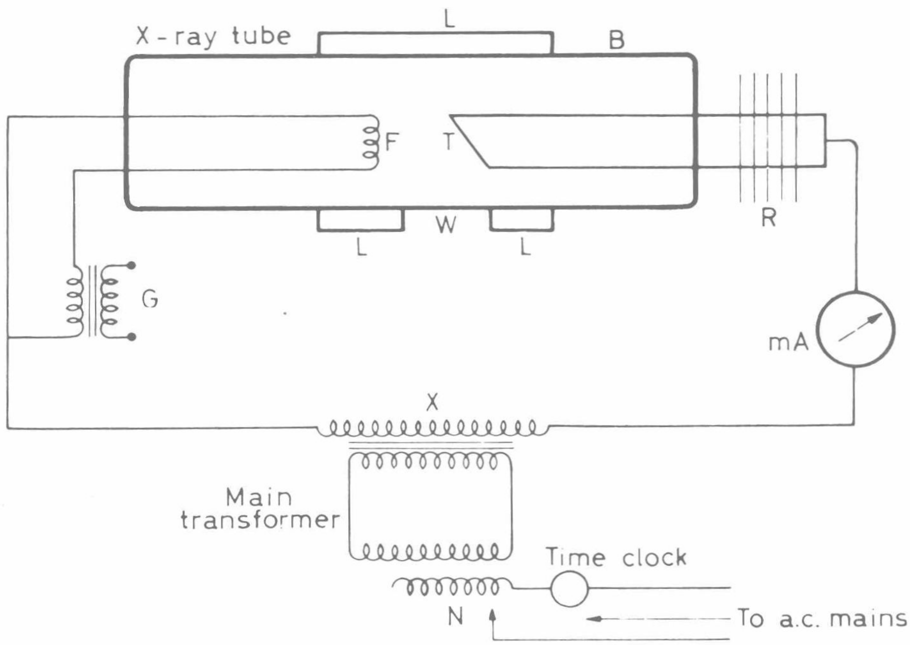


Figure 7. Simplified diagram of an x-ray tube and transformer circuit

The transformer (X) is supplied with a suitable alternating current main, and raises the potential of the current from 200 to 400 volts to between 40,000 and 150,000 volts, the actual value being regulated by the auto-transformer (N).

The filament and the target are connected to the terminals of the secondary coil of the transformer (X), and the filament is made negative to the target by the application of the selected high potential. The negatively charged electrons emitted by the hot filament then travel towards the target. Here they are stopped abruptly, with the consequent generation of x-rays, which emerge through the small glass window (W). The impact also generates much heat in the target, and this is dissipated by the cooling radiator (R).

A milliampere (mA) meter, if placed in the circuit, gives an approximate measure of the quantity of x-rays emitted per unit of time. A radiograph taken with 100 mA for one second is identical to one taken with 10 mA for ten seconds, other factors being kept constant.

The duration of exposure is controlled by a time clock; a convenient range for clinical work being 0.003 to 8 seconds.

Kilovoltage in relation to quality of ray and time of exposure

An x-ray tube gives out a heterogeneous beam of radiation in which energy is distributed in various proportions among the different wavelengths and is sharply cut off at the shortest wavelength. The higher the voltage applied the shorter is the wavelength at the point it is cut off. In medical diagnostic radiology the peak kilovoltage (kVp) applied is usually in the range of 40–150 kVp.

Within a range of 50–80 kVp a rise of 10 kVp will halve—while a fall of 10 kVp will double—the mA required to produce a film with more or less the same blackening or density.

Absorption of x-rays

The absorption of an x-ray beam as it passes through a part of the body is proportional to the number of atoms in the path of the beam and to the fourth power of their atomic number. X-rays affect photographic emulsions in much the same way as light, so that if a suitable photographic film is placed on the opposite side of the individual to the x-ray tube and an exposure is made, the x-rays passing through an individual cause varying degrees of blackening in the developed film. There are only five basic densities that can be appreciated in a correctly exposed radiograph. They are as follows.

(1) Air or gas density

These are the most transradiant and therefore result in the greatest degree of blackening in the developed film.

(2) Fat

This is slightly more transradiant than the other non-calcified soft tissues.

(3) Soft tissues

Soft tissues other than fat are of intermediate transradiancy and therefore appear grey in a correctly exposed radiograph. All the soft tissues including muscle, blood vessels, brain, liver, and liquids such as blood, intestinal juices, and urine absorb x-rays to a similar extent, and so cannot be separately distinguished in a radiograph.

(4) Calcified structures

Such structures, for example, bone, are the least transradiant, and therefore appear whitest in the film.

(5) Artificial contrast agents

These absorb x-rays owing to the high atomic number of one of their major constituents, for example, iodine or barium.

X-RAY IMAGING

In order to produce an x-ray image the x-ray beam is directed at the relevant part of the body which is interposed between the x-ray tube and a suitable photographic film. An exposure is made and the film is processed.

The film is similar to that used in light photography, and is sensitive to both light and x-rays. The film can be placed between intensifying screens which fluoresce if exposed to the x-rays. The image produced by the x-rays is then enhanced by the light image produced by the screens and less exposure is needed.

Alternatively, the image can be viewed on a fluorescent screen placed in the position of the film (*Figure 6*). The image is very faint and can only be seen if the observer adapts his eyes to the very low intensity of light. This may take up to 15 minutes in the dark. Movements of the heart, diaphragm, alimentary tract or urinary tract when outlined with a contrast medium can be observed by this technique which is known as fluoroscopy.

A more sophisticated method of imaging is shown in *Figure 7*. The screen image is scanned by a television camera and converted to electrical signals. These can be greatly magnified, converted back to an image and viewed on a conventional television screen. With this type of system adaptation of the eyes to the dark becomes unnecessary. The television image can be photographed on a still film or cine film, or stored on Videotape, so that repetitive viewing is possible. The direct photograph (still) image is comparable to that seen in the conventional full-sized film (*see Figure 371*). Cine radiography is especially valuable when the image changes rapidly, as in the swallowing of a barium emulsion, or in contrast studies of the heart chambers, great vessels or coronary arteries.

Factors involved in the production of an image and its recognition are shown in a very simplified form in *Figures 5* and *6*.

Factors affecting the clarity of the image

Movement of the subject

The image may be blurred as a result of movement of the whole or part of the subject. Movements may be unavoidable; for example, those of the heart beat, or respiratory movements in unconscious persons or in babies. A common avoidable cause is respiratory movements during the exposure. This can be corrected by repeating the radiograph with the breathing held in full inspiration.

Blurring due to unavoidable movement may be mitigated by shortening the x-ray exposure time, when possible.

Technical faults

These may be due to inappropriate or faulty equipment, and include an unnecessarily large focal spot on the target of the x-ray tube, or poor contact between the intensifying screens and the film because of a faulty cassette.

Poor contrast

Although not always affecting the clarity of the image, contrast affects the ease with which shadows may be seen.

(1) Contrast is reduced if the kilovolts used are unduly high, or the tube filtration is excessive.

(2) Contrast is reduced by faulty film development resulting from the wrong chemical constituents, too short a time in, or too low a temperature of, the developer solution.

(3) Contrast is reduced if there is some fogging of the film. This occurs if the dark room lighting is too bright. The film may be fogged by stray ionising radiation generated in the x-ray department or by stray radiation from a radium or isotope source with insufficient protection in the vicinity of the x-ray film store. Films will also be fogged if they have been stored too long or at too high a temperature.

Excessive scatter radiation

Contrast is reduced by scatter radiation, some of which is unavoidable. The thicker the part of the body, and the denser the soft tissues, the more scatter radiation. It is a particular problem in radiography of the chest, especially in a person with a large antero-posterior diameter and a great deal of soft tissue in the thoracic wall. It is always a problem in radiography of the abdomen. Scatter is greater in fat than thin persons, and in fat persons even the proximal parts of the limbs may show poor contrast from excessive scatter radiation.