Cunningham's Textbook of Anatomy

Twelfth edition

Edited by

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Preface

This edition of *Cunningham's Textbook of Anatomy* follows the same general principles as the last in order to retain its suitability for undergraduate medical students and postgraduates studying for higher qualifications. Foreshortened medical courses increase the need for this type of text, and though the modern trend is to denigrate factual information in education, the corpus of information essential for a medical practitioner is not easily obtained unless some details are studied.

The entire text has been revised to remove unnecessary information and to keep it as short as is consonant with clarity. Three of the sections, Digestive, Respiratory, and Radiographic, have been entirely rewritten, while two others, Joints and Central Nervous System, have been extensively altered. One hundred and sixteen new illustrations have been introduced. The Radiographic sections appear as short parts at appropriate positions in the text of each section, separated from the text by double rules. The radiographic illustrations, previously gathered together in plates, have been repositioned in association with the corresponding anatomical illustrations and text so that an immediate comparison of the two images can be achieved and the tedious process of searching for the plates overcome. Illustrations of some new radiographic techniques have been included, and because of the increasing importance of computerized axial tomography in diagnosis and assessment of treatment, an atlas of twenty-eight photographs of transverse sections of the head, neck, and trunk has been introduced. This series supplements the illustrations of such sections which already appear in the text, and permits the student to visualize anatomy as it is displayed in axial tomography and to follow structures through the body. It also shows the relative positions of the major structures without the displacement which dissection inevitably produces. Twelve of these pictures have corresponding, though inevitably not identical, tomographic scans placed beside them for comparison, and the sections are viewed from below to fit with the convention used in axial tomography. This series also supplies the information necessary to interpret the pictures obtained with ultrasound techniques.

I am indebted to the Contributors, new and old, for their forbearance with editorial foibles and their unstinted help, and to the Staff of the Medical Department of the Oxford University Press for their continuing assistance. I am also grateful to Professor E. Samuel and Dr R. A. McKail for obtaining many of the new radiographs and tomographic scans, and to Dr G. T. Vaughan for supplying several special radiographs and scans.

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September 1979

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Contents

1 Introduction

G. J. ROMANES

ANATOMY deals with all those branches of knowledge which are concerned with the study of bodily structure. Originally it meant the cutting up of the body for the purpose of determining the character and arrangement of its parts. It is concerned with knowledge of the architecture and interrelation of the parts of the body whether obtained by dissection with scalpel and forceps (**gross** or **macroscopic anatomy**) or uncovered by magnification with the hand lens or microscopes of all types (**microscopic anatomy**).

In the process of gross dissection, the body is studied region by region producing a sort of geography of the body—**regional** or **topographical anatomy**. This demonstrates that each region consists of the same kinds of tissues (bones, muscles, nerves, blood vessels, etc.) arranged in different ways for particular purposes. Thus the whole body is seen to be composed of a limited number of different tissues each of which comprises a system, the study of which constitutes **systematic anatomy**. Within each system, similarity of structure in some of its different parts indicates a similarity of function of these parts, while differences in the arrangement of other parts argue for differences in function. Similarly, the varying associations of the different systems in the regions of the body give clues to their functional importance. Thus, though the study of structure is a science (**morphology**) in itself, the functional inferences which can be drawn from it, and which are susceptible to experimental investigation, form one of its most important features (**functional anatomy**).

Microscopic anatomy differs from gross anatomy only in the size of structure which may be studied. It deals with the architecture of tissues, **histology**, and of the basic elements or cells of which they are constructed—**cytology**. The great increase in magnification which is obtained with the electron microscope has uncovered structural details within individual cells which are at once of great functional importance and structural beauty, and has made it possible even to visualize some of the larger molecules within cells, thus bringing anatomy within the realms of biochemistry and allowing of the elucidation of structural details invisible with the light microscope. It should be stressed that such magnifications enlarge not only the true structures but also the artefacts which arise from the processes necessary for the preparation of tissues, but it should also be clear that at this level, as in histology and in gross anatomy, no functional theory can be accepted until it has been shown to be compatible with the structure of the organ or system concerned.

No living body is a static structure, but is subject to change from the moment of conception till the time of death, and these changes, which are common knowledge, represent the alterations in structure which differentiate the fertilized egg from the embryo, the child, the adult, and the aged. These processes, which constitute the development and growth of the individual (**ontogeny**), proceed at very different rates and involve different tissues at the various stages. They can be divided into prenatal or intra-uterine development or **embryology**, and postnatal changes. Some postnatal changes are immediate and allow the foetus to adapt itself to extra-uterine life, while others persist during growth and involve every tissue for the purpose of increasing the size of the individual. Yet others continue throughout life for replacing those tissues which are subject to wear and tear, and for altering the strength or volume of tissues in relation to the demands placed upon them. The last two continue throughout life, and are exemplified by the continuous replacement of the skin and the increased size of the muscles and strength of the bones in manual labourers or their decrease in the sedentary.

In the growing individual the rate of growth is not uniform in all tissues at the same time; thus the postnatal growth of the limbs is proportionately much greater than that of the head, and the rate of growth is not equal in all parts of the limbs at the same time, either in the same or different individuals. Rates of growth are different in the sexes, females reaching their final height and puberty earlier than males, and showing periods of rapid growth at different ages from those in the male. Some structures such as the sex organs lie dormant only to make a rapid spurt of growth at puberty when the secondary sex characters appear, while the placenta, which is derived from the fertilized egg and is useful only for the period of intra-uterine life, shows many age changes by the end of that period (10 lunar months) which the tissues of the body, developed from the same egg, will show only scores of years later.

The structural changes which involve the individual (ontogeny) are superimposed on another developmental process which involves every member of the animal group collectively, and through which gradual changes in the structure of animals are believed to take place. This evolution constitutes the ancestral history or **phylogeny** of the individual, and just as Man is part of the Animal Kingdom, so Human Anatomy is part of a larger subject, the study of which is known as **comparative anatomy** and **comparative embryology**. These subjects have produced much of the evidence on which the theory of evolution is based and, drawing information from a wide spectrum of animals, have tended to formulate laws governing the relation of form and structure which, for the vertebrates, is known as Vertebrate Morphology.

The student of medicine is not in a position to become conversant with every aspect of anatomy, but he should understand that a knowledge of anatomy is essential to him in the practice of medicine, since he will be unable properly to examine a patient and recognize abnormality without a sound knowledge of the normal. He must be able to transfer information obtained on the cadaver to the living body so that he can visualize the arrangement of structures within the body from the surface—**surface anatomy**. In this he can derive considerable help from the use of X-rays and slices of the body, but he should lose no opportunity of confirming on himself and his friends the various structures which can be felt or seen and of trying to analyse the movements which the body can perform. The student will inevitably fail to gain from his studies any real interest and

enlightenment if he allows the learning of detailed facts from a book to obscure the primary purpose of attempting to discover the function of the body by the examination of its structure.

TOPOGRAPHICAL ANATOMY

Anatomy is a descriptive science which uses a series of clearly defined and unambiguous terms to indicate the positions of structures relative to each other and to the body as a whole. In human anatomy the body is always described erect with the palms of the hands facing forwards, that is, in the standard or anatomical position, shown on the left of FIGURE 1.1. Three artificial sets of planes are described which are the co-ordinates forming the basis of any description; of these, the sagittal and coronal planes run parallel to the long axis of the body but at right angles to each other, while the transverse or horizontal plane cuts across the body at right angles to the other two.

1. **Sagittal** planes run from the front to the back of the body, and one of these divides the body into two apparently equal halves, the middle or **median plane** [FIG. 1.1]. Any structure which lies in a sagittal plane nearer to the median plane than another is said to be **medial** to it, while the other is said to be **lateral**; structures lying in the median plane are said to be **median**.

2. **Coronal** planes also run parallel to the long axis of the body and pass through it from side to side. Those nearer the front of the body are **anterior** or **ventral**, while those which lie nearer the back are **posterior** or **dorsal**. The terms anterior and posterior are used in human anatomy while dorsal and ventral are applicable also to the quadrupedal position and are used particularly in comparative anatomy. Anterior and posterior are used for the most part as relative terms but are also absolute when they refer to the surfaces of organs or of the body. The surfaces of the body are cut by the median plane at the anterior and posterior median lines respectively.

3. **Transverse** or horizontal planes need no description. Of any two, that lying nearer the head is said to be **superior** or **cephalic** (headward), while the other is **inferior** or **caudal** (tailward).

Thus the relative position of any structure in the body is described as medial, lateral, anterior, posterior, superior or inferior to another, or any combination may be used, e.g. superomedial, posterolateral, etc. It should be appreciated that in quadrupeds the terms anterior and posterior are synonymous with cephalic or headward and caudal or tailward. Certain advantages are therefore to be gained in using the latter terms together with dorsal and ventral since they are applicable to all circumstances.

Certain other terms are also used:

1. In any two adjacent structures, that nearer to the surface of the body is **superficial** or external while the other is **deep** or internal, irrespective of the plane in which they may lie; thus the teeth are deep to the lips and the scalp is superficial to the skull.

2. The relation of a third structure lying between two others is described as intermediate (middle) in whatever plane they may be arranged; thus they may be medial, intermediate and lateral, or anterior, intermediate and posterior, etc.

3. In the limbs certain additional terms are commonly used to overcome the difficulties of description arising out of the mobility of these structures and of using the term caudal especially in the lower limb. Though all the other terms are applicable in the anatomical position, they become difficult to apply when, for example, the arm is raised above the head.

i. The parts of the limbs further from the trunk are **distal** while those nearer are **proximal**. The hand is distal to the forearm and the leg is proximal to the foot.

ii. In the hand and foot the surfaces corresponding to the palm and sole are known as the **palmar** and **plantar** surfaces, while the

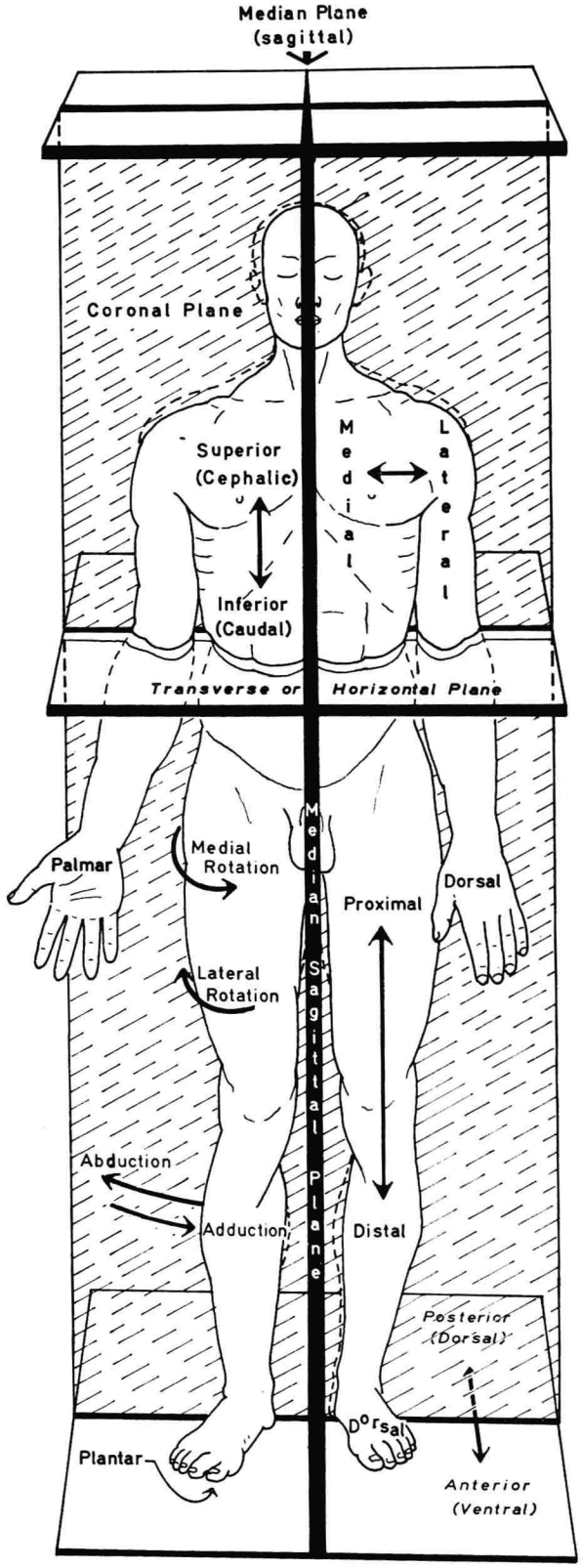

FIG. 1.1. A diagram illustrating the use of some anatomical terms referring to position and movement.

opposite surfaces, the dorsum of the hand and the dorsum of the foot, are the **dorsal** surfaces, even though the dorsal surface of the foot is superior in the anatomical position; a situation which arises from the rotation of the lower limbs which brings the plantar surfaces into contact with the ground.

iii. The lateral or thumb side of the forearm and hand may be designated the radial side from the radius, a bone which occupies this position in the forearm, while the medial or little finger side similarly may be called the ulnar side. Similarly in the leg and foot the terms fibular and tibial may replace lateral and medial respectively.

MOVEMENTS

The terms used to describe movements are also related to the above planes. Thus *movements of the trunk* or neck in the sagittal plane are known as **flexion**, forward bending, and **extension**, backward bending, and in a coronal plane as **lateral flexion**. Turning movements around the long axis are known as **rotation**.

The *movements of the limbs* are more complicated, but again those in the sagittal plane are known as flexion and extension. Flexion carries the limbs anteriorly and folds them. Extension is the reverse movement. On the other hand movement of the limbs in a coronal plane is almost limited to the proximal joint and carries the limb either further away from the median plane, **abduction**, or closer to it, **adduction**. Similar movements occur at the wrist when the hand is slewed on the forearm in the plane of the palm, and these are known as abduction or **radial deviation** and adduction or **ulnar deviation**. Abduction and adduction in the fingers and toes are named with reference to movement away from or towards the median plane of the hand, which passes through the middle finger, and the median plane of the foot, which passes through the second toe. Rotation in the limbs, as in the trunk, is represented by a movement of the whole limb or a part of it around its long axis. Medial or lateral rotation referring to the direction of movement of the anterior surface of the limb.

A special example of rotation occurs in the thumb and to a lesser extent in the little finger. Medial rotation of the thumb brings its palmar surface into opposition with the palmar surfaces of the fingers. This movement of **opposition** is characteristic of the hand, is an essential part of grasping and holding, and the basis of many skilled movements.

A very special form of rotation is the movement of one forearm bone (the radius, which carries the hand with it) around the other (the ulna). This is not simple rotation of the forearm on its long axis since the ulna remains stationary during the movement. At the limits of this movement the palm of the hand faces either anteriorly, the **supine position**, or posteriorly, the **prone position**. Thus movement to the prone position is known as **pronation** while **supination** describes the reverse movement. At the ankle joint the movements are in the sagittal plane and in either direction are known as flexion; **plantar flexion** if the movement is towards the sole, **dorsiflexion** if it is towards the dorsum. Distal to the ankle joint, the foot may be moved so that its sole is turned to face inwards or, to a lesser degree, outwards; these movements are named **inversion** and **eversion** respectively.

SYSTEMATIC ANATOMY

The description of the several systems of organs separately and in logical order, constitutes systematic anatomy, and is the plan upon which this book is based. The several parts of each system not only present a certain similarity of structure but are also associated in specialized functions. As already pointed out, functional anatomy merges insensibly into physiology. It begins with simple ideas, such as that the skeleton has the primary function of a supporting framework of the body, and the muscles have the primary function of moving the parts of the framework; it advances by deductions about the function of parts from their anatomical arrangement (such as Harvey's famous discovery of the circulation of the blood (1628), from observations and simple experiments on the valves of the veins and of the heart): it is also concerned with the wider field of the interrelations of parts belonging to different systems—for example, the anatomical localization in the nervous system of the origin of nerve fibres concerned with the regulation and control of the functions of different organs. Anatomy and physiology are indeed but two different aspects of one subject, separated by their methods of investigation. Structure and function are in reality indissolubly associated; and that is the basis of systematic anatomy. Thus there are:

1. THE LOCOMOTOR SYSTEM, which includes:
   (i) The bones and certain cartilaginous and membranous parts associated with them.
   (ii) The joints or articulations.
   (iii) The muscular system. With the muscles are usually included fasciae, synovial sheaths of tendons, and bursae.
2. THE DIGESTIVE SYSTEM, which consists of the alimentary canal and its associated glands from the mouth to the anus.
3. THE RESPIRATORY SYSTEM, the nasal passages, larynx, windpipe, and lungs.
4. THE UROGENITAL SYSTEM, composed of the urinary organs and the genital organs—the latter differing in the two sexes.
5. THE DUCTLESS GLANDS, which, though heterogeneous in their origin, structure, and particular functions, are conveniently grouped together as a 'system', for they share the common feature of releasing into the blood stream secretions which are distributed throughout the body and have a profound influence on its functions. They include the thyroid and parathyroid glands, the thymus, the hypophysis cerebri and pineal body (these two are attached to the brain), and the suprarenal glands.

The term splanchnology denotes the knowledge of the organs included in the digestive, respiratory, and urogenital systems, and the ductless glands.

6. THE NERVOUS SYSTEM, which is divided into:
   (i) The central nervous system—the brain and the spinal medulla (*cord*).
   (ii) The peripheral nervous system—the nerves and their ganglia.
   (iii) The autonomic nervous system, comprising the sympathetic and parasympathetic systems of nerves and ganglia.
   With the nervous system may be included:
   (iv) The organs of the special senses (sight, hearing, smell, taste).
   (v) The skin and its appendages (nails, hair, etc.), which is the largest organ in the body and an important sensory apparatus.
7. THE BLOOD VASCULAR SYSTEM, including the heart and blood vessels (arteries, veins, and capillaries).
8. THE LYMPHATIC SYSTEM of lymph vessels, lymph nodes, and spleen.

MICROSCOPIC ANATOMY (HISTOLOGY)

The organs which constitute the various systems of the body are constructed of tissues which can only be studied satisfactorily under the microscope. This reveals them to be formed of two distinct but closely interrelated elements: the cells, and the intercellular materials which are the products of the cells themselves. Each **cell** consists of

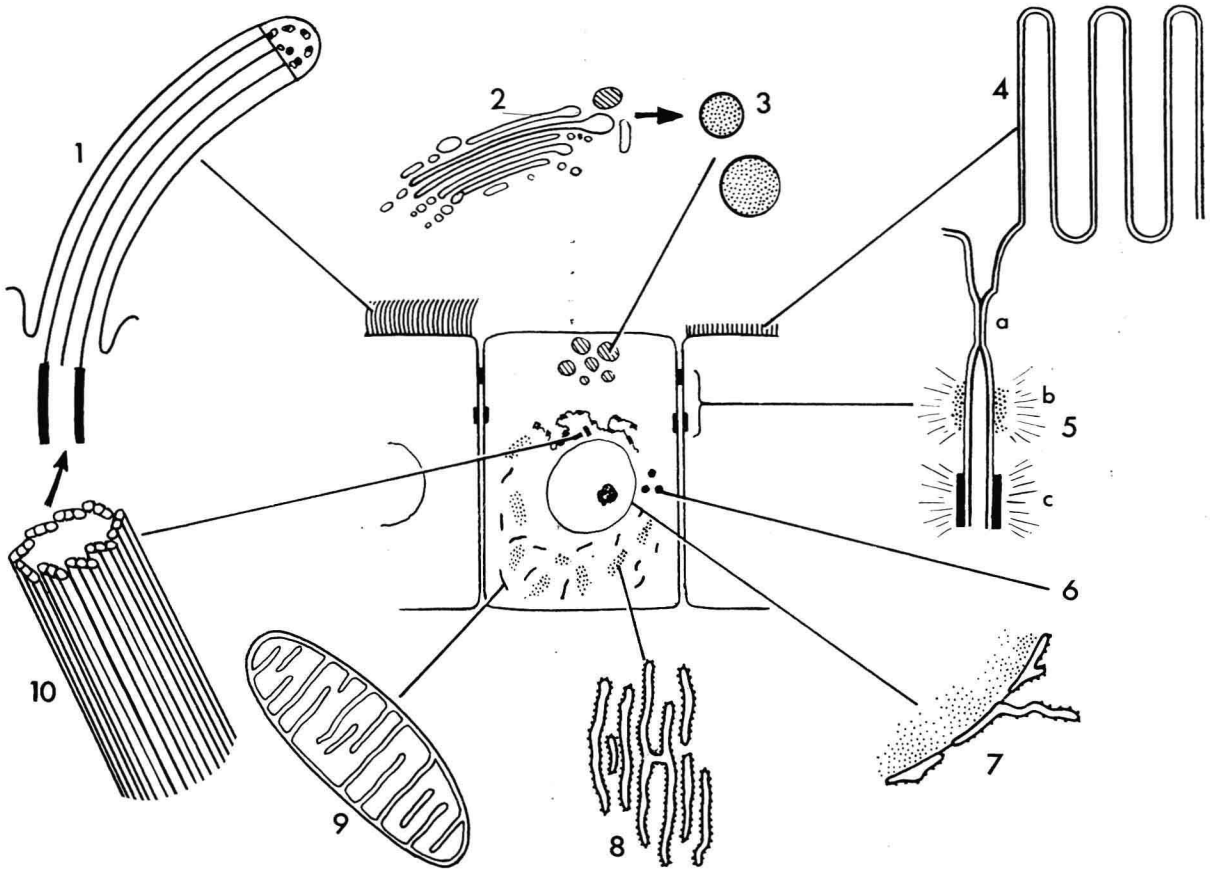

FIG. 1.2. Some of the surface and cytoplasmic modifications of cells. Not all the structures shown are present in every cell, and the diagrammatic cells shown are unlikely to be found adjacent to each other.

1. Cilia. These long, motile processes are found in many epithelia, (e.g. respiratory epithelium). Each contains nine pairs of tubules around its periphery (5 of the 9 are shown in the longitudinally sectioned cilium) and a central pair. The basal body from which each arises appears to be a centriole. Thus in ciliated epithelium the usual two centrioles which make up the centrosome (10) seem to have multiplied considerably.
2. The Golgi complex lies close to the nucleus, towards the free surface in secretory cells, but may surround the nucleus, e.g. in nerve cells. It consists of layers of flattened, membranous sacs, and gives rise to the secretion granules of the cell. It is believed that materials produced by the rough endoplasmic reticulum (8) are further elaborated in the Golgi complex to produce the secretory material.
3. Secretory granules are enclosed in a membrane derived from the Golgi complex.
4. Where absorption is taking place the surface of the cells frequently shows an array of fine, non-motile, finger-like processes, **microvilli,** which greatly increase the surface area of the cell. These are found in the epithelial cells of the intestine and the proximal convoluted tubules of the kidney.
5. Three types of adhesions between cells. a. A tight junction where the outer layer of the trilaminar cell membranes fuse. b. A zone of adherence forms a continuous strip where intestinal epithelial cells come together. The cell cytoplasm is granular close to the membrane, and fibrils in the cytoplasm pass into the granular region. c. A desmosome or point of adherence between cells. The inner layer of the cell membrane is thickened and fibrils in the cytoplasm pass into it. These are widely distributed in the tissues of the body and may appear as half desmosomes where an epithelial cell is attached to the underlying connective tissue, e.g. in skin.
6. Lipid droplets in the cytoplasm.
7. Part of the nuclear membrane to show the nuclear pores.
8. Rough endoplasmic reticulum. These membrane sacs are studded with ribosomes (particles of ribonucleoprotein). They are mainly responsible for the basophilia of the cytoplasm, e.g. in secretory and nerve cells, and are concerned with protein synthesis, including enzyme production. Scattered ribosomes are also found free in the cytoplasm, and there is endoplasmic reticulum which does not carry ribosomes; smooth endoplasmic reticulum.

9 Mitochondria. These structures, found in all cells, are principally concerned with oxidative mechanisms, but they may also play a part in protein synthesis.

10. Centrioles. All cells capable of division contain a pair of cylindrical centrioles which form the centrosome and usually lie close to the nucleus at right angles to each other. Early in mitosis they are duplicated, one pair passing to each end of the cell and forming the basis of the spindle. Each consists of nine triplets of tubules, and where it forms the basal body of a cilium, each triplet appears to be continuous with a twin tubule of the cilium. There is no central structure in the centriole corresponding to the central pair of tubules in the cilium.

The cytoplasm also contains fibrils, glycogen granules, lysosomes, etc. The latter contain proteolytic enzymes in a membrane, but may cause autolysis of the cell if they escape into the cytoplasm. They are probably concerned, amongst other activities, with the digestion of phagocytosed foreign material.

a minute mass of colourless, watery, living substance or protoplasm whose external surface is a delicate, lipoid-containing, cell-membrane about 1/1 000 000 mm thick which separates the cell from its neighbours and from the intercellular substances. The cell contains one (occasionally several) smaller, often centrally placed, body, the **nucleus**, which is surrounded by a membrane and embedded in the remainder of the protoplasm, cytoplasm. Cells vary in size from 8 to 200μm in diameter (a μm = a micrometre, which is 1/1000 of a millimetre); the majority lie between 10 and 30μm and are invisible to the naked eye. They also show many different shapes and some have processes which extend over considerable distances from the cell body (up to 1 m in the case of some nerve cells) while striated muscle cells may be several centimetres long and have many nuclei. It is a mistake to assume that cells have a static shape just because they always appear similar after the processes of preparing them for microscopy. In fact, all cells undergo changes in shape and constitution and many of them are capable of movement. The nucleus differs from the cytoplasm in containing all the deoxyribonucleic acid of the cell, and has within it one or more small bodies (the nucleoli) which contain ribose nucleic acid. The nuclear membrane has numerous pores through which nuclear material is believed to enter the cytoplasm [FIG. 1.2], but these are not simple apertures for they do not allow free ionic exchange between nucleus and cytoplasm. The cytoplasm contains a number of structures within it which are similar in all cells but of different degrees of development in each.

1. **Mitochondria** [FIG. 1.2(9)] are minute rod-like structures which appear at high magnification to consist of a sac of membranes the inner layer of which is folded into the interior (cristae) to a greater or lesser degree. These structures contain the energy-producing oxidative enzymes present in the cytoplasm.

2. **Golgi complex** [FIG. 1.2(2)] has the appearance of a collection of flattened vesicles within the cell, usually aggregated near the nucleus. It is intimately associated with the formation of secretory granules in many cells.

3. **Endoplasmic reticulum** [FIG. 1.2(8)] consists of membrane-like structures arranged in tubes or sheets, often carrying minute granules of ribonucleic acid (ribosomes). It seems to be concerned with protein synthesis in the cells and is present in large amounts in secretory cells such as those of the pancreas, liver, and nervous system. Such a high content of nucleic acid makes the cytoplasm take up basic dyes and thus appear blue or purple when stained with basic dyes. Endoplasmic reticulum without ribosomes is present in many cells, and is concerned with lipid metabolism. Ribosomes are also found free in the cytoplasm, as are granules of glycogen.

4. **Fibrils** [FIG. 5.2] of many kinds are found in several different types of cells, but particularly in muscle cells where each myofibril is formed of a number of even finer filaments, myofilaments (in this case composed of actin and myosin). In nerve cells there are fine neurofibrillae and also neurotubules. Tubules are also found arranged in pairs in cilia (the motile processes of some cells) and in sperm tails, and in triplets in the basal bodies of these structures as in the centrioles from which they appear to be formed.

5. The **centrosome** is a minute structure which contains two small, dense, cylindrical bodies, the **centrioles** [FIG. 1.2(10)], which lie at right angles to each other. It lies close to the nucleus and forms the achromatic spindle in cell division. It is absent from those cells which have become highly differentiated and have lost the power of division, e.g. most nerve cells.

6. **Vesicles** in scavenging or phagocytic cells may be ingestion vacuoles which are produced where a part of the cell membrane is engulfed by the surrounding cell surface and nipped off, thus containing material which lay outside the cell. This process is very active in some cells and is a method whereby particulate and other matter may enter the cell and even be transferred across it. In the latter case the vacuole is discharged at another surface of the cell; a process which is believed to occur in many situations where transport of large molecules or particles though a cellular membrane is involved, notably in the endothelium of capillaries and in the lining cells of the intestine. Vesicles may also contain substances produced by the cells, and their contents can likewise be discharged at the cell surface, the lining of the vesicle being incorporated in the cell membrane. One special type of membrane-enclosed vesicle, the lysosome, is very variable in appearance under the electron microscope. It contains numerous enzymes which destroy proteins (acid hydrolases) and are known to discharge their contents into phagocytic vesicles, thus digesting their contents. Such action is important in the destruction of phagocytosed bacteria, etc. Normally the enzymes are isolated from the cell cytoplasm, but may escape when the cell is damaged, thus leading to its destruction.

7. The **cell-membrane** is a lipoid-containing structure which undergoes many alterations in shape and may be thrown into complicated folds or even into numerous thin finger-like processes or **microvilli** [FIG. 1.2(4)] which markedly increase the surface area of the cell. These are therefore found in situations where cells are concerned with absorption, as in the gastro-intestinal tract and in parts of the urinary apparatus. Here they constitute what is known as a brush border because of the appearance of the microvilli under the light microscope. Other thinner, longer, and motile processes of the cell called **cilia** [FIG. 1.2(1)] are present in many situations, including the surface cells of the respiratory tract and parts of the genital tract. In the former they are concerned with the movement of a surface film of moisture so that particles of dust which are breathed in may be carried away, and in the latter with the transport of ova along the oviduct. The cell membranes of adjacent cells may be separated by variable amounts of intercellular substance or they may be applied and even adherent to each other, e.g. in epithelia and endothelia [FIG. 1.2], and where the former are attached to connective tissue. Apart from well-defined structures such as the cilia, the cell membrane during life is in a state of constant movement.

Growth of the body as a whole is achieved either by the division of cells and their consequent increase in number, or by the growth of the individual cells (e.g. muscle), or by the increase in the amount of intercellular substances of all kinds. The normal division of cells is known as **mitosis** and is a complicated process whereby the material in a cell is equally shared between the two daughter cells. The stages of this are shown diagrammatically in FIGURE 1.3A. The first sign of division, the prophase, is seen in the duplication and movement of the centrosomes to opposite ends of the cell. Condensation of the nuclear material into a series of long, nodular, intertwined, double filaments occurs, and these pairs of identical filaments, the **chromosomes**, steadily shrink in length and increase in thickness and density. The nuclear membrane disappears, a series of fibrils radiates from each centrosome, and apparently passing through the condensed chromosomes, forms the **achromatic spindle** on the equator of which the chromosomes are arranged in a disc.

The two filaments of each chromosome now begin to separate, apparently drawn apart (the metaphase) by the fibrils of the achromatic spindle. Thus the single disc of chromosomes splits into two discs, one moving towards each centrosome. This is the anaphase. Towards the end of the anaphase the cell becomes constricted in the region of the original equatorial disc of chromosomes and this constriction gradually deepens until the cell finally divides into two daughter cells, each containing one disc of chromosomes. These gradually elongate to form a tangled skein of fine filaments as in the prophase, except that each filament is now single. The nuclear membrane re-forms and all evidence of the chromosomes as separate bodies disappears, leaving two daughter cells which are small replicas of the original cell. These grow to the parent size and synthesize the materials necessary for a further division, including duplication of the chromosomal filaments.

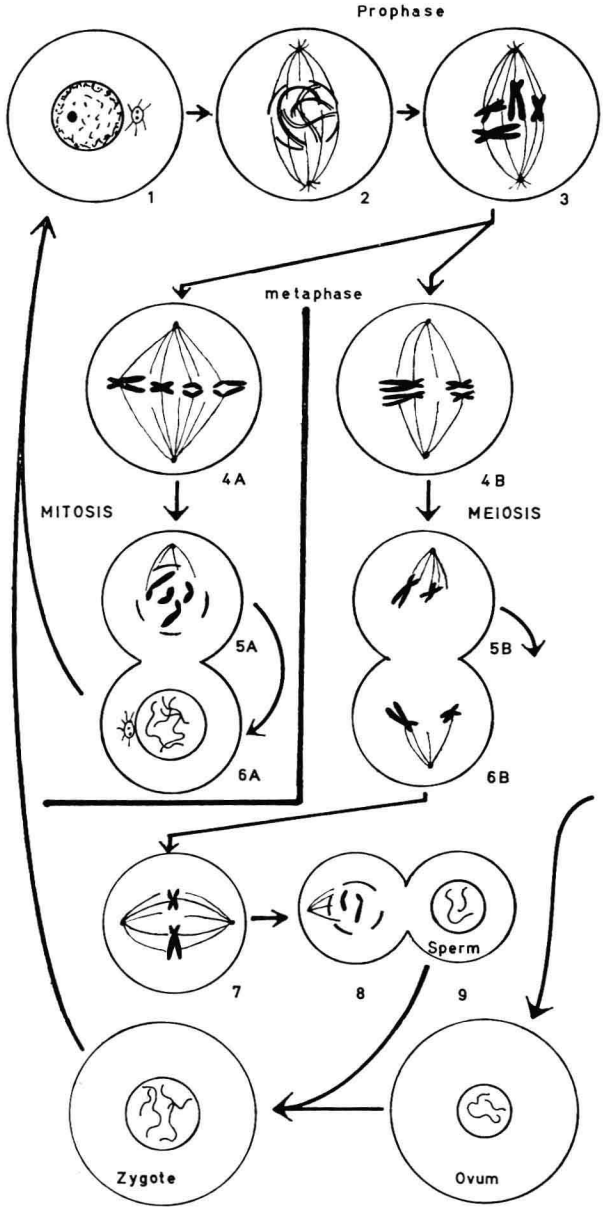

FIG. 1.3A. A diagram to indicate the processes involved in the division of a cell. On the left, the common division of mitosis which gives rise to two daughter cells with the same number of chromosomes as the parent cell. On the right, reduction division or meiosis, the process used in the production of ova and spermatozoa whereby four daughter cells are formed, each with half the number of chromosomes present in the parent cell. The figure shows the formation of spermatozoa, four cells of equal size, the only difference in the production of ova being the formation of one large ovum and three small polar bodies. To avoid confusion, a hypothetical cell containing only four chromosomes is shown.

FIG. 1.3B. *Above*. A photograph of human male chromosomes arrested in mitosis. *Below*. The same chromosomes arranged in corresponding pairs. By courtesy of Dr W. M. Court Brown.

Mitotic division is found in all growing cells with the exception of the germ cells in the ovary and testis. These undergo a very similar process [FIG. 1.3A] except that in the prophase the chromosomes, each consisting of two filaments, arrange themselves in corresponding pairs [FIG. 1.3B], each pair representing four filaments of the mitotic prophase. In the subsequent separation of metaphase and anaphase, these pairs separate from each other, and half of the original chromosomes passes into each daughter cell. This process constitutes meiosis or reduction division and is a preparation of germ cells with half the normal complement of chromosomes ready to have this number made up by a similar reduced complement from the germ cell of the opposite sex at fertilization.

In each species of animal the number, shape, and arrangement of the chromosomes is constant and in the normal cell is always an even number. In human cells there are forty-six chromosomes, composed in the male of twenty-two similar pairs and one dissimilar pair known as the X (large) and Y (small) chromosomes [FIG. 1.3B], and in the female of twenty-three similar pairs, there being a pair of

X chromosomes in that sex. In mitotic division each of the forty-six chromosomes is split longitudinally into two equal parts so that a replica passes to each daughter cell; thus their chromosome content and therefore the material which they inherit from the parent cell are identical and consist of an equal share of the chromosome material derived originally from the ovum and sperm at fertilization. In meiosis, on the other hand, the chromosomes are not split but arrange themselves in pairs which are similar in appearance (with the exception of the X and Y chromosomes in the male cell) but different in origin, one of each pair having been derived from the ovum, the other from the sperm. When these pairs of chromosomes separate as the cell divides, each daughter cell receives half the number that the parent cell had, and since some of the chromosomes which each daughter cell receives were originally derived from the ovum and some from the sperm, the chromosomal content of the two cells is not the same and the inheritance (genes) which each carries is different.

In addition to this relatively simple process the chromosomes lying in pairs prior to the metaphase of meiosis fuse at a point along their length and may separate again in such a fashion that they exchange a corresponding part. Thus some of the chromosomes passing into each daughter cell may be a mixture of the chromosomes derived originally from the ovum and sperm and therefore different from both. The separation of homologous chromosomes in meiosis is brought out most clearly by the pairing of the X and Y chromosomes and their passage into opposite halves of the dividing testicular germ cells from which the spermatozoa are derived, so that half the sperms contain X and half Y chromosomes, and the chromosomal determination of sex depends on the type of spermatozoon, X- or Y-containing, which fertilizes the X-containing ovum. Complete or partial failure of separation of the pairs of chromosomes (non-disjunction) can occur. Thus a complete pair may pass to one daughter cell so that this chromosome is missing from the other. Zygotes arising from fertilization with such gametes would either have three such chromosomes (trisomy) or only one. Such non-disjunctions are usually lethal to the zygote except in the case of the sex chromosomes and in some of the autosomes trisomy of which usually produces profound abnormalities. Thus trisomy of chromosome 21 leads to mongolism (Down's syndrome) with 47 chromosomes in those that survive. A similar result may arise from translocation of a part of one chromosome to a member of another pair, e.g. part of 21 to 14. At meiosis, the normal 21 may pass into the same daughter cell as the abnormal 14. In this case, fertilization will lead to trisomy 21 with a normal number (46) of chromosomes, though there is one unduly large chromosome (14+21) and a single normal 14.

It will be appreciated that all cells derived from the fertilized ovum by mitotic division must of necessity have an equal complement of chromosomes and yet a wide variety of different tissues are formed from these apparently uniform cells. This is an interesting but unexplained phenomenon since all the daughter cells of the developing ovum are capable of forming any tissue up to a certain phase in development, but after this stage is reached they are capable of forming only the tissue which is appropriate to their position in the developing embryo—a probable source of identical twins each with its own amnion and chorion [p. 33]. Thus separation of the first two daughter cells derived from the amphibian ovum leads to the formation of two complete animals. At a later stage, transplantation of cells, to a new situation, is followed by their development into a tissue appropriate to their new position, provided that the transplantation is made at a sufficiently early phase. Each cell is, however, a complex of structures, and the differences between cells represent a difference in degree of development of these different characters (e.g. mitochondria, endoplasmic reticulum, fibrils, etc.) rather than a basic difference in the constituents of the cells. Once a cell has developed the characteristics of a particular tissue, it and its daughter cells retain these unless some profound change occurs in its basic constitution, as can arise in cancer.

The apparent similarity of the chromosomal pattern in a single species no doubt determines the similarity of its members, but does not prevent the cells which make up any individual member from developing the marked variations which occur in different tissues. It should be appreciated, however, that just as individual members of a species are different, so all the cells of each individual have certain common chemical characteristics which are unique to that individual and which represent, it is believed, minor differences in the molecular arrangements of the complex molecules which make up the chromosomes and which are faithfully reproduced from cell to cell. Only two individuals derived from a single fertilized ovum, identical twins, can have exactly the same chromosomal pattern and it is only in these cases that tissues can be transferred from one to another and survive. In all other cases, including non-identical twins, brothers and sisters, the chemical specificity of the individual tissues is recognized by the host to which it is transplanted and it is unable to survive because of the host reaction to this foreign, though similar, tissue.

TISSUES OF THE BODY

The animal body consists essentially of a thick-walled cylinder lined internally and covered externally with a continuous layer of cells, or epithelium, called entoderm and ectoderm respectively. The tissue which they enclose is the mesoderm and the two epithelia are continuous at the mouth and anus, the entoderm forming the lining of the alimentary and respiratory passages and the ectoderm the skin. Both epithelia send prolongations into the mesoderm which are thereby divorced from the protective or absorptive functions of the surface layer and undertake different activities, including the formation of glands which discharge their secretions to the surface of the epithelium from which they are derived along the epithelial stalk, or duct, which connects them. Examples of these are the liver, pancreas, sweat and mammary glands, and hair follicles. Some downgrowths, however, become separated from the surface and discharge their secretions into the blood stream, endocrine glands, or take on quite other functions, e.g. the nervous system, which is derived in this fashion from the ectoderm.

The mesoderm forms all the cells which originate neither in ectoderm nor in entoderm, thus including all the epithelia lining the spaces which develop in mesoderm, the blood and lymph vessels, the serous cavities which surround the heart, lungs, alimentary canal and central nervous system, bursae, tendon sheaths and joint cavities. It also forms muscle, blood, and connective tissue cells, the gonads, and the lining epithelia of most of the urogenital tract.

Connective tissue cells are the source of the intercellular substances of the body including connective tissue fibres, the numerous inelastic, white, collagen fibres and their slender counterparts, the reticular fibres, as well as the yellow elastic fibres.

It should be appreciated that the intercellular substance fills the entire extracellular space, permeates every organ and is continuous with the surface of all the cells which are exposed to it. It is responsible for holding the various organs in place and yet for allowing the requisite amount of movement between them. Thus in some situations where free movement is essential the extracellular material is in the form of a fluid, as in the blood and lymph vessels, in the cavities of joints, tendon sheaths, and bursae and in the spaces surrounding the heart, lungs, abdominal viscera, and central nervous system. Even these fluids are variable in consistence, ranging from the thin watery lymph to the thick glutinous material in some joints. Elsewhere the fluid contains a fine meshwork of

connnective tissue fibres (loose **areolar tissue**) which is sufficiently delicate to allow a considerable amount of movement between adjacent tissues. This is found between the bundles of fibres in a muscle, and surrounds many other tissues such as nerves and ligaments which have to slide on adjacent structures during movement, and organs which have to be capable of considerable distension such as the gullet and the urinary bladder. This loose areolar tissue forms most of the planes of cleavage in the body and allows the rapid spread of infection through it.

In other situations the extracellular material is stronger. This can be either by an increase in the number of fibres which it contains, or by the deposition of different substances produced by the connective tissue cells in the interstices of the meshwork it forms. Thus in many situations the connective tissue cells become loaded with fat, or the fibres are surrounded with mucopolysaccharides to form the gelatinous basement membranes which surround some cells, or with the more solid sulphated mucopolysaccharides to form cartilage, or with calcium salts to form bone.

Where both strength and flexibility are required, only the fibrous elements are increased to form:

1. Compact layers of interlacing collagen fibres. This is the deep **fascia** which invests the entire body and sends sheets inwards between the various organs to surround them with a sheath of greater or lesser density which, because it is felted, is equally strong in all directions. It therefore produces structures such as the epimysium and peritendineum (within which each muscle and tendon respectively slides) the epineurium which confers on peripheral nerves their great strength, and the tough fibrous capsules of such organs as the kidneys and testes.

2. Muscles may be attached to some of the sheets described above, and where they are thus subjected to a pull in one direction, large numbers of collagenous fibres are laid down in this direction, conferring on the sheet a glistening appearance and forming a flat tendon or **aponeurosis**. In an exactly similar fashion the fibrous capsule which surrounds each type of movable joint is subjected to forces unequally in its several parts; where these are greatest there is a similar addition of fibres to form the **ligaments** which give stability to the joints and which are usually therefore a part of the capsule. Most of the ligaments so formed are inelastic or collagenous but a few contain a preponderance of elastic fibres and are yellowish in colour; to this group belong some of the ligaments of the vertebral column. The thickness of such ligaments and aponeuroses is directly related to the forces which they are called upon to resist. The thick rounded **tendons** which arise from muscles of fusiform shape are formed in the same way and have the same structure as ligaments and aponeuroses.

Since the ligaments, aponeuroses, and tendons are but part of the general extracellular material, they are continuous with the same tissue which forms the fibrous basis of cartilage and bone and are thereby directly attached to these tissues by fibres which penetrate them as part of their structure. In a similar fashion, extracellular materials are continuous with the surfaces of the cells which they surround but do not penetrate. Thus the collagen fibres of a tendon are attached to the outer membrane of muscle cells (sarcolemma), and the collagen fibres of the dermis are attached to the deepest cells of the epithelium (epidermis) which covers them, binding the outer protective tissue to the underlying structures.

Reticular tissue is a special kind of areolar tissue formed of very fine collagen (reticular) fibres in a loose network supporting the proper tissue of various organs. It is especially seen in lymph nodes, tonsils, the spleen, the liver, and bone marrow. The connective tissue cells associated with reticular fibres are frequently phagocytic (**macrophages**), that is, they are capable of ingesting particles injected into the living animal. These cells and others of similar properties in the blood and elsewhere are collectively known as the reticulo-endothelial system because of their frequent association with reticular fibres and the endothelium of lymph and blood vessels.

The cells of the connective tissue in some situations may take up and store large quantities of fat, thus forming **adipose tissue**. The individual cells are swollen with the accumulation of fat which forms a single globule within the cytoplasm. Groups of them form small nests enclosed in the collagen network which may be either very delicate, as in perirenal fat, or dense as in the palm of the hand, the back of the neck, and the scalp, where they increase the resilience of the superficial fascia. Everywhere they help to control heat loss. Another type of fat storage, brown fat, is found especially in hibernating animals in which the fat forms a large number of fine globules in the cytoplasm giving the cells a foamy appearance.

In the embryo the connective tissue forms a loose cellular network or mesenchyme from which are developed the connective tissues, cartilage, bone, fat, smooth muscle, lymph nodes, endothelium, blood cells, and macrophages of the adult. Then these cells are very different from each other and from the mesenchyme cells, except in the case of fibrous tissue cells. As a general rule the greater the degree of differentiation in the development of a cell, the more it loses its primitive potentiality to form cells of various kinds and in a few cases it may even lose its ability to undergo mitosis (e.g. nerve cells). The similarity of fibrous tissue cells in the adult to the mesenchyme cells of the embryo, has led to the assumption that some of them at least retain the ability to form other kinds of cells, but it is doubtful if in fact they have more than a very limited ability to do so. Certainly if the blood-forming or lymph cells are destroyed they are not replaced, and injuries involving smooth muscle and other specialized tissues are repaired with fibrous tissue. However, it does seem that the connective tissue cells which are most closely allied to each other can fulfil different roles in some circumstances. Thus fibrous tissue cells, cartilage cells, and bone cells, which share the ability to form collagen and probably also elastic fibres, seem to be partly interchangeable, since cartilage masses can be formed in a broken bone, even when this is developed originally in membrane and no cartilage cells would normally be present (Girgis and Pritchard 1955), and ossification can occur in connective tissue in abnormal situations. However, ossification is difficult to produce experimentally in abnormal situations, and cannot be produced in many sites where there is an adequate supply of connective tissue cells no different in appearance from those in areas, such as the kidney, where abnormal ossification is easily induced.

Whether they are interchangeable or not, the cells derived from mesenchyme retain to a very full measure the ability to react to changing circumstances. Thus, in the rabbit's ear, Clark and Clark (1934, 1940) have shown the remarkable changes which can occur in the vascular pattern; growth of new capillaries, the development in their wall of muscle fibres, and a complete change in the pattern of blood vessels, even to the temporary formation of arteriovenous anastomoses, as a result of changes in the flow of blood through the ear. Again the thickness of tendons and bones can be modified in relation to the stresses placed upon them, the blood-forming bone marrow can react to blood loss by the rapid production of new cells, and under an adequate stimulus the fixed tissue macrophages appear in large numbers, and becoming motile, move towards and ingest foreign material.

These changes and many others are going on constantly in the body, and the study of the cadaver and of histological preparations alone gives very little idea of the vital processes which no student of anatomy should ignore if he is to understand the significance of the structures he studies.

One of the most formidable tasks which face the medical student at the beginning of his studies is the need to acquire the vocabulary of medicine and to use it with precision. For this purpose it is essential to obtain a clear understanding of anatomical terms and this the student can obtain only by repeated reference to a good medical dictionary. The following short glossary defines some of the