Anatomy and Physiology for Physiotherapists

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Preface

Physiotherapists need to know a great deal about bones, joints and muscles; enough, indeed, to require them to read one of the more ponderous tomes on anatomy. They also require a detailed knowledge of the physiology of parts of the nervous system, of the muscular system, and of the effects of exercise on the cardiovascular and respiratory systems, so that one of the rather advanced textbooks of physiology is needed. Their knowledge of other systems of the body can easily be met by a study of one of the smaller textbooks. This book has been written in the hope that it will replace, in one volume, the small library of suitable textbooks which the physiotherapist needs in the study of these basic subjects and, indeed, may be an improvement on them since it deals with the subjects purely from a physiotherapist's point of view. It is essentially a student textbook and there is thus a certain amount of repetition where it is thought that this might be helpful in driving home a point and there are also a number of mnemonics and *aides memoires* which, childish though some of them may be, have been found useful, often by the authors themselves, in remembering details. It is perhaps superfluous to add that the diagrams are diagrammatic—they, again, are meant purely as an aid to learning and do not necessarily present an accurate representation of the human body, which may better be studied in an anatomical atlas or in a living subject. We hope that this book will also be helpful after student days are over and that the practising physiotherapist will continue to find it useful as a reference book in her everyday work and in understanding some of the disease processes that she will encounter.

Contrary to the belief of many students, anatomy and physiology are one and the same subject, even though they employ different methods of research. Structure and function are mutually interdependent—our knowledge of the mechanism of muscle contraction is based on structural studies with the electron microscope while a description of the attachments of latissimus dorsi makes sterile reading without a knowledge of the use that can be made of this muscle by paraplegics. For this reason, rather than dividing the book into two sections—anatomy and physiology—the subjects are integrated as far as possible so that, for example, the chapters on the nervous system deal both with the structure and function of this rather difficult subject.

We have tried, as far as possible, to keep the terminology up to date, using S.I. units and the Paris anatomical nomenclature, but in places we have also used other terminology since this is more likely to be met in a clinical context. Thus, blood pressure is recorded in mm Hg rather than kilopascals, while we have preferred to use the term 'posterior root ganglion' rather than the modern (and less sensible) 'spinal ganglion'.

We would like to express our sincere thanks to all our colleagues and co-

examiners in the Chartered Society of Physiotherapy who have, perhaps unconsciously, taught us so much about the applications of anatomy and physiology to physiotherapy. In particular we would like to thank Miss Dilys Gronow, who, in addition to giving us much invaluable advice, has read parts of the manuscript and suggested numerous improvements. We would also like to express our gratitude to Miss Mary Jo Drew who prepared all the illustrations from our own crudely drawn efforts and whose patience and tolerance must have been stretched to the utmost as drawing after drawing was returned to her many times for minor alterations. We also owe a debt of gratitude to Miss Pamela Lee, Miss Janice Gunn and Mrs. Joan Moffat, who between them have typed the manuscript at least twice over. Finally, we have the greatest pleasure in thanking the publishers, and in particular Mr. Per Saugman, for their help, advice and encouragement during the preparation of this book.

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Contents

1 · Introduction

The human body, in elementary textbooks, is often compared to an engine and analogies are drawn between food and fuel, energy output and horsepower and expired air and exhaust gases. The physiotherapist is at some disadvantage compared to the engineer, however, in that the subject of his or her attentions is almost completely covered with skin and other tissues through which all manipulations and examinations have to be carried out. Furthermore, each patient is an individual with his own likes and dislikes and he may often be reluctant to carry out instructions, either through anxiety or pain. This book will attempt to give you a theoretical knowledge of the structure and function of the body, but much of the real learning will have to be done with the hands and eyes from the living body. Only by careful and accurate palpation and manipulation can the normal structure of the tissues and their normal functioning be understood and the limitations imposed by disease be appreciated.

Although anatomy and physiology are often regarded as separate subjects, they are much better thought of as different aspects of the same study. A knowledge of pure anatomy is meaningless without understanding how the structures involved contribute to the functioning of the body and, similarly, function cannot be fully understood without a knowledge of structure, either as seen with the naked eye or on a microscopic level. We have not, therefore, divided this book up into 'anatomical' and 'physiological' sections but have dealt rather with the different systems of the body from a combined viewpoint. Naturally, some chapters will have a preponderance of description of structure while others will be concerned mainly with physiology but in the majority of chapters a combined approach has been used.

Much of your future work will be concerned with bones, muscles and joints, and you will therefore need a very good knowledge of their structure and function and be able to identify individual muscles and also to put joints through their full range of movement. You will need to have a good idea of the mechanisms by which the nervous system controls muscular activity and the effects of such activity on the body as a whole. The methods by which the body produces the necessary energy for muscular activity are also important. On the other hand, many aspects of anatomy and physiology need only be understood in outline and these will be dealt with quite briefly. The organs and tissues of the body can only function efficiently when the environment in which they work is satisfactory, and it is essential that the internal environment of the body is kept very constant with regard to temperature, chemical composition, acidity or alkalinity and oxygenation. You will therefore find that you will need to study at some length the means whereby the internal environment of the tissues can compensate for changes in the external environment and for the changes produced by body activity.

CELLS AND SYSTEMS

The basic unit of living matter (not only animals but also plants) is the cell, and the whole body is composed of cells, extracellular material and water, both intra- and extracellular. The idea of the cell was first introduced in 1839, by Schleiden and Schwann (one a botanist and the other a zoologist), and the difficulty of understanding the body mechanisms before this time can be well understood by reading an account of the process of conception which was written before it was realised that the essential step here was the fusion of two cells—a spermatozoon and an ovum. In a book published in 1821 a Dr. T.Bell M.D., wrote: 'Now the animal mucilage of semen is nearly pure albumen . . . it will powerfully attract the carbon which the blood rejects . . . Now albumen united with carbon forms fibrin . . . hence as the blood enters the albuminous drop, the union of its carbon with the surrounding albumen will form a muscular ring; successive rings will of course be formed as the carbonated blood passes onward . . . Thus muscular canals will be formed and vessels will shoot through the mass.'

It is difficult for us, nowadays, to imagine trying to work out the process of fertilisation without a knowledge of cells and their genetic structure, but Dr. Bell's account must have sounded quite convincing in his time. Once the idea of the cell was appreciated, however, it became possible to understand how cells could become modified to carry out particular functions, how they could be put together to form tissues and how damaged tissues can repair themselves.

This book will therefore start with a description of the basic components of a typical cell and the structure of cells which have become specialised to carry out particular functions. Most cells do not exist as isolated units (except for blood cells and other cells which have a nomadic type of existence) but are grouped together with other cells of similar or differing types together with varying amounts of extracellular material, to form *tissues and organs*. These will be described in the next chapter.

The body as a whole consists of a number of different tissues and organs which, for the sake of convenience, can be grouped into various *systems*. Thus the muscular system consists of a number of separate muscles, together with their tendons and other accessories, whose main functions are to maintain the posture of the body and to carry out movements, including locomotion. The nervous system consists of the brain, spinal cord and peripheral nerves which receive information from the tissues and send nerve impulses out to the tissues to stimulate their activity. A number of other systems are concerned with other aspects of bodily function and the greater part of this book will deal with each system in turn. In general, it will be found most suitable to describe the anatomy and histology of each system and then to go on to show how the structures which have been described are able to carry out their functions. In this way the two subjects of anatomy and physiology will be integrated.

INTRODUCTION TO ANATOMY

The anatomy of certain systems is of special concern to physiotherapists and will have to be learnt in considerable detail. Thus descriptions of the structure and functions of the bones, joints and muscles will occupy a great deal of the

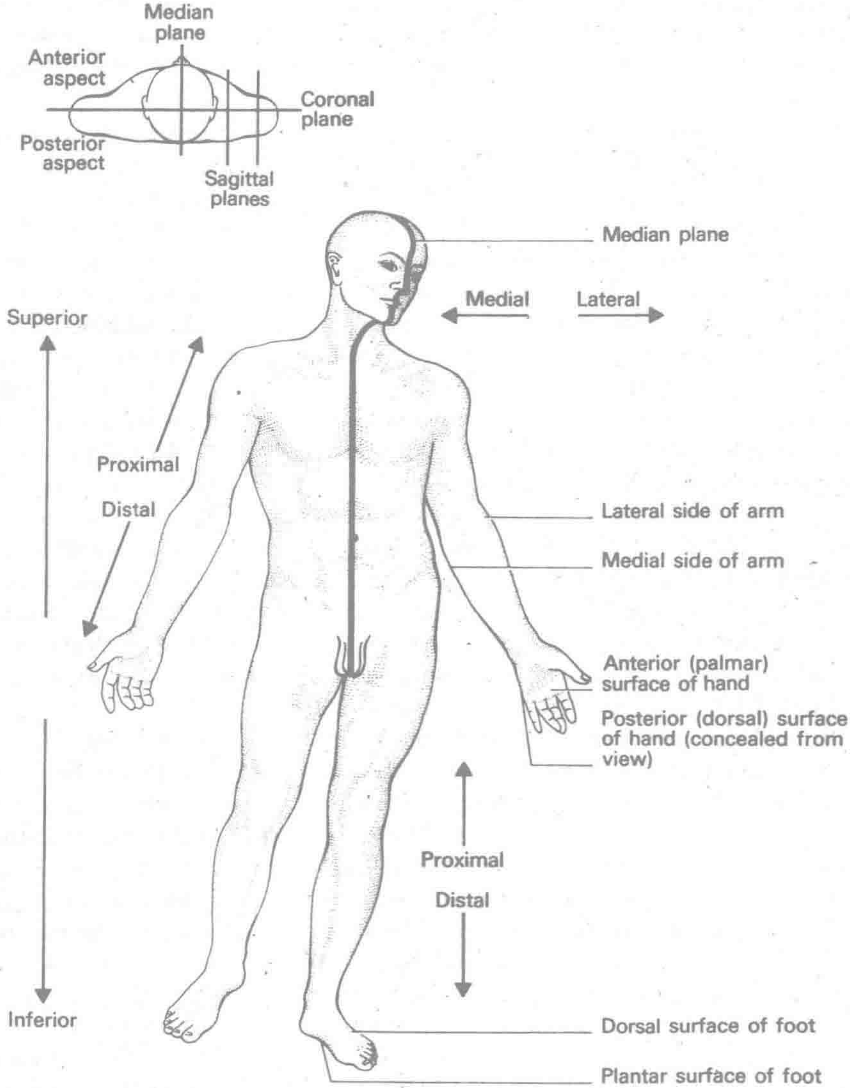

Fig. 1.1. Some of the most commonly used descriptive terms.

book, but since anatomy is basically a descriptive study you will find it helpful to read these chapters in conjunction with a practical study of the living body and of the dried bones. In this way you should try to obtain a mental picture of the structures which lie under the skin so that you will be able easily to understand what you can feel in patients in whom the structures may be abnormal. In order to describe these structures, however, it will be necessary to use a standard terminology and to refer to their position relative to each other and to the body as a whole. In order to do this, the body is imagined to be standing upright with the feet pointing towards the front and the palms of the hand facing forwards—this standard position is known as the *anatomical position* and descriptive terms are always used as though the body were in such a position. Thus the wrist is always said to be 'below' or 'inferior to' the elbow, even though when the arm is held above the head it is above it.

The terms used to describe the positions of structures are shown in Figure 1.1. The anterior surface of the body is that which faces forwards in the anatomical position and is alternatively known as the *ventral* surface. The corresponding surface of the hand is usually called the *palmar* surface. The posterior surface of the body is also known as the *dorsal* surface or *dorsum*. A plane parallel to this is called the *coronal* plane and a plane at right angles to the coronal plane is the *sagittal* plane. A structure which is nearer to the midline of the body than another structure is said to be *medial* to it, while if it is farther away it is *lateral*. Thus, in the anatomical position the thumb is on the lateral side of the hand and the big toe is on the medial side of the foot. Distance from the root or origin of a structure is indicated by the terms *proximal* and *distal*, proximal meaning nearer to and distal meaning farther away from. Hence the wrist is distal to the elbow and a hair has its root at the proximal end. The terms *superficial to* and *deep to* are often used in referring to the relative position of structures and these are particularly useful in describing regions such as the sole (or plantar surface) of the foot which is normally examined upside down. Thus, it is tempting to say that, in this region, the muscles lie beneath the skin whereas in the anatomical position they are actually above it—confusion may thus be avoided by saying that they are *deep to* the skin.

Terms which are used to indicate movements are shown in Figure 1.2. Bringing together two ventral surfaces is known as *flexion* (as in bending the elbow) and movement in the opposite direction is *extension*. Bringing a structure nearer to the midline is *adduction* (as in lowering the arm to the side) and the opposite movement is *abduction*. In *rotation*, a limb or the trunk is rotated about its long axis—in the case of the limbs, rotation may be defined as *medial* or *lateral*. A special form of rotation takes place in the forearm, where the radius, carrying the hand with it, rotates around the ulna. This type of rotation in which the palm of the hand is turned to face backwards is called *pronation*, while the opposite movement is called *supination*—thus the forearm is supinated in the anatomical position. A special type of movement also occurs in the foot. Turning the foot so that the sole is directed medially is known as *inversion*, the opposite movement being *eversion*. In the case of the hip and shoulder and at certain other joints, a compound movement occurs which is known as *circumduction*. In this movement the limb describes a cone whose apex is at the joint; circumduction at the shoulder joint may be demonstrated by drawing a circle on the blackboard while the elbow is kept extended.

A comparison of the upper and lower limbs may, at first, be puzzling when these terms are used. The big toe and the thumb are obviously comparable and yet the big toe is medial and the thumb lateral. Similarly, one would expect the back of the knee region to correspond to the front of the elbow. These apparent contradictions may be understood by reference to the intra-uterine development of the limbs. In the fetus, at an early stage of development, the palms of the hands and the soles of the feet both face medially so that the thumb and the big toe occupy a corresponding position; they are said to lie at the *pre-axial* border of the limb—i.e. the border nearest to the head end of the fetus. Similarly the dorsal surfaces of the hand and of the foot face in the same

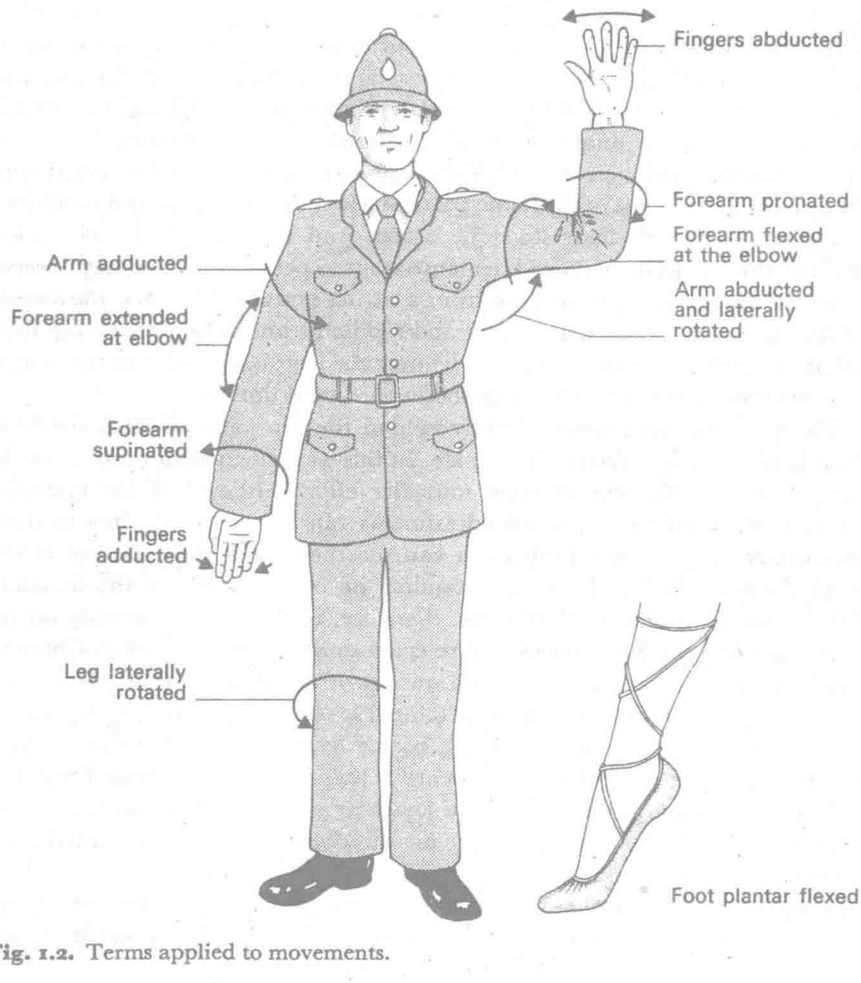

Fig. 1.2. Terms applied to movements.

direction, as do the knee and the elbow. Bringing the ventral (palmar) surface of the hand nearer to the ventral surface of the forearm is flexion and bringing the sole of the foot nearer to the calf of the leg is also flexion. During development the upper and lower limbs rotate in opposite directions so that the thumb becomes lateral and the big toe medial, but flexion at the ankle joint, by definition, is still a movement of straightening the foot on the leg (Fig. 1.2). Flexion does not therefore necessarily mean 'bending'. Confusion can be avoided by using the terms *plantarflexion* (or true flexion) and *dorsiflexion* (extension). Once this explanation is understood you will see why the muscles on the calf of the leg and on the front of the forearm are flexors; you will also find it easier to understand the distribution of dermatomes (p. 87).

If you have studied zoology you may find these terms confusing, after being accustomed to describing quadrupeds, in which the head is at the anterior end of the body rather than at the upper end. Another feature of the biped which you will need to think about is the position of the centre of gravity. This is not important in quadrupeds since the centre of gravity normally lies well within the quadrangle formed by the four feet; but in man, a perpendicular dropped from the centre of gravity (the *line of gravity*) must fall between the two feet for a position of stable equilibrium to be maintained. If the weight is mainly taken on one foot, as usually occurs in a relaxed standing position, the line of gravity must pass through the weight-bearing foot and this calls for adjustment of the position of the rest of the body, particularly the pelvis, spine and shoulders. This principle is well understood by artists, and a study of Michelangelo's David or the Venus de Milo will demonstrate it to perfection. You may observe it yourself whenever you stand up from a sitting position—the first movement to take place is not extension of knee and hip joints but flexion at the hip joint so that the centre of gravity comes to lie over the feet; only then can the weight be transferred to the feet so that the body can stand upright.

The line of gravity passes slightly behind the hip joint, towards the front of the knee and just in front of the ankle. In this way the upright posture can be maintained with the minimum of muscular effort, although if the muscular system is observed closely, small adjustments can be seen from time to time, particularly in the lower limb. You can see these even more clearly if you watch the leg muscles of someone standing on one leg. One of the functions of the lower limb and trunk muscles, therefore, is to balance the body on the lower limb and this function will be referred to from time to time in Chapters 5 and 11. The head too, is balanced on top of the spine so that only a very slight muscular contraction is needed to hold it steady—the effect of relaxation of these muscles can be seen during a boring lecture, when heads are seen to drop forward suddenly before being wearily hauled back to the upright position.

Finally, you must realise that the anatomy and physiology which will be described in the book refers only to the most frequently encountered individuals. It is well known that no two persons have identical fingerprints and a brief examination will reveal that the pattern of veins on the back of the hand varies from individual to individual. Similar variations occur in the more important structures in the body so that it is not uncommon, for example, to find an extra rib attached to the last cervical vertebra, a sciatic nerve which divides in the pelvis rather than behind the knee and a biceps muscle with three heads instead of two. Similarly, the 'normal' blood pressure is very difficult to define since it varies within such wide limits, and the state of muscle tone (p. 106) may vary enormously so that one person may be 'droopy' with poor posture and another alert and upright. The more important and common of these variations will be described in this book but you must be prepared to meet many other variations, and at times you will find it difficult to decide whether a particular feature is normal or diseased. Similar variations will be met in psychological as well as in physical make-up; and whereas one patient will refer to a pain as 'excruciating' another patient with a similar condition may merely admit to it 'hurting a bit'.

INTRODUCTION TO PHYSIOLOGY

In the preceding section, the 'normal' blood pressure was used as an example to discuss the importance of normal biological variation, an extremely important concept which you must understand thoroughly. We can also discuss the subject of blood pressure in this section in order to show some of the ways in which physiologists think about the functions of the body. The pressure which the blood exerts on the walls of its containing vessels is important in any consideration of the circulation of the blood and of its adequate distribution to all parts of the body. The physiology of blood and of the circulatory system is concerned with a study of these phenomena and the ways in which they are adjusted to fulfil precisely the requirements of the body in all circumstances. Such a study will involve understanding the composition of the blood, the origin of its various components and how their formation is regulated to maintain optimal amounts of each of them within the circulation. We shall need to study the functions of the components of the blood. Then we must study the nature of the heart and its beating which maintain the circulation of the blood and how the beat is regulated so as to ensure that output from the heart at all times balances the return of blood to it from the veins. The 'blood pressure', by which we mean the pressure in the distributing arteries, must be studied in its various aspects. What factors affect blood pressure? These include output from the heart, elasticity of arteries, viscosity of blood, the body's position and the rate at which blood can 'run off' from the arteries into the small vessels in the tissues. These studies must be clearly distinguished from those concerning the regulation or control of arterial blood pressure.

Virtually all physiological functions, as well as growth and all structural development, are regulated so that they perform optimally for the body's needs. It is usually possible to look at a regulatory process from the point of view of the purpose to be served. Since the brain controls so many of the body's activities and since it is the first part of the body to be affected by a fall in blood pressure, we can say: 'The blood pressure *is regulated so as to ensure* an adequate supply of blood to the brain.' We can take this a stage further. The principal regulatory mechanism for arterial blood pressure is the alteration of the resistance to flow of blood from arteries to the tissues. This is achieved by altering the calibre of the muscular branches of the smallest arteries (*arterioles*) in response to nerve impulses reaching them from the brain. Our purposive statement can now read, 'The blood pressure is regulated, so as to ensure an adequate supply of blood to the brain, *by nerve impulses which cause alterations in arteriolar resistance elsewhere in the body*. But this statement is still incomplete. It fails to tell us the final vital link in the whole picture. How does the nervous system know the blood supply to the brain or the blood pressure are not correctly adjusted? Signals must reach it to inform it that the pressure is incorrect. In this instance it is the level of blood pressure itself that is the source of the signals. In the walls of some arteries (aorta and carotid arteries) are pressure detectors (*baroreceptors*) that signal the pressure level. If this rises the receptors produce more impulses. If it falls they produce fewer. It is these impulses, varying with changes in pressure, that then change the output of nerve impulses to the arterioles. This change will always be such that the alteration in blood pressure is reversed. *Thus a fall in blood pressure* (such as that produced by a blood donation, about 0.5 litres) *causes reduced signalling from the baroreceptors. This causes an increase in the number of nerve impulses to arterioles. This causes an increase in resistance to flow of blood from the arteries and thus a rise again in the arterial blood pressure towards normal so that the perfusion of the brain with blood is adequately maintained.*

This whole description is one example of what physiologists call *homeostatic control* or *homeostasis*, which means 'maintaining a constant state'. Here a change in blood pressure is detected by the baroreceptors and these bring about changes in the nervous system and its control of blood flow to tissues that reverse the changes in blood pressure. Engineers refer to such regulatory processes as *negative feedback loop controls*. This expression reminds us of two related phenomena that form part of all control systems. The first is that alterations in the aspect of the system being studied (in this instance, the pressure of blood in the arteries) themselves bring about the responses that affect the alterations. The second is that at some stage in the loop (here it is the nerve impulses to the arterioles) an activity is negatively affected by the alteration that the control loop regulates.

Homeostatic control systems are purely automatic, in that they are 'built in' to the body, just as thermostats (consisting of a temperature detector and a switch) are built into domestic electric water heaters. The functions of detecting a change and of producing the response that reverses the change are constant features of such control systems. It is always possible, and much to be preferred, then, to replace a purely purposive description of a change in function by a cause–effect one. This describes a change as a response (the effect) caused by some sort of receptor being stimulated and this stimulus (the cause), directly or indirectly, produces the change.

This cause–effect description of events does not only cover homeostatic mechanisms which maintain the constancy of state of a living body, but it must also be used when change of state leads to changes in some physiological function. Let us take another example. When muscles contract, they transform chemical energy into kinetic energy and a limb, it may be, moves. The ultimate source of the chemical energy comes from the oxidation of materials obtained from the blood, the oxygen itself also coming from the blood. One might use a purposive form of explanation. 'Blood flow in exercising muscle increases *so that the muscle may receive* the increased oxygen, etc., that it needs.' But such a statement tells us nothing about the mechanism involved. The correct cause–effect description would be: 'The exercising muscle *liberates materials which act on arterioles* and cause them to relax. *More blood can then flow into the muscle capillaries* and increase the oxygen, etc. supplied to the muscle.' Although in this example the identity of the materials released by exercising muscle which act on the arterioles is not known for certain, the statement of cause and effect is far more precise than the purposive statement. It tells us what mechanism causes the blood flow increase and leads us to the point of further research and perhaps to a rational understanding of disease processes and their treatment.

Such cause–effect processes, whether concerned with homeostasis or not, are found throughout the body whenever any function is being started, maintained at a constant level, or stopped. Attention has recently been directed to intracellular control processes, both of the manufacture of proteins (p. 13) and of many of a cells's chemical activities. In the study of the function of organs and systems of the whole body, physiologists continually study the cause–effect links between events. Where these links use the nervous system as the mediating pathway we call them *reflexes*. The control of growth and development of the body's structures must also be largely dependent upon similar cause–effect processes for its full description. Finally, all disease states, by disturbing normal function, will set off trains of cause–effect changes which must be described and understood before the disease process itself can be accurately defined and treatment logically planned.

2 · The Structure and Function of Living Cells

INTRODUCTION

Since the human body is entirely composed of cells and of extracellular material which is produced by cells, it is logical to begin a study of the body by describing the structure of an individual cell. This can be done by using as an example one of the unicellular plants or animals which are capable of maintaining an independent existence, such as the Amoeba or the yeast cell and, indeed, such cells are often used for basic research. It would be more realistic, however, in this account, to describe a typical mammalian cell, even though many of the components are very similar to those found in plants and lower animals. It is rather difficult to select a 'typical cell' since all the cells of the body are specialised in structure in order to carry out their particular function: this specialisation occurs during development of the body and the process is known as *differentiation*. Thus, the fertilised ovum, which is less than 150 micrometres (μm) in diameter, must be capable of giving rise to cells as different in appearance as nerve cells, muscle cells and connective tissue cells. This it does by repeated divisions and as division occurs the daughter cells become more and more differentiated and less and less able to give rise to cells of other types. Development of the human body therefore involves two processes: *differentiation* (mostly occurring in the first two months of gestation) and *growth*, which involves the division of cells to give rise to more cells of the same type. In general it may be said that the more specialised a cell becomes, the less able it is to change into other forms of cell, or in some cases, even to reproduce itself. Thus, as will be described in Chapter 3, some cells of connective tissue remain undifferentiated and can therefore, when the occasion demands, divide to give rise to specialised cells of various types. To go to the other extreme, nerve cells are so highly specialised that they cannot divide to replace other nerve cells that have been affected by disease or injury so that destruction of a part of the brain or spinal cord leaves permanent damage. (It is very important to understand, however, that nerve cell *processes* outside the brain and spinal cord can regenerate as long as the cell body is not affected—see Chapter 8.)

THE STRUCTURE OF CELLS

LIGHT MICROSCOPY

This began in the 17th century and was the only method of examination available until relatively recently. The most important advances were made in the 19th century when the technique of cutting thin sections was developed, and