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The Physiological Basis of Physiotherapy

Baillière Tindall

THE PHYSIOLOGICAL BASIS OF PHYSIOTHERAPY

and other professions related to medicine

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Preface

This is a textbook of applied physiology, relating normal human physiology to the disorders of function responsible for the commoner diseases encountered in the practice of medicine and allied professions. Particular attention has been devoted to the applied physiology of nerve, muscle, connective tissues, bones and joints, and the respiratory and nervous systems, disorders of which account for a large proportion of the work of physiotherapists. The book is based on the course in physiology at the University of Cape Town for students studying for a university degree in physiotherapy, occupational therapy or nursing; it is similar to the course attended by students of medicine and science, who are, however, expected to know more about the experimental evidence for physiological beliefs and less, at this stage, about their clinical relevance.

Since it is assumed that the reader is attending or has attended a course in human anatomy, the gross structure of the organs of the human body and their relations are not described in detail but such details of microscopic structure are given as are essential to an understanding of function. These include some of the intimate details of cell structure revealed by electron microscopy. The biochemical content of the book is the minimum required for an understanding of normal physiology and the commoner pathological conditions described, but, because of its clinical importance, lays some stress on acid–base balance.

The book is intentionally dogmatic in its approach. Since its purpose is not to train professional physiologists but to prepare students for the practice of physiotherapy, the experimental evidence for the statements made is omitted; this is readily available in larger textbooks to the student who wishes to study the subject in greater depth. The emphasis in this book is on explaining common medical and surgical conditions in terms of disorder of normal function.

The book has been prepared in close collaboration with the Departments of Physiotherapy, Occupational Therapy, and Nursing Tuition of the University of Cape Town. The author wishes to record his gratitude to the staff of these departments, to the physicians and surgeons of the Groote Schuur Hospital, and to the staff of his own department for constructive criticism of the book at every stage of its preparation.

The author wishes to thank also Miss Jeannie Walker, Mrs Beatrice Bramwell and Miss Rosemary Page, who drew the illustrations; Mrs Rose Marie Estment, Mrs Maureen Oosthuizen and Mrs Claire Meyer, who typed the manuscript; Mr Frank Kennedy for graphs and photographs; and Mrs Jean Sloan for help with proof-reading and for preparing the index. Messrs Edward Arnold kindly gave permission for the use of Figs 11.5, 26.3, 26.5, 26.6 and 26.7 from the author's textbook, *Physiology for Students and Teachers of Physical Education*. Other acknowledgements are made in the text where appropriate.

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GENERAL PRINCIPLES OF PHYSIOLOGY

INTRODUCTION

The study of living creatures (*biology*) is conveniently divided into the study of their structure (*morphology*) and the study of their functions (*physiology*). This book deals with human physiology, and it is assumed that its readers are also studying human morphology (*anatomy*), but it includes the essentials of microscopic anatomy (*histology*) because some knowledge of the detailed structure of the various parts of the body is essential to an understanding of how they work.

For students of physiotherapy and the other healing professions it is not sufficient to understand only the normal function of the human body, although this is more interesting than the derangements which occur in disease; the commoner aberrations of function which occur in particular diseases must also be understood so that treatment may be rational and effective. Furthermore the exaggeration or failure of particular functions in disease often provides useful information about the normal activity. For these reasons the emphasis of this book is on applied physiology, and the abnormalities of function associated with the commoner diseases of each system are described.

In this introductory chapter some general physiological principles are introduced, which are essential to an understanding of the function of the systems described in later chapters. These include the storage and utilization of energy in the body, some physical principles involved in the passage of fluids through membranes, hydrogen ion concentration, and the regulation of physiological functions. The pattern of the two great regulating systems, to be described in detail later in the book, is briefly outlined.

ENERGY EXCHANGE

Living creatures, like other physical systems, cannot create or destroy energy; they can only convert it from one form to another. The activities associated with life require energy, which is derived from the oxidation of food material. The rapid oxidation which we call combustion results in rapid production of heat. If this were to take place inside a cell the temperature would soon rise sufficiently to kill it; this is avoided by the oxidative processes in the cell taking place more slowly and in stages. The total amount of energy released is the same but it is released in small amounts and much of it is stored, instead of being immediately dissipated as heat.

Energy from the oxidation of food material is used to convert adenosine diphosphate (*ADP*) to adenosine triphosphate (*ATP*). The linkage of the third phosphate group requires a considerable amount of energy, which is released when ATP breaks down to ADP. This occurs whenever energy is required for vital activities and more ATP is formed whenever the energy for its synthesis is available.

Although much of the energy released by the breakdown of ATP is in the form of heat, a proportion of it is transformed into other forms of chemical energy in the synthesis of the organic structure of the body, into electrical energy for some of the processes which depend on electric charges, or into mechanical energy for movements. Chemical energy may be converted to an equivalent amount of any other form of energy and it is convenient to measure all forms in terms of one.*

* The unit of energy, work, and quantity of heat in the international metric system (Système International, 'SI') is the joule (J). The joule is the work done when the point of application of a force of 1 Newton is displaced through a distance of 1 metre in the direction of the force. Rate of work (power) is measured in watts (W). 1 W = 1 J/sec (Appendix I).

The traditional unit of energy and work used in human physiology is a unit of heat (kilocalorie, kcal). The kilocalorie is the amount of heat required to raise the temperature of 1 kilogram of water 1 degree Celsius; it is still convenient to use the kilocalorie in measurements which involve heat. 1 kcal = 4187 J.

BODY FLUIDS

Water is the principal constituent of the body. It accounts for about 72% of the mass of the cells and about 99% of the mass of the fluid which fills the spaces between the cells. The body fluids inside and outside the cells are dilute solutions of electrolytes in water.* In dilute solutions the electrolytes are almost completely dissociated into ions.

Diffusion

Molecules in a gas or in solution are moving randomly in all directions and tend to become evenly dispersed. This involves net movement of molecules from regions of higher concentration to regions of lower concentration. Uniform dispersion will still take place if the region of higher concentration is separated from the region of lower concentration by a membrane through which all the molecules can pass freely. If, however, one solution is separated from another by a membrane through which only water can pass freely (*semipermeable membrane*) or through which only water and some of the substances in solution can pass (*selectively permeable membrane*), water molecules will pass into the solution of higher concentration (*osmosis*).

Osmosis

The cell wall is a selectively permeable membrane, so the composition of the body fluids is an important factor in the passage of water through the cell wall.

Osmosis may be demonstrated *in vitro* by separating a solution

* Although the concentration of the substances dissolved in the body fluids can be expressed simply in terms of mass per unit volume (mg/100 ml) chemists prefer to express it in moles (gram-molecules) per litre. Concentrations in the body fluids are more conveniently expressed in millimoles per litre (mmol/litre).

To convert mg/100 ml to mmol/litre the concentration in mg/100 ml is divided by the atomic or molecular mass and multiplied by 10 (to convert mass/100 ml to mass/litre), e.g.

$$Na^+ = 335 \text{ mg/100 ml}$$
$$= \frac{335 \times 10}{23}$$
$$= 145 \text{ mmol/litre.}$$

of glucose from pure water by a membrane of cellophane which permits the passage of water but not of molecules of glucose (Fig. 1.1). Water immediately starts to pass through the membrane into the glucose solution and continues to do so until some opposing force, such as gravity, balances the osmotic attraction of the glucose. The pressure which exactly balances the attractive force of the glucose is the *osmotic pressure*. Since there are two types of molecule (water and glucose) bombarding the membrane on one side and only one (water) on the other side, and only the molecules of water are small enough to pass through the pores of the membrane, there is a net passage of water into the solution of glucose until the opposing force is sufficient to drive the same number of molecules of water in the opposite direction.

The osmotic pressure of a solution depends on the number of

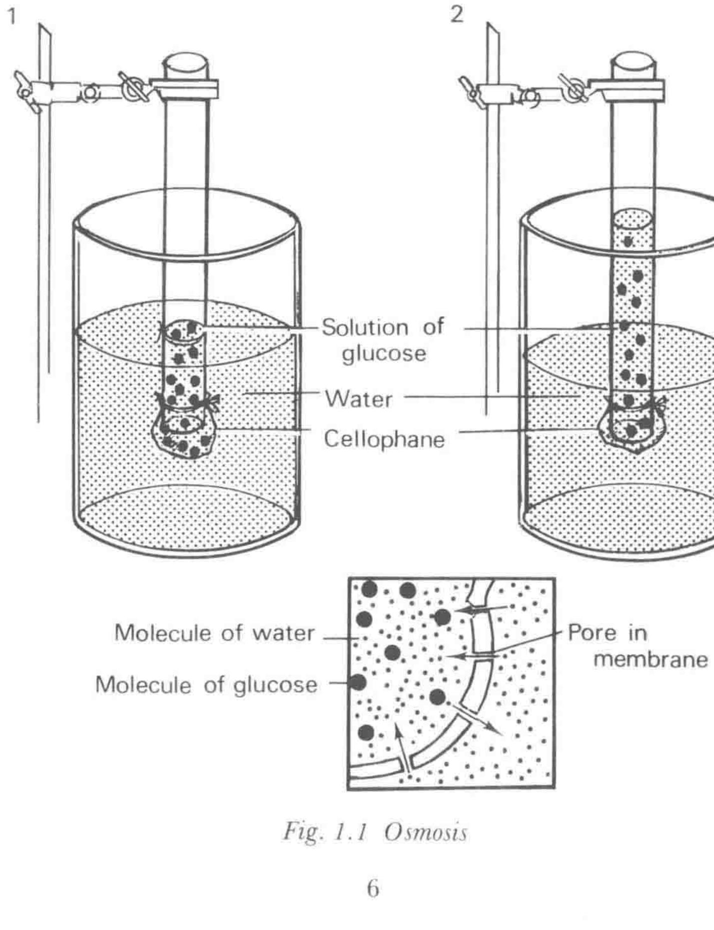

Fig. 1.1 Osmosis

particles in solution, so a given mass of large molecules (e.g. protein) exerts less osmotic pressure than the same mass of smaller molecules (e.g. glucose). Electrolytes exert a very high osmotic pressure in relation to their mass because they are small molecules, dissociated in solution into ions, each of which exerts its own osmotic pressure.

COLLOID OSMOTIC PRESSURE

Normally the osmotic pressure inside the cells is the same as that outside the cells. The osmotic pressure exerted by the electrolytes in both cases is very high (about 5900 mmHg) but a small fraction of the osmotic pressure exerted by the cell contents is due to large molecules of protein (*colloids*) which cannot pass out through the cell membrane.

Since the concentration of electrolytes is the same in blood plasma as in tissue fluids and the blood plasma has a much higher protein content the plasma attracts fluid through the walls of the smallest blood vessels from the surrounding tissues. The colloid osmotic pressure of the plasma is only about 25 mm Hg, although the concentration of plasma proteins is about 7 g/100 ml, because the protein molecules are very large.

DIALYSIS

If a solution containing an electrolyte and a colloid is separated from pure water by a membrane permeable to the electrolyte but not to the colloid, water passes by osmosis into the solution and the electrolyte diffuses out. If the water is constantly renewed, the smaller molecules may be withdrawn almost completely from the solution (dialysis).

pH

One constituent of the body fluids, the concentration of which must be kept within clearly defined limits for normal body function, is hydrogen ions. Water is normally split to a very slight extent into hydrogen ions and hydroxyl ions.

$$H_2O \rightleftharpoons H^+ + OH^-$$

In pure water the splitting yields one ten-millionth of a gram (10^{-7} g) of hydrogen ions per litre of water and the equivalent amount of hydroxyl ions (17×10^{-7} g). Since the concentration of hydrogen ions $[H^+]$ and of hydroxyl ion $[OH^-]$ is the same the reaction is neutral.

In any aqueous solution the product of the concentration of hydrogen and of hydroxyl ions $[H^+][OH^-]$ remains constant at 10^{-14} M*. If acid is added $[H^+]$ rises above 10^{-7} M and $[OH^-]$ falls correspondingly. For instance if $[H^+]$ rises to 10^{-6} M $[OH^-]$ falls to 10^{-8} M. Similarly if alkali is added $[OH^-]$ is increased and $[H^+]$ correspondingly diminished.

It is convenient to express the degree of acidity or alkalinity of a solution in pH units. *pH is the negative logarithm to the base 10 of the concentration of hydrogen ions.* pH 7 thus represents $[H^+]$ of 10^{-7} M, which is a neutral solution; a pH below 7 is acid and above 7 is alkaline. Since pH is a logarithmic unit a change of one pH unit represents a ten-fold change in $[H^+]$.

REGULATION OF BODY FUNCTIONS

The life of a cell and of the whole animal depends on very precise coordination of its numerous activities. Minor disorders of any of the activities cause disease and any major disorder leads to death.

The regulating systems

In a multicellular animal the activities of individual cells must be directed to the needs of the animal as a whole. In higher animals, where particular functions are performed by particular systems, the activities of these systems must be coordinated. Both coordination within the body and appropriate response to external stimuli are regulated by the two great controlling systems, *nervous* and *endocrine*, each of which influences the activity of the other. In general, rapid response to sudden changes is achieved by the nervous system and gradual adaptation to prolonged change by the endocrine system.

Nervous system

The nervous system in man comprises the brain and spinal cord (*central nervous system*) and the nerves which connect the brain and spinal cord to all the organs of the body (*peripheral nerves*). Sensory nerve fibres in the peripheral nerves convey information to the central nervous system about the state of the

* M = molar. A molar solution of any substance contains 1 mole (gram-molecule) per litre of solution.