OXFORD TEXTBOOK OF FUNCTIONAL ANATOMY

VOLUME 2
Thorax and Abdomen

by PAMELA C. B. MacKINNON
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Contents

CHAPTER 1

Introduction

Expectations and use of the book

In writing this book we have deviated from traditional approaches and attempted to emphasize functional and living anatomy and its imaging in medical practice. The book has been designed to enable students of morphology, whether they be medical or dental, physiotherapists or radiographers, nurses, or any other student of the biology of Man, to understand the functional design of their own body and that of others. To dissect an entire cadaver from head to toe can be very instructive and is essential for aspiring surgeons. However, the recent escalation of knowledge in all branches of the preclinical and clinical medical sciences, for which time must be provided in medical teaching programmes, makes this impractical in most courses. Nevertheless, the understanding of how the body is built and how it works is fundamental to the practice of all aspects of medicine.

This book therefore guides its readers through the fundamentals of anatomy using appropriate prosections and a partial dissection of the body. For those who do not have access to such material it can also be used by reference to the reader's own body and to the illustrations. In this volume of *Functional Anatomy* the embryological development of body cavities and organs has been outlined, when appropriate, to aid understanding not only of normal anatomy but of certain abnormalities which will be encountered in the clinical course. However, liberal reference should also be made to embryology, histology, physiology, and biochemistry texts. It is important that you are able to answer the questions which have been inserted throughout the book; if the foregoing text has been absorbed and the anatomical specimens properly investigated then most should not prove difficult. Others have been posed to stimulate your reading of related texts. Personal notes on your anatomical investigations made in the margins of the book will prove invaluable. At some future time, rapid perusal of a seminar containing additional comments of your own will ensure an equally rapid recall of the basic information. This is a book which, if used properly, should never be discarded.

'Living anatomy' is the structure and function of the body in its living state; it is a study of our skeletal system which protects the vital organs and gives attachment to muscles; of muscles and joints which provide for movement between the various skeletal units; of the highly specialized cardiovascular system through which oxygen and nutrients are pumped to individual cells of the body and waste materials are collected for excretion; of the various organs within the head and neck, thorax, and abdomen which enable the body to remain viable by ensuring a homeostatic environment for each individual cell; of the reproductive system which ensures continuity of the species; and of the nervous system which receives and integrates information from both the internal and external environments and which, through our speech, movements, and behaviour, enables us to express our individual character and personality. This volume deals with the thorax and abdomen and, like Volume 1 (Musculo-Skeletal System), is set out in 'seminars' which require two to three hours study. Some students may wish to study the abdomen separately from the thorax. If this is so, then the thorax can conveniently be read after the first eight seminars of *Head and Neck* (Vol. 3) in which the upper respiratory tract is studied.

The changing form of the body and its relations to function

Always remember that 'the body' is not a single assembly-line product. It develops in the uterus and this development usually produces a 'normal' individual. It develops and grows further during childhood and adolescence to produce the adult form. On occasions, any part of this development may be imperfect to a greater or lesser degree. It will also be obvious to you that variation among normal individuals exists. It is important that you develop a concept of the **range of normality** so that you can judge what is abnormal. For this purpose many illustrations of abnormalities are included in the book. In later adult life, ageing changes lead to senescence. Remember that most bodies donated for examination in the dissecting rooms are those of elderly people.

External differences between male and female are mostly obvious; however, the body of both sexes undergoes many cyclic changes of a circhoral and diurnal nature and that of the female undergoes in addition a monthly cycle. Throughout life, the body responds morphologically to functional demands (e.g. hypertrophy of cardiac (heart) muscle) and to abuses and injuries by repair and healing.

'The body' which you must consider is therefore not the static, usually elderly form which you see on the dissecting room table, but rather a living, dynamic organism, constantly changing and responding to the functional challenges of its environment.

Any region of the body consists of a number of different tissues. The anatomical form that these tissues take in any region is the result of their evolution to fulfil a functional role. The structure of tissues can be considered on two levels. The microscopic structure is the object of study in histology. The macroscopic (naked eye) and radiologic structure is the subject of these seminars.

Terms used in accurate anatomical description (1.1, 1.2)

For ease of communication and convenience of description the body is always considered as standing erect, facing ahead, the arms by the sides and the palms of the hands facing forwards with the fingers extended. Place yourself in this position and note that it differs in a number of ways from your normal stance.

The terms **anterior** (ventral) **posterior** (dorsal) refer to structures facing the front and back of the body respectively. Structures in the antero-posterior midline are said to be **median**, those close to the midline **medial**, and those further away **lateral**. Structures above are referred to as **superior** (or cephalic); structures below as **inferior** (or caudal). **Proximal** means nearer to the origin of a structure, **distal** is the opposite. **Superficial** means nearer the skin, **deep** is the opposite.

Anatomical planes

Sagittal —a vertical plane lying in the antero-posterior plane (longitudinal).

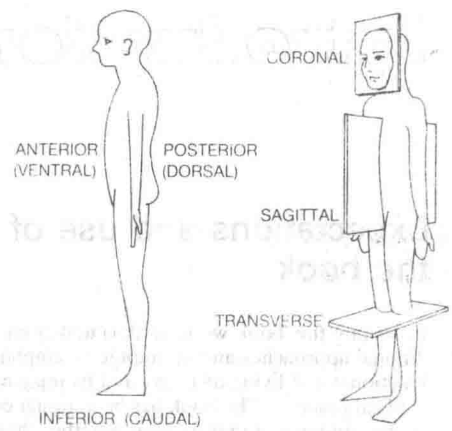
Coronal —a vertical plane at right angles to the sagittal.

Transverse—a horizontal plane at right angles to both coronal and sagittal.

Oblique—any plane that is not coronal, sagittal, or transverse.

Movements

A forward or anterior movement of the trunk (or limb) is usually termed **flexion** while a backward or posterior movement is **extension**. If the non-rotated back is kept straight and the trunk is bent to either side the movement is referred to as **lateral flexion**. **Rotation** of the trunk occurs at the thoracic region but not in the lumbar region (see Vol. 1, *Musculoskeletal System*). Specific movements such as those of respiration are dealt with in the appropriate seminars.



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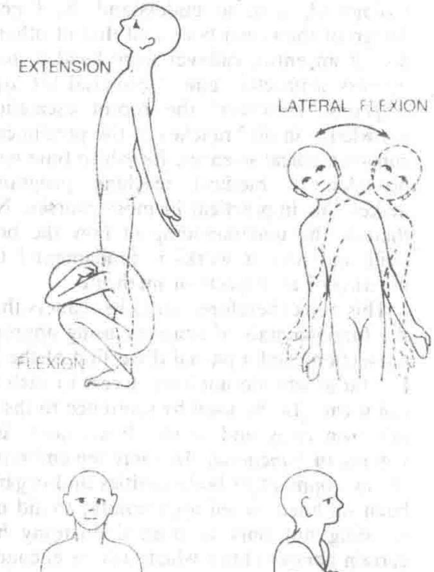

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CHAPTER 2

Systematic thinking about tissues

This section indicates the range of topics that should be considered when studying a tissue or part of the body.

Skin

Consider:

• The **degree of keratinization** (horniness): keratinization is protective. Compare, for example, the skin of the gluteal region on which we sit with that of the distal end of the penis (which is protected by the foreskin). The degree of keratinization can be altered by functional demands, for instance the tougher gluteal skin seen in professional cyclists.

• The **degree of hairiness** and type of hair: only the palms, soles, eyelids, and penis are hairless. The **density** and **coarseness** of the hair differs from region to region. The **distribution** of body hair is sexually dimorphic, the male pattern in which hairs extend from the pubis to the umbilicus being dependent on circulating androgens. Abnormal hair distribution can sometimes reflect endocrine imbalance.

• The presence of **dermal ridges**: these function in gripping and probably also in texture recognition as, when the ridged skin is moved over an object of interest, they produce vibrations that are sensed; their pattern forms the fingerprint.

• The **sweat glands** and their openings: the openings of **eccrine** sweat glands can be located on the surface of the dermal ridges. Eccrine glands are found over most of the body surface in Man and secrete a colourless watery saline. The number of open active sweat glands on most parts of the body can be increased by exercise. The **apocrine** sweat glands in the axilla and external genitalia produce sweat with a higher organic content due to cellular breakdown. Odour formation is due to bacterial enzymes which break down the secretion on the skin surface.

• The number of **sebaceous glands** and specializations such as are found on the areola of the nipple. Their secretion is derived from whole cells which are sloughed off into the lumen of the gland.

• The **skin creases**: at these pronounced lines, which are found especially around joints, the skin is more firmly attached to the underlying tissues. Skin (flexure) creases are different from the fine crease-like lines which appear in the skin of old people. The latter are caused by degeneration of collagen fibres and a reduced attachment of the skin to underlying tissues.

• The **skin cleavage lines** (of Langer): these cannot be seen, but maps are available; in general they run circumferentially round the trunk. They mark the orientation of the fibrous tissue bundles in the skin. Incisions **along** a Langer's line will heal with a fine, barely noticeable scar; those **across** the lines will tend to produce a more 'heaped up' scar (keloid).

• The **blood supply of the skin**: this is derived from local vessels. Capillary loops can be observed if the skin of the nail bed is cleared with a drop of oil and observed with a dissecting microscope. The thermal sensitivity of skin vasculature can readily be demonstrated with hot and iced water. In cold conditions much of the cutaneous blood supply is short-circuited from arterioles to venules by arteriovenous anastomoses.

• The **innervation of the skin**: stimuli to the skin are defined in terms of forms of energy (e.g. mechanical or thermal), their spatial distribution, intensity, and rate of change. It is now clear that some cutaneous sense organs are highly sensitive to mechanical and others to thermal stimuli, and yet others are less specific.

There are variations in mechanoreceptive spatial discriminatory power in different regions which is usually measured by the two-point discrimination threshold. This is the smallest distance between two simultaneously applied mechanical stimuli that can be perceived as two rather than one.

You will need to know:

• The **local nerve supplying** an area of skin: this is needed both for diagnosis of nerve lesions and application of local anaesthesia.

• The **spinal nerve** which supplies the area of skin: this is necessary for the diagnosis of spinal cord and spinal nerve lesions. The area of skin supplied by a spinal nerve is called a **dermatome**.

Superficial fascia

This is the subcutaneous connective tissue. It varies considerably from place to place.

Consider:

• The degree of **fat** accumulation and its regional variation: compare the abdomen of many older men and women who have developed a paunch, with the distal end of the penis.

• The presence of fibrous sacs containing a little fluid: these subcutaneous **bursae** are found wherever there is movement and potential friction between tissues. For instance, they permit the skin to move freely over bony prominences.

• The **fibrous tissue content**: this determines the attachment of the skin to deeper structures. Compare the degree of attachment at the junction of the abdomen and thigh (inguinal region) and on the anterior abdominal wall. It is prominent at skin creases, and forms **suspensory ligaments** of breast, penis, etc. In some areas **sheets** of fibroelastic tissue are present, such as the membranous layer of the superficial fascia of the anterior abdominal wall.

• The presence of superficial **vessels and nerves** passing through the fascia to the skin.

Deep fascia

This is the connective tissue that covers and ensheathes muscles. It is also attached to bones. Although mainly fibrous, in most regions it also contains fat and fluid. Its thickness varies very considerably depending on functional requirements. Over expansile regions such as the penis it is very thin, but in other areas, such as the leg, it forms a non-expansile sleeve which is important in the mechanics of venous return. Where sheets of strong fascia exist they often form sites for muscle attachments, e.g. the thoracolumbar fascia which gives attachment to abdominal wall muscles. In larger texts you will find that many fascias are named after the muscle that they cover, but only a few of these are important to remember. In certain parts of the body the deep fascia is strongly attached to the skin (see above).

Bones

You should be able to identify any bone and hold it in the position that it occupies in the living body. You should also be able to judge whether a pelvis has originated from a man or woman.

Consider:

• The position of the **articular surfaces**, e.g. on the head, tubercle, and distal end of a rib, and the bones with which they articulate.

• **Named parts** and **prominences**, especially those that are palpable in the living subject.

• The site of the major **muscle attachments** which may or may not be associated with roughened areas or protrusions of the bone.

• The site of the major **ligament and membrane attachments**.

• The **blood supply** and the position of any nutrient arteries.

• The **marrow cavity** content of red or fatty marrow: its extent in both the child and the adult.

• Any specializations of the **trabecular** pattern within the bone or thickenings of the cortex which reinforce particular lines of stress in the bone. These are well seen in the pelvis, for example.

• The **ossification** of bone—and whether it occurs **in membrane** or **in cartilage**. All bones of the thorax and abdomen ossify in cartilaginous models. Their **primary centres of ossification** appear *in utero*, and their secondary centres appear at around puberty, fusing at 17–25 years of age. The time of appearance of these centres need not be committed to memory, but you should acquire a general understanding of the sequence of ossification of the different parts. The development of the different centres can be useful in determining the age of bones, and in assessing whether the skeletal age of a child matches its chronological age.

Joints

Joints are the articulations between the bones and their form varies widely in relation to the functional requirements of the articulation. The degree of **mobility** varies widely: some joints permit virtually no movement; in others, only the smallest gliding or angular movements occur, and in yet others, a large range of movement in different planes can occur. Consider the factors that will influence the range of movement. All joints must, however, be **stable**. In joints which have considerable mobility, always consider the specializations which give stability to the mobile structure.

Joint type and its relation to movement

Joints are classified as being of different **types** depending on the nature and conformation of the material that separates the bones (**fibrous; cartilaginous; synovial**). At any joint the nature and range of **movements** that can occur will depend on the physical characteristics of the tissues uniting the bones, on the shape of the articulating surfaces, on the ligaments that surround the joint, and on the mechanical advantage and line of pull of muscles crossing the joint.

Where solid fibrous or cartilaginous tissue links the bones to form **fibrous** or **'primary' cartilaginous** joints, respectively, the amount of movement will depend on the degree of deformation of that tissue that can be produced by muscular effort. For example, the first rib is linked to the manubrium of the sternum by the first costal cartilage; torsion of the cartilage allows the sternum to rotate slightly in relation to the first rib during respiration.

The bones of a **'secondary' cartilaginous** joint have articular surfaces which are covered by hyaline cartilage and linked together by fibrocartilage, which may have a significant fluid component. Such joints are found between the manubrium and sternum, between vertebral bodies (intervertebral discs; see Vol. 1 Chapter 8), and at the pubic symphysis. Each intervertebral disc permits only a small degree of movement, but the sum of movement at each disc gives the spine considerable flexibility. As the discs age, fluid is lost and mobility reduced. The degree of movement may also vary physiologically as with the pubic symphysis, which becomes more mobile at the end of pregnancy due to secretion of a hormone (relaxin) which affects the composition of the connective tissues linking the two pubic bones.

Where there is a joint cavity filled with synovial fluid and a capsule lined with synovial membrane, then such **synovial** joints are potentially quite freely movable, as is the hip joint. However, the sacroiliac joint is a synovial joint at which negligible movement occurs due to the interlocking surfaces of the opposed articular cartilages and the very strong ligaments that hold these surfaces locked together. The main movements of respiration occur at synovial joints between the rib cartilages and sternum and between the ribs and vertebrae; and the synovial articulations between adjacent vertebrae permit mostly rotation in the thoracic region of the spine, and flexion and extension but little or no rotation in the lumbar region (see Vol. 1, Chapter 8).

• Consider the **stability** of a joint. This depends on:

(*a*) the articular surfaces;
(*b*) ligaments;
(*c*) muscles.

Note that only the muscles provide an active support and can stabilize a joint in any position by the simultaneous contraction of antagonistic pairs. Ligaments prevent movement only at the limits of the normal range. If the muscles are paralysed, ligaments will soon stretch and joint deformity will ensue.

The structure of any joint therefore reflects an evolutionary compromise between mobility and stability in relation to the function of the joint.

For any joint note:

• The **articulating surfaces**: the bones that take part, and the shape of their articular surfaces. In some cases the areas of contact in different movements is important.

• The **capsule**: its extent, attachments, strengths and deficiencies. The capsule is usually attached to the margins of the articular surfaces.

• The **ligaments**:

(*a*) Intrinsic ligaments are thickenings of the capsule laid down along particular lines of stress.
(*b*) Accessory ligaments also limit movement of the joint in various directions but are separate from the capsule.

• The **synovial cavity and membrane** (if present): synovial membrane usually lines all the non-articulating surfaces within a joint. It secretes synovial fluid which lubricates and, in part, provides nutrition for the joint. Due to its thixotropic properties synovial fluid becomes less viscous between rapidly moving surfaces, and more viscous and supportive when not subjected to shear forces. The actual amount of synovial fluid is very small, there being scarcely more than a molecular layer of fluid between the articulating surfaces. Some larger incongruities are taken up by mobile fat pads covered with synovial membrane.

On radiographs of synovial joints, the 'space' between the articulating bony surfaces is occupied largely by the articular cartilage, which is radiolucent, the fluid 'space' being minimal. The radiolucent nature of articular and fibrocartilage is well seen in intervertebral discs.

• Any **bursae**: some are extensions of the synovial membrane out of the joint capsule which provides fluid-filled sacs to give friction-free movement, e.g. movement of tendons over bones. Others related to the joint may not connect with the synovial cavity.

• **Intra-articular structures**: **fat pads** covered with synovial membrane help to spread synovial fluid. **Intra-articular discs** of fibrocartilage usually divide the cavity of joints in which movement occurs in two separate axes.

• **The blood supply**: there is usually a good anastomosis of the arteries around joints with a large range of movement, and many of the local arteries give branches to the capsule. This arrangement ensures a good blood supply distal to the joint even if the position of the joint tends to reduce the flow in large arteries.

• The **nerve supply**:

(*a*) the capsule of joints has a very important **sensory** nerve supply that conveys **mechanoceptive** information to the central nervous system concerning the direction, rate, and acceleration of any movement of the joint, and **pain** fibres. In general, a nerve which supplies a muscle that acts over a given joint will also supply sensory fibres to that joint. The capsule has an important pain-sensing nerve supply that signals excessive movement. An intact sensory nerve supply is thus essential to protect a joint from trauma; if lost, extensive damage to the joint can soon occur.
(*b*) **vasomotor** fibres of the sympathetic nervous system supply arterioles of the synovial membrane.

Skeletal muscles and the movements they produce

Many details of muscle topography are not of clinical importance, though there are obvious exceptions such as the arrangement of the muscle layers around the inguinal canal in understanding hernias. In general, it is important to understand groups of muscles that produce given movements and their innervation.

• The **actions of muscles**: these have been determined in a variety of ways—by performing different movements and feeling which muscles contract; by dissection; by pulling on tendons and inferences from morphology; by electrical stimulation; and by recording by electromyography, cinematography, flashing light photography.

The muscles acting in any given movement may be classified as:

Prime movers (agonists) which produce the required movement.

Synergists which prevent any unwanted movements which would also be produced if the prime movers acted alone.

Essential fixators which clamp the parts in the position on which the movement is based.

Postural fixators (e.g. of the trunk) which prevent the body being toppled by movements of heavy parts which shift the centre of gravity.

Antagonists which are the muscles which oppose the prime movers in a particular movement. During the movement they are normally relaxed in proportion to the power of the prime movement.

So-called 'paradoxical' actions may counter the forces of gravity (e.g. spinal extensors contract when a heavy weight is lowered to the ground by flexion of the spine).

Such combinations of muscles in elemental movements are relatively stereotyped. The stimulation of prime movers, synergists, and fixators, and the inhibition of antagonists are determined by **programmes** laid down in the central nervous system. Some programmes are inherited and enable certain animals to rise on to their limbs and run immediately after birth; others are laid down as the result of learning.

A particular muscle may be a prime mover in one programme, an antagonist in another, a synergist or essential fixator in others.

Having considered the actions of any muscle you should note:

- The **attachments** of the muscle: most skeletal muscles have their primary attachment to separate bones and therefore cross joints. In the anterior abdominal wall, the flat muscles on each side give rise to tendinous sheets or **aponeuroses**, which meet in the midline fibrous **raphe** where the fibres interdigitate. Contraction of these muscles will compress the abdominal contents. Similarly the muscular fibres of levator ani meet in the midline posteriorly as the anococcygeal raphe, which forms the most posterior part of the pelvic floor.

The **origin** of a muscle is usually described as its more proximal attachment, or the attachment that usually remains fixed during the prime movement that the muscle produces.

The **insertion** is the more distal attachment and usually the part that moves. These terms are really only used for convenience of description since often muscles act in quite different ways in different movements.

- The **shape** of a muscle and the **arrangement of its fibres**: two basic equations govern the form of a muscle, both being dependent on the angle at which the fibres are arranged:

(*a*) The degree of shortening is proportional to the length of the muscle fibres.

(*b*) The power of a muscle is proportional to the number and strength of muscle fibres.

- The **blood supply** to muscles: although muscles need a good blood supply, the details of the local arteries of supply are rarely of importance. In general, adjacent arteries supply a muscle.

Visceral muscle

Visceral muscle cells contain actin and myosin which enable them to contract, but the arrangement of these molecules is not ordered as it is in skeletal muscle and they therefore do not have a striated appearance. This histological difference is associated with function in that visceral muscle contracts more slowly and in a more sustained manner than does skeletal muscle. Furthermore, the single visceral muscle cells are quite short in comparison to the syncytial skeletal muscle fibres. Visceral muscle is found in many different parts of the body including the arterioles which can thereby regulate blood flow to tissues and organs, and in the walls of all the hollow viscera of the abdomen and pelvis. In the wall of the lower respiratory tract it acts to regulate the diameter of the lumen and thus the resistance to air flow. Throughout the intestine it forms an inner circular and an outer longitudinal coat. Between and inside the muscle coats lie autonomic neural plexuses supplied from both the sympathetic and parasympathetic nervous systems. Individual muscle cells in the bowel wall are not independently innervated (unitary) and have relatively few motor nerves. Much of their rhythmic contraction is myogenic and governed by pacemaker regions or by previous stretching of the muscle. The individual cells are linked by gap junctions through which a wave of electrical excitation can pass along the sheet of muscle.

The function of innervation in such muscles is more to enhance or depress the rate and force of the endogenous rhythmic contractions. This is clearly exemplified by the return of peristalsis to the gut after the removal of all autonomic motor nerves. Some small contractions of intestinal visceral muscle provide a 'to and fro' movement of contents that aids digestion and contact with the absorptive surfaces; other movements of the large bowel wall segment the contents, and other co-ordinated contractions provide peristaltic waves which spread for long distances and move intestinal contents from the stomach to the anal canal. The circular muscle around a viscus can be so arranged as to form a **sphincter** which can prevent movement of its contents. The best example of this is at the junction between the stomach and duodenum, where the pyloric sphincter governs the movement of stomach contents into the duodenum. Other sphincters such as that between oesophagus and stomach are areas of increased circular muscle tone, with no obvious hypertrophied circular muscle.

In other organs, such as the uterus, the contraction of the smooth muscle wall is controlled much more by hormones than by nerves.

Arteries

For any artery consider:

- Its commencement and parent vessel.
- Its **course**, particularly where the vessel's pulsations are palpable (over bone) or the vessel is exposed to injury. Where arteries cross bone, such sites may form useful 'pressure points' where digital pressure can arrest haemorrhage (e.g. the external iliac as it passes over the pelvic brim deep to the inguinal ligament to become the femoral artery). The course of larger vessels can be mapped in the living by use of an ultrasonic Doppler shift-based probe. Radiologically, vessels can be demonstrated by the injection of radio-opaque material into the circulation at an appropriate point (angiography).
- Its **major branches** and **mode of termination**.
- Its **area of supply**.
- The **degree of anastomosis** with other major vessels. Some vessels such as the central artery of the retina are truly **end arteries**, with no anastomosing vessels: many are functionally end arteries because of very limited anastomosis, e.g. the renal arteries and the coronary arteries: yet others have plentiful anastomoses, e.g. the arteries which unite around the greater and lesser curves of the stomach, the arcades of vessels supplying the small intestine, and the arteries which link together to form the marginal artery of the large bowel.

Veins

For any vein consider:

- Its **mode of commencement**, remembering that this is distal and will drain either **superficial** tissues (skin and superficial fascia) or **deep** tissues (i.e. beneath the deep fascia).
- Its **course**, particularly where the vein can be punctured with a needle for intravenous administration of substances or withdrawal of blood for testing: also areas which are liable to trauma.
- The extent of any **valves** within the veins. There is a marked regional variation in the incidence of valves. Most of the large veins of the thorax and abdomen lack valves. The negative pressure generated in the thorax by respiration helps to suck venous blood back to the heart, and the compressive force of anterior abdominal and other muscles also aids venous return.
- The **mode of termination** and **major tributaries**: in the abdomen, all veins from the alimentary tract drain, not to the inferior vena cava for return to the heart, but to the hepatic portal vein which forms sinusoids between the sheets of hepatocytes in the liver. In this way the liver can control the amount of absorbed nutrients passing into the systemic circulation. Points of anastomosis between the systemic and portal circulations are important to note because these can become distended if pressure in the portal circulation is increased.
- The **area of drainage**.
- The **degree of anastomosis** with other veins (see portal-systemic anastomoses above).

Lymphatics

Lymphatic vessels cannot be detected by routine examination of a living subject unless they are inflamed. Also, they are difficult to dissect. They can be demonstrated radiologically after injection of radio-opaque dyes. It is, however, crucially important that you are familiar with the lymphatic drainage of an area since both infection and malignant tumours can spread by this route. For the thorax and abdomen consider separately the drainage of the thoracic and abdominal walls, and of the viscera.

Consider:

- The **lymph vessels** that drain an area.

From the walls of the thorax and abdomen: **superficial** lymphatics of the trunk run with veins; above the waistline lymph drains into the axillary lymph glands, while below the waistline lymph drains into the superficial inguinal group of glands; **deep** lymphatics of the body wall (e.g. within the rectus sheath) tend to run with arteries (as with veins the division between superficial and deep is the deep fascia).

Lymphatic drainage from the thoracic and abdominal viscera is considered in individual seminars. Note that, within the abdominal cavity, lymphatic vessels draining viscera tend to run with arteries. Lymphatics draining the small intestinal villi (lacteals) have the special function of receiving emulsified fat which has been absorbed. The vessels therefore have contents which appear milky after a meal.

- The **primary receiving lymph nodes** and the extent to which these can be palpated: the wall of the bowel contains increasing amounts of lymphatic nodules from stomach to anus, reflecting the increasing number of live bacteria within the bowel lumen. Small lymph glands lie on the mesenteric surface of the gut and their draining vessels pass back along the small arteries to reach other lymph glands situated at the major branching points of the arteries. Eventually they reach pre-aortic glands lying on the front of the aorta around the origin of the three major arteries to the bowel. These major lymph trunks then drain into the cisterna chyli and from thence via the thoracic duct to the venous system.
- The **route** whereby lymph returns to the bloodstream.
- The **degree of anastomosis**: in general there is very considerable anastomosis between the lymphatics serving adjacent areas so that, when lymphatics are blocked by tumour, nodes

not normally draining an area may become involved.

Nerves

For any nerve that you study consider:

• The **types of fibre** that it contains.

(*a*) **Somatic**—serving the skin and musculoskeletal system.

(*b*) **Autonomic**—serving the viscera, glands, and blood vessels.

The autonomic system is subdivided into **sympathetic** and **parasympathetic** components which differ in their origin, distribution, and function. In both systems fibres may be: (*a*) **motor** (efferent) or (*b*) **sensory** (afferent). In the limbs most nerves contain sympathetic fibres and their somatic component may be motor, sensory, or mixed.

• The **origin** of the various fibres: for somatic nerves this is both the **spinal root**, and immediate **nerve of origin**. For autonomic nerves the origin is the **ganglion** or **cranial nerve** of origin. Note that many sympathetic fibres travel as a plexus around major vessels.

• The **course** of the nerve, particularly where it is palpable or liable to trauma.

• Its **major branches**.

• The **muscles supplied** and the effect on movement or trauma to the nerve.

• The **skin supplied** and the area of anaesthesia produced by trauma to the nerve.

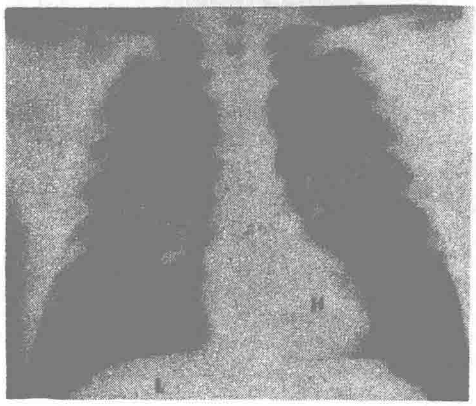
• The **organs supplied** (autonomic innervation) and the effects on their function. Remember that in the limbs sympathetic fibres are distributed not only to blood-vessels, but also to sweat glands and erector pili muscles.

CHAPTER 3

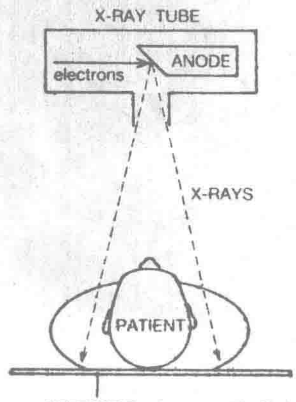
Medical imaging

B. SHEPSTONE and S. GOLDING

One of the most important adjuncts to physican examination in the study of the anatomy of living subjects is **medical imaging**. Since the turn of the century images **(radiographs)** obtained with x-rays have been the standard method of visualizing many areas of the body. Images can now be obtained using sound waves **(ultrasound imaging)**, or by using radiation emitted from substances which have been administered to the patient **(nuclear imaging)**. Recently, computerized techniques have been developed which display a cross-sectional 'slice' of the body. The first of these, **computed tomography** (CT), uses conventional x-rays and its principles have been extended to nuclear medicine to produce **emission computer assisted tomography** (ECAT), and to the nuclear magnetic resonance effect to produce a **magnetic resonance image** (MRI) based on magnetic fields.



3.2
Postero-anterior radiograph of thorax.



3.1
The principle of radiography.

Radiography

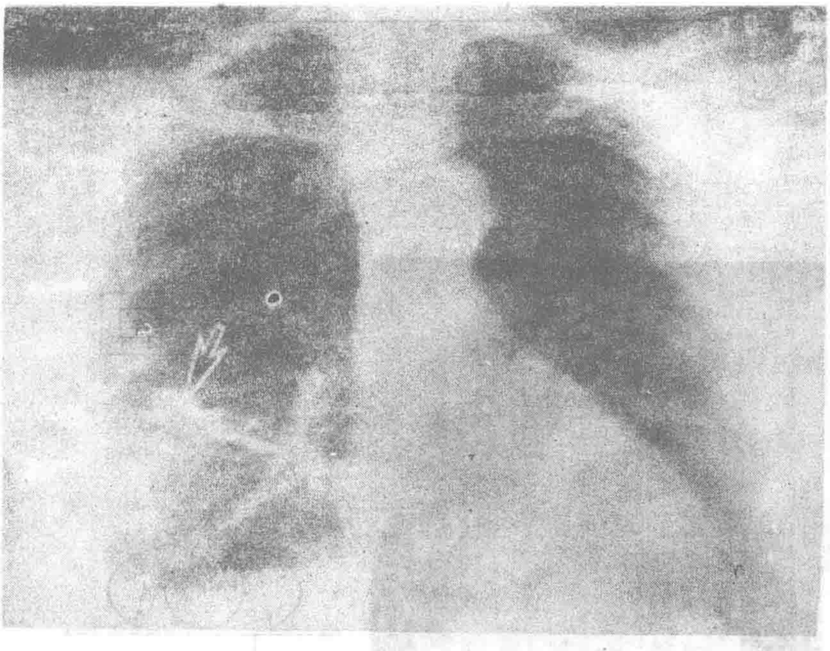
In November 1895 when Wilhelm Roentgen was working on electron beams produced in a Crookes' tube, he noticed light being emitted from material on nearby bench. He realized that some form of emission other than electrons was passing through the tube and causing the material to fluoresce. Placing his hand between the tube and the fluorescing material he saw a shadow of his bones and realized the implications of his observation. By the end of the year he had published an important paper on the newly discovered 'x-rays' which rapidly led to the setting up of primitive x-ray departments in many hospitals.

X-rays are part of the electromagnetic radiation spectrum and can be produced by bombarding a tungsten anode with electrons under high voltages. When the electrons strike the anode their kinetic energy is converted to heat and radiation, including x-rays. In medical radiography the tungsten anode is suspended over the patient so that the beam of x-rays passes through the body; the emerging radiation is then picked up by a detector which is usually photographic film (3.1). Since photographic film is sensitive to x-rays, the film will be exposed to a degree that depends on how much of the beam has passed through the patient and how much has been absorbed by the different tissues of the body. Air is radiolucent, bone and metal radio-opaque. In the chest, good contrast is provided by the bone, soft tissues, and air-containing lungs, and a clear image of most major structures such as the heart (H), liver (L), and pulmonary vessels (*arrows*) can be obtained (3.2). In the abdomen, however, most of the organs are of similar density with respect to x-rays and, although gas in the bowel (♦) and bone can be distinguished, there is very little extra information to be obtained from soft tissue structures although the outlines of the kidneys are just visible (▶) (3.3).

3.3
Antero-posterior radiograph of abdomen.

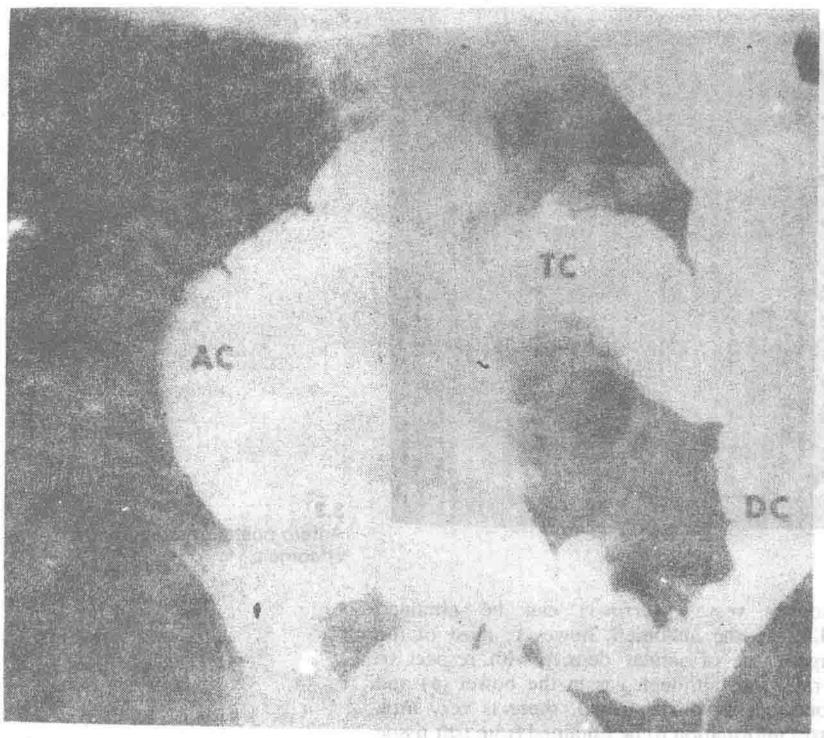
Fluoroscopy (screening)

If a fluorescent screen is substituted for photographic film a direct image is produced. This enables movements of organs to be studied. It is



3.4
Conventional radiograph showing an opacity in right lung (*arrow*).

3.5
Tomogram of the plane of focus containing the opacity (nodule) in right lung.



3.6
Radiograph of abdomen after radio-opaque barium has been administered by rectal enema.

customary nowadays to view the image on a television screen: an amplifier system or 'image intensifier' is usually employed which ensures a good picture with a reduction in the dose of radiation. The fluoroscopic image can then be recorded by photography or video, or by a digital computer which stores the information received (**digital radiography**).

Tomography

Can be used to overcome the superimposition effects present in the conventional radiographic image. The x-ray tube and the film move around the patient in a constant relationship to the plane of interest which therefore appears as a sharp image; the overlying and underlying areas move relative to the tube and film so that their image is blurred. The effect of tomography is therefore to produce a clear image of one plane only. It is widely used in the investigation of the chest, kidneys, and skeleton. Examine the conventional radiograph (**3.4**) which shows an opacity in the right lung. Note that in the tomogram (**3.5**) the plane of focus is such that only the nodule is clearly seen.

Contrast media

It is often not possible to distinguish many organs by conventional radiography, especially in the abdomen. This problem can be overcome by the use of contrast media which are usually either pastes of inorganic barium salts for rectal or oral ingestion, or organic substances containing iodine for intravenous administration. To demonstrate the oesophagus and stomach, a suspension of barium sulphate is given to a patient by mouth. The colon can be similarly studied if barium is introduced through the rectum; note that it has filled the descending colon (DC), transverse colon (TC), and ascending colon

3.7
'Double contrast' radiograph of stomach.

(AC) (3.6). More information is provided about the lining of the intestine if a small quantity of suspension is used and the gut is then distended with air, giving a 'double contrast' image. In 3.7 barium fills the upper part of the stomach of the recumbent patient, while the mixture of gas and barium allows detail of the lining mucosa to be seen.

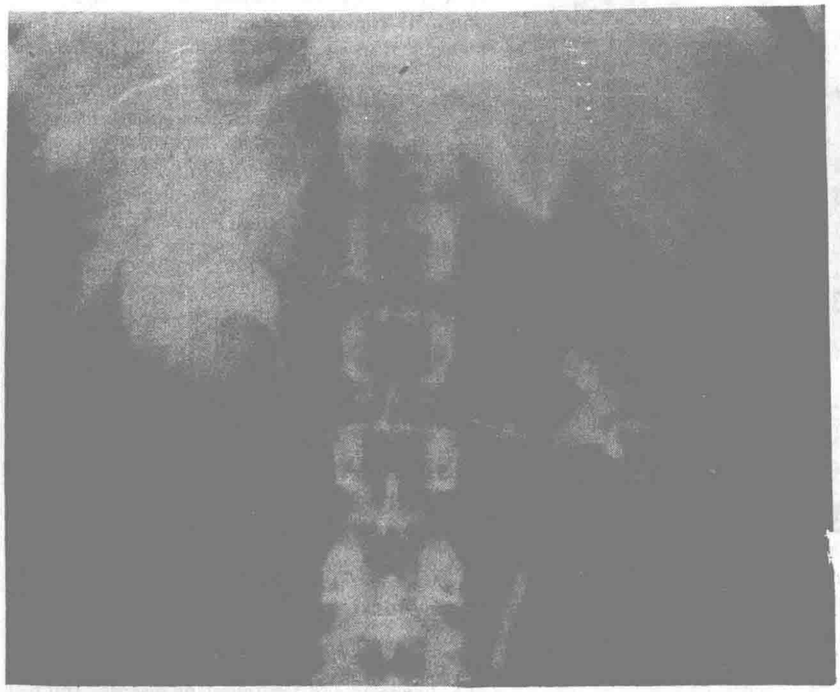
Iodine contrast media have many applications; they can be injected intravenously to be excreted by the kidneys (**intravenous urogram**) (3.8). The contrast medium is concentrated by the renal parenchyma, making the kidney more obvious than in 3.3 and is excreted into the real collecting system, renal pelvis, and ureter (*arrows*). Injections of contrast medium can also be made into a joint (**arthrogram**), into the bronchial tree (**bronchogram**), or around the spinal cord (**myelogram**).

It is also possible to study blood vessels by inserting a fine tube (catheter) into an accessible vessel, for example the femoral artery, and passing its tip into the desired vessel, where contrast media can be injected (3.9). The catheter (*arrow*) has entered the left renal artery (*arrowhead*) and contrast medium has outlined small vessels within the kidney. This procedure, called **angiography**, can be applied to vessels of the gut or head and neck, and even the chambers of the heart.

Ultrasound imaging

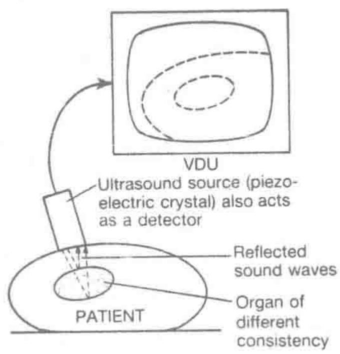
Sound waves travelling in a medium are partly reflected when they hit another medium of different consistency. This produces an echo and the time taken for the echo to reach the source of the sound indicates the distance from the reflecting surface. Ultrasound imaging detects and analyses these echos. Ian Donald, Professor of Obstetrics in Glasgow, realized the potential of this technique and developed it to study the pregnant uterus and the fetus.

Ultrasound consists of high-frequency sound waves that cannot be detected by the human ear. When ultrasound travels in human tissue it undergoes partial reflection at tissue boundaries; thus a proportion of the sound waves return as an echo while the rest continue (3.10). Bone almost totally absorbs the sound and therefore no signal can be obtained from bone or the

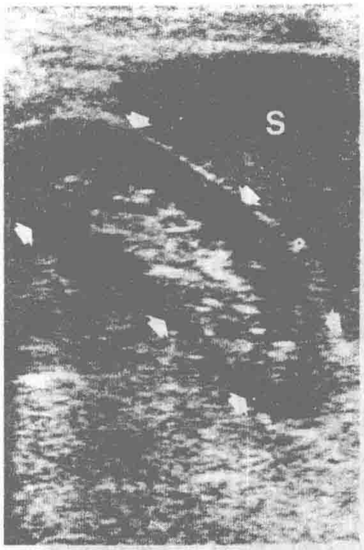


3.8
Intravenous urogram.

3.9
Renal angiogram.



3.10
The principle of ultrasound scanning.



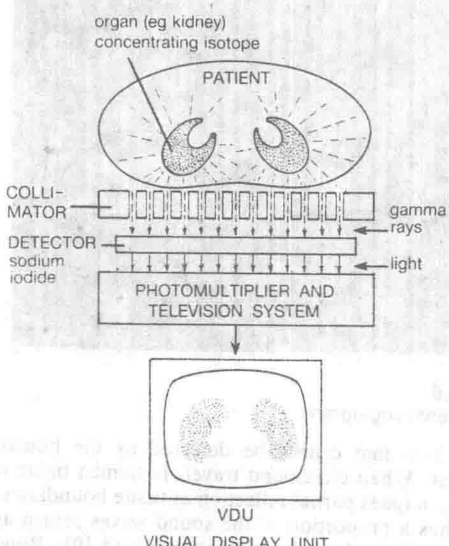
3.11
Ultrasound image of left kidney (*outline arrowed*; S–spleen).

structures beyond. Neither can a signal be obtained from gas-containing viscera. These two facts are responsible for significant limitations to the use of this technique. However, it has the great advantage that there are probably no damaging effects at the sound energies used and it can therefore be used to monitor the developing fetus (see **6.10.10**). The images are sectional in that they represent a 'slice' of the body in the plane of the ultrasound beam. Ultrasound is used in the investigation of the kidney (**3.11**), liver, and biliary system (see **6.6.5**). Figure **3.11** shows an ultra sound image of the left kidney. The image represents a horizontal slice through the organ, which is outlined (*arrows*). The parenchyma which lies peripherally has relatively low-level echoes. The high-level (*bright*) echoes in the centre of the kidney come from the collecting system. (S-spleen). Recently machines have been developed which have a rapidly repeated scanning action, enabling movement of various organs such as heart valves to be studied ('real-time' ultrasound).

Nuclear imaging

Nuclear medicine may be broadly defined as the use of radioactive isotopes ('radionuclides') in the diagnosis and treatment of disease. Interest to the student of anatomy arises from that branch of nuclear medicine called nuclear imaging or 'scintigraphy', whereby a 'map' of the uptake of radionuclide in a given organ system or pathological lesion can be produced by means of an instrument called a gamma camera. Analysis of such an image (which depends not only on morphology, but also on function) is then of use to the diagnostician in elucidating the nature of the patient's problem.

Historically, the subject began in 1896 with the discovery of radioactivity by Henri Becquerel, followed by the development of the radionuclide tracer method by Georg von Hevesy, the discovery of artificial radionuclides by Irene Curie and her husband, Frederic Joliot, and the invention of the gamma camera by Hal Anger.



3.12
The principle of nuclear imaging.

The basis of the gamma camera is a large, flat crystal of sodium iodide which converts into light rays the gamma rays emitted from radionuclides which have been injected into the patient. These light rays strike a photosensitive surface and cause the emission of electrons. The latter are amplified by a photomultiplier and eventually electrical pulses are formed. These electrical pulses can be used to produce an image on a television screen or be used as input to a computer system (**3.12**).

A number of radionuclides are used in a form described as 'radiopharmaceuticals'. The principal radionuclide used is Technetium-99m (which is very safe for the patient in terms of absorbed radiation dose, and has a convenient half-life of 6 hours), but others are also available, e.g. Iodine-123, Thallium-201, Gallium-67, Indium-111. These radionuclides are coupled to various compounds designed to deposit them in the organ of interest. For example, Technetium-99m phosphates will deposit in bones. Technetium-99m coupled to sulphur colloid will be phagocytosed by macrophages and so be deposited in the reticuloendothelial system. Figure **3.13** shows images of a normal liver and spleen viewed from anterior (**3.13a**), anterior oblique (**3.13b**), and posterior (**3.13c**). Note that, because the spleen is situated posteriorly in the abdomen it is more clearly seen in the posterior view (L-liver, S-spleen). Figure **3.13 d,e,f** shows corresponding images of a liver in which tumour deposits have displaced the normal Kupffer cells so that radionuclide is not taken up in these areas (*arrows*). Iodine-123 as sodium iodide will be taken up by the thyroid. The normal uptake of such a radiopharmaceutical in an organ must be well known to the radiologist, so that any deviation from the normal pattern is rapidly detected.

Cross-sectional imaging

Computed tomography

In the early-1970s Godfrey Hounsfield, of EMI Ltd, discovered a way of producing very clear cross-sectional images of the body using x-rays. This was hailed as the most significant advance in radiography since Roentgen's discovery and he, like Roentgen, was awarded a Nobel Prize.

Computed tomography (CT) is similar to conventional radiography in that a beam of x-rays is passed through the body and is measured on emerging. The difference between CT and conventional x-ray methods is that a very narrow beam is used and an array of highly sensitive photoelectric cells is substituted for photographic film. The beam is rotated around the patient and density measurements are made