Basic Biology Course

11 Hormones

BASIC BIOLOGY COURSE
UNIT 4
COMMUNICATION BETWEEN CELLS

BOOK 11

Hormones

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Foreword

This book, with the brief title *Hormones*, complements *Nerves and Muscle*, the previous book in the Basic Biology Course, since together they provide a framework for understanding how communication is achieved between cells. Yet in a way the title belies the fact that the text deals with much broader issues of homeostasis, namely the ways in which an organism regulates its activities and bodily functions to maintain a relatively stable internal physiological state, despite variations in the environment.

The subject of chemical communication is a vast one, and to attempt complete coverage of the subject within a single book in a self-instructional format would be impossible. We have chosen, therefore, to confine the topic to five examples from mammalian physiology and to pursue these examples in some depth. We hope that you will find the case study approach intellectually stimulating and challenging, so that at the end of the book you will be able to apply many of the principles of homeostatic control raised in these selected studies to some situations which are unfamiliar to you.

Brighton, Sussex

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M.R. Eraut

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Contents

Introduction

Discussion

In the previous book of this unit (Book 10, *Nerves and Muscle*) you were presented with the flow diagram in fig. 1 to show how an organism like man can respond to changes in both his internal and external environments. This ability to maintain a 'steady-state' condition is referred to as HOMEOSTASIS. Both the nervous system and the hormonal system cooperate in providing homeostatic control, as shown below.

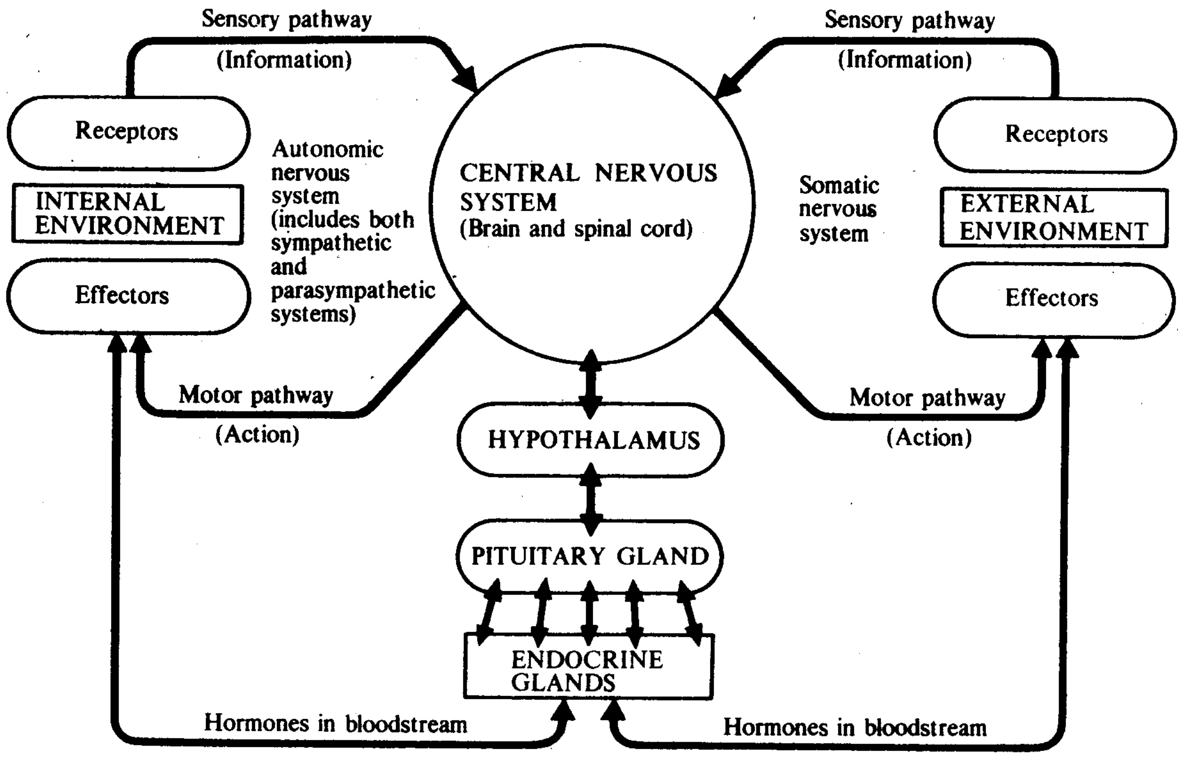

Fig. 1

The first half of Book 10 was concerned with the structure of neurons, particularly the properties of their cell membranes, and how messages are conducted by neurons as a result of the transient changes in the membrane's permeability to Na^+ ions.

In this book we concentrate on the other aspect of communication between cells, namely CHEMICAL COMMUNICATION. You may be wondering why there is a need for both a nervous system and a chemical system of communication (via the cir ulatory system), especially as the nervous system is extremely quick and efficient in carrying messages between various parts of the body. The answer is that they have complementary roles. Whereas the nervous system has the advantage of speed, specificity and transience, the endocrine (hormonal) system is slow, usually generalized in its action, and persistent. Although hormonal stimulation may be relatively short term (minutes), it is often much longer, ranging from days to months or even years.

However, the subject of chemical communication is a vast one. Consequently we have decided to select five examples from mammalian systems and discuss them in some depth, rather than attempt a wide, and perhaps rather superficial, coverage of the whole subject area. Indeed we have found that the case study approach is intellectually more satisfying to the student.

The major areas chosen for study include: (i) control of digestive secretions; (ii) control of blood sugar levels; (iii) control of water and electrolyte balance; and (iv) control of reproductive cycles. In all cases there is a need to provide a brief anatomical background to each situation and this we have done by using colour slides in conjunction with the text.

We begin the first case study, however, by examining the cardiovascular (blood) system, because it is this system that is primarily responsible for carrying chemical messages between cells.

Preknowledge requirements

Considerable knowledge from previous books in this series is assumed as follows:

(i) the fine structure of cells as interpreted from electron micrographs (Book 2, *Electron Microscopy and Cell Structure*);

(ii) the structure and function of cell membranes including the principles of diffusion, osmosis and active transport (Book 5, *Cell Membranes*);

(iii) a knowledge of the structure of proteins, their synthesis and their role as enzymes (Book 7, *Enzymes*, and Book 9, *Protein Synthesis*);

(iv) a general understanding of metabolic pathways as given in Book 8, *Metabolism and Mitochondria*;

(v) an outline knowledge of the organization and structure of the nervous system and the way in which nerve impulses are conducted between cells (Book 10, *Nerves and Muscle*).

Objectives

At the end of this book you should be able to:

(1) Define the terms homeostasis, endocrine gland, exocrine gland, hormone, autacoid, neurohumor, positive and negative feedback control.

(2) Describe in outline how blood is circulated by the mammalian heart and the importance of the circulatory system in facilitating communication by hormones.

(3) Describe the interrelationship between the endocrine system and the nervous system in achieving homeostasis, particularly the important roles played by the hypothalamus and pituitary.

(4) Describe in outline any of the five specific examples illustrated in the case studies showing how the endocrine system and the nervous system interact in homeostasis.

(5) Give examples of:

  (*a*) hormones which act synergistically in inducing a physiological effect;

  (*b*) hormones which act antagonistically in inducing a physiological effect.

(6) Present evidence to support hypotheses concerning the possible mechanism of hormone action at the cellular level.

(7) Interpret graphical, tabulated and micrograph data related to homeostatic control processes.
(8) Apply the principles of homeostasis learnt in the five case studies to other physiological systems in mammals which are unfamiliar.

Instructions on working through programmed text

The book is arranged into five case studies, each programmed into questions and answers arranged sequentially down the page. You are provided with a masking card with which you should cover each page in turn and then move the masking card down to reveal two thin lines

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This marks the end of the first question on that page. Record your answer to the question in a notebook under the section heading or case study. Then *check* your answer with the answer given. If your answer is correct, move the masking card down the page to the next double line, and so on. If any of your answers are incorrect, retrace your steps and try to find out why you answered incorrectly. If you are still unable to understand the point of a given question, make a note of it and consult your tutor. The single thick line

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is a demarcation between one frame and the next. 'Summaries' and 'Intermissions' in the book are convenient stopping and starting points, since it is unlikely that you will have time to read through the whole book in one session. Always read the appropriate summary again before going on to a new section. Additional stopping points are marked by thick double lines.

Case Study 1 Chemical communication and the cardiovascular system

Background and definition of terms

1 It has been known for many centuries that if the testes (the male reproductive organs producing sperm) are removed from sexually mature cockerels, the comb and wattles of the normal cockerel (see fig. 1*a*) gradually shrink in size and lose their turgidity and bright colouring. The castrated animal is referred to as a capon (see fig. 1*b*). There is also a corresponding behavioural change whereby the normally aggressive behaviour towards other males is lost.

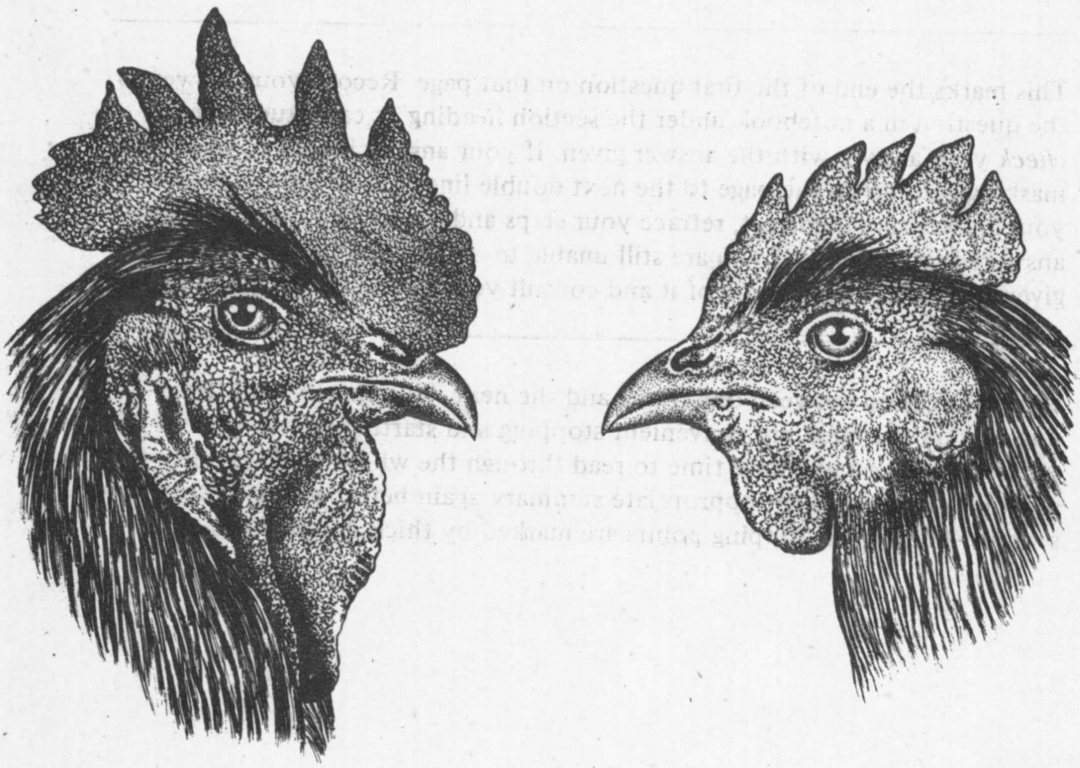

Fig. 1. (*a*) A normal cockerel. (*b*) A castrated cockerel or capon.

Bearing in mind (i) the subject matter of this book, and (ii) the fact that the testes are located anatomically some considerable distance from the comb and wattles of the bird, propose a hypothesis to explain the observations outlined above.

The testes produce an active substance which circulates in the blood. This substance in turn promotes the development of the highly coloured comb and wattles of the cockerel as well as influencing the cockerel's aggressive behaviour.

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2 In fact this hypothesis was advanced as long ago as 1849 by the physiologist Berthold, who decided to carry out experiments to test its validity.
How would you test the validity of the hypothesis?

There are several alternatives which you may have thought of:
(*a*) transplant testes from normal cockerels into capons (i.e. castrated cockerels);
(*b*) inject extracts of the testes into the bloodstream of capons;
(*c*) try to isolate and identify the active constituent from the testes which produces the secondary male sexual characters, and inject this into the bloodstream of capons.

When any one of these experiments is carried out the normal comb and wattles are soon restored.

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3 In the particular case outlined above, the active constituent is a 'male'-inducing hormone called ANDROGEN. A relatively pure form of this hormone was first isolated from the testes of bulls by McGee in 1927. Gradually more became known about its chemical structure so that today pure crystalline androgens can be synthesized whose effects, even in microgram doses, are extremely potent. What is perhaps even more significant is that since this basic discovery about chemical communication, research into hormones in general has proliferated enormously. Indeed today, as a result of amino acid sequencing and X-ray crystallographic techniques, biochemists now know the three-dimensional molecular structure of several important hormones of relatively high molecular weight, such as insulin and glucagon (see Case Study 3); and have considerable insight into their mode of action on cells.
Hormones are produced in various glands, known as ENDOCRINE or ductless glands because they secrete their products directly into the bloodstream. The endocrine glands, which are richly supplied with blood, appear to be distributed rather randomly throughout the body, as can be seen in fig. 2, which shows their approximate location in the human body.
The word HORMONE (literally an 'excitable substance'), was first introduced by Starling in 1905; but since certain hormones have an inhibitory function some authors subsequently have preferred the term AUTACOID (meaning 'from the body'), to include all types of chemical communication, whether local or general in their effect throughout the body. Even this term, however, has not proved entirely satisfactory, because neurophysiologists use the term NEUROHUMOR when referring to chemical substances released by special neurosecretory cells in the brain.
With these points in mind, let us briefly examine the circulatory or cardiovascular system, because it is this system which provides most of the important access routes for chemical communication between cells.

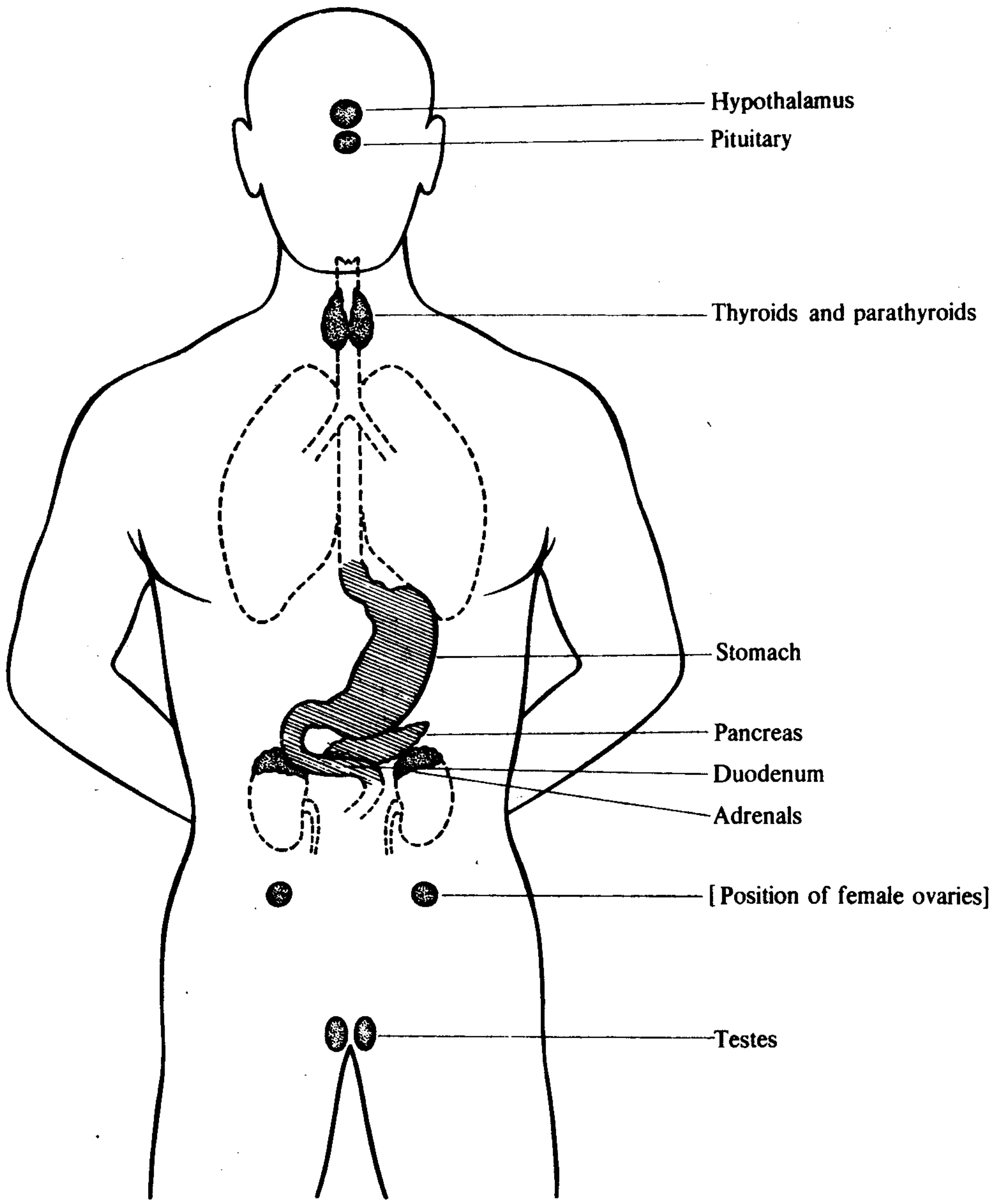

Fig. 2. The positions of the endocrine glands in man.

The organization of the cardiovascular system

4 In fig. 3 you see a photograph of a plastic replica of the arterial blood system in a buman baby. In what general ways is it
(*a*) similar to, and
(*b*) different from
the nervous system in its arrangement?

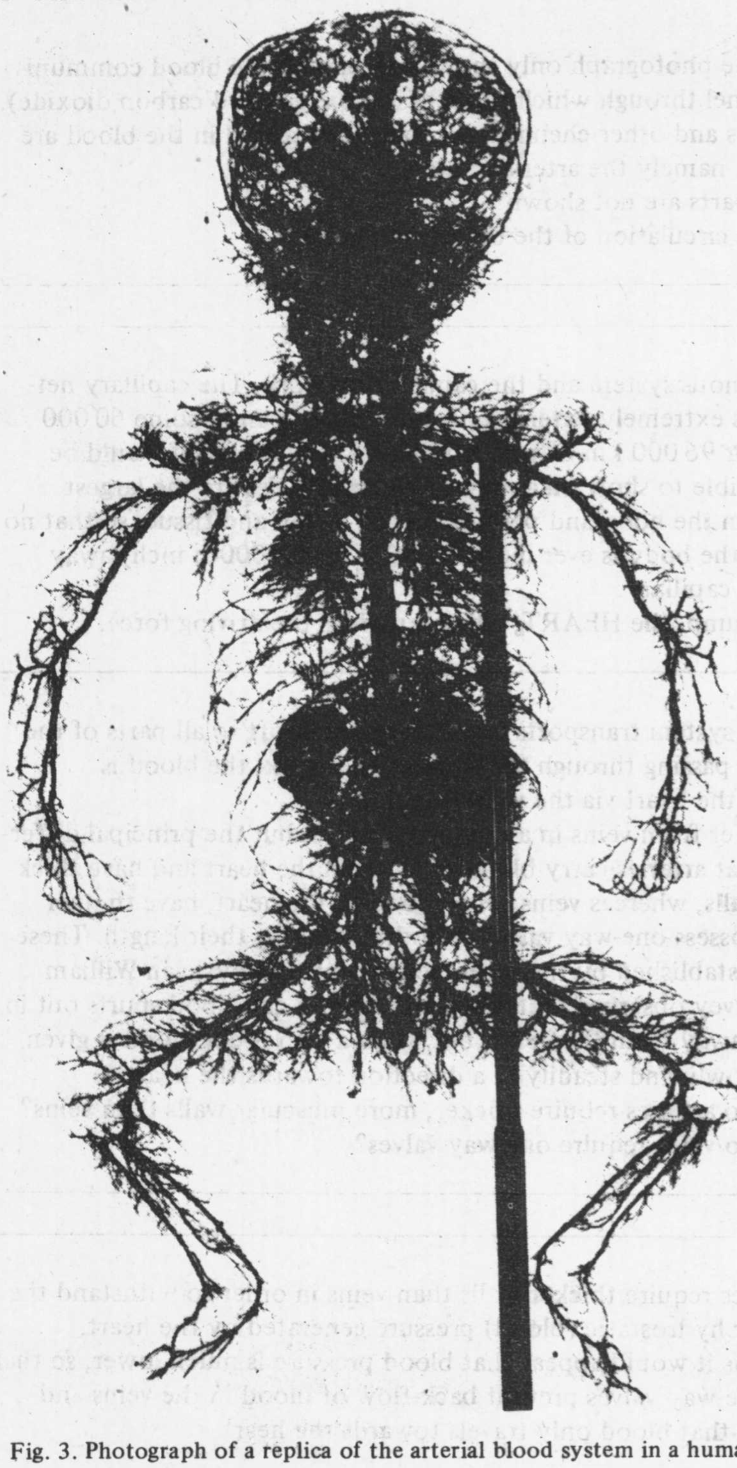

Fig. 3. Photograph of a replica of the arterial blood system in a human baby.

(*a*) It extends over the whole of the body.

(*b*) The network is extensive but more 'irregular' in appearance than the central nervous system. In contrast to the spinal cord, for example, which is straight, giving off regular pairs of nerves between each of the spinal vertebrae, the main artery (the aorta) is not straight and there are much denser 'patches' of blood vessels which correspond with some of the major organs in the body, e.g. heart, lungs, alimentary tract (gut), kidneys and brain.

5 However, the photograph only shows one part of the blood communication channel through which food, gases (oxygen and carbon dioxide), glucose, salts and other chemical substances dissolved in the blood are transported, namely the arterial system.

(i) What parts are not shown?

(ii) How is circulation of the blood maintained?

(i) The venous system and the capillary network. The capillary network is extremely extensive, comprised in man of some 60 000 miles or 96 000 km of very tiny blood vessels, which would be impossible to show on a model. The capillaries are the largest organ in the body and permeate every organ and tissue, so that no cell in the body is ever more than 25μm (1/1000th inch) away from a capillary.

(ii) By a pump, the HEART, which provides the driving force.

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6 The arterial system transports blood from the heart to all parts of the body. After passing through the capillary network, the blood is returned to the heart via the venous system.
Arteries differ from veins in a number of ways, but the principal differences are that arteries carry blood away from the heart and have thick muscular walls, whereas veins carry blood to the heart, have thinner walls and possess one-way valves periodically along their length. These facts were established by the seventeenth-century physician William Harvey. Harvey observed that when an artery is cut blood spurts out in a direction away from the heart, but when a vein is cut blood is given out more slowly and steadily in a direction towards the heart.

(i) Why do arteries require thicker, more muscular walls than veins?

(ii) Why do veins require one-way valves?

(i) Arteries require thicker walls than veins in order to withstand the greater hydrostatic (blood) pressure generated by the heart.

(ii) In veins it would appear that blood pressure is much lower, so that the one-way valves prevent back-flow of blood in the veins and ensure that blood only travels towards the heart.

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1 THE CARDIOVASCULAR SYSTEM

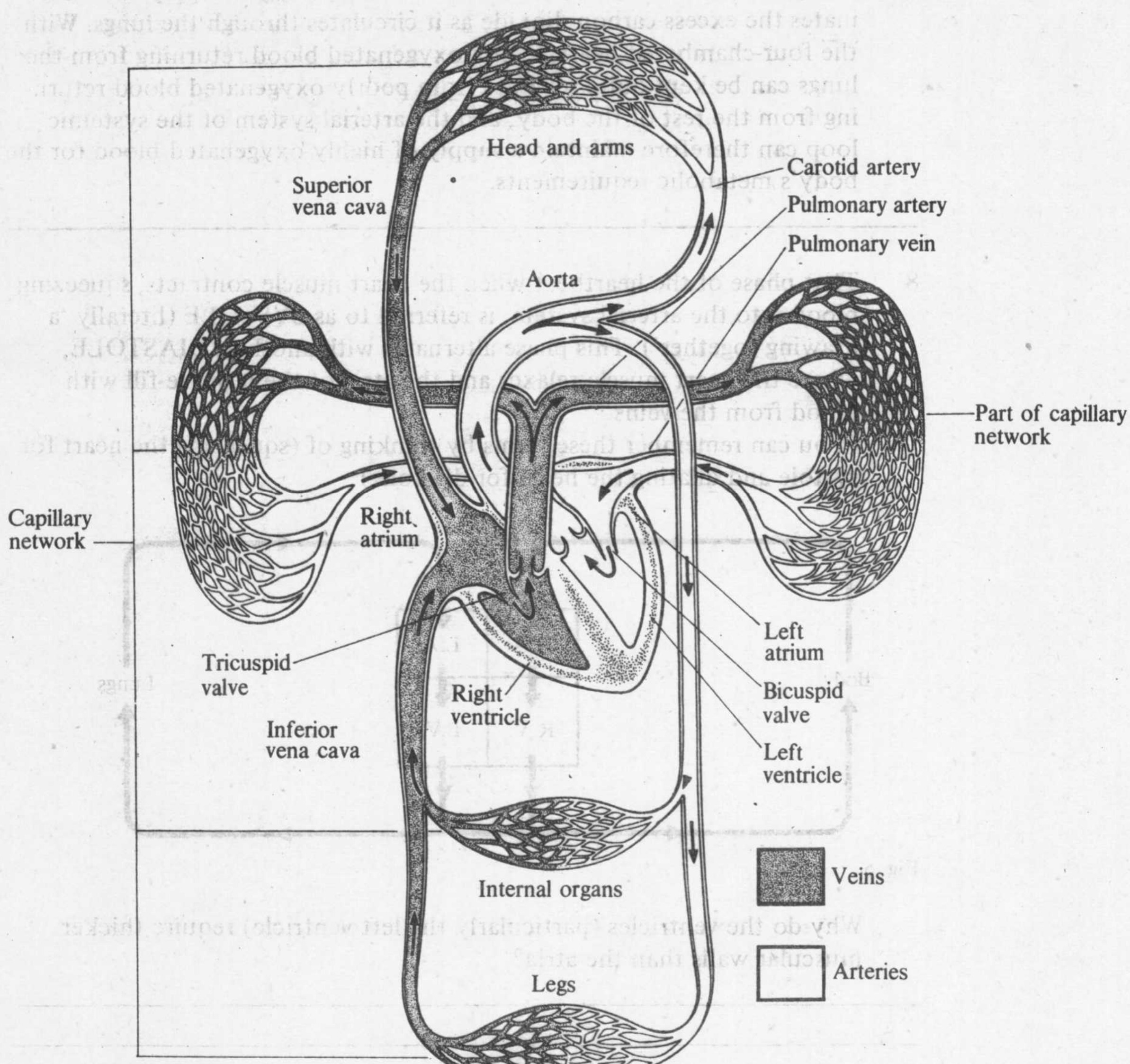

Fig. 4. A diagrammatic representation of the cardiovascular system in man. The tricuspid and bicuspid valves control blood flow between the atria and ventricles on the right and left sides respectively.

7 The heart is essentially a strong muscular pump. In mammals it is divided into four chambers. Two of these chambers, the ATRIA, have comparatively thin muscular walls, whereas the other two chambers, the VENTRICLES, have thick muscular walls.
The four-chambered heart enables a 'figure of 8' or double circulation to be maintained. One loop, the pulmonary loop, takes blood to and from the lungs; the other loop, the systemic loop, circulates blood to and from the body. Not all animals have a four-chambered heart, yet it is regarded as one of the successful evolutionary features of birds and mammals. Why?

The pulmonary 'loop' replenishes the blood's oxygen supply and eliminates the excess carbon dioxide as it circulates through the lungs. With the four-chambered heart, highly oxygenated blood returning from the lungs can be kept quite separate from poorly oxygenated blood returning from the rest of the body, and the arterial system of the systemic loop can therefore maintain a supply of highly oxygenated blood for the body's metabolic requirements.

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8 That phase of the heartbeat when the heart muscle contracts, squeezing blood into the arterial system, is referred to as SYSTOLE (literally 'a drawing together'). This phase alternates with another, DIASTOLE, where the heart muscle relaxes and the atria of the heart re-fill with blood from the veins.
(You can remember these terms by thinking of (squeezing the heart for systole and dilating the heart for diastole.)

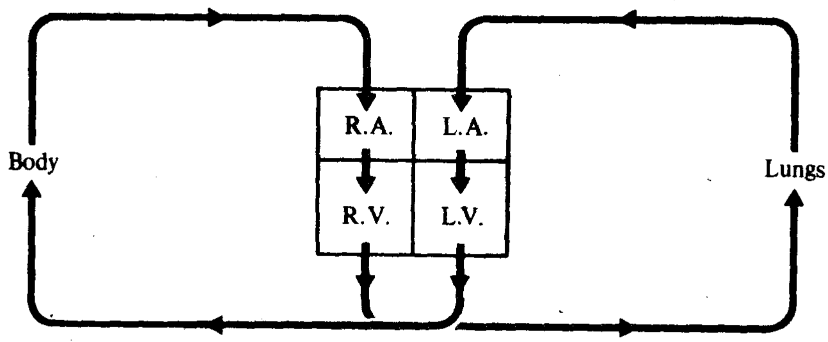

Fig. 5

Why do the ventricles (particularly the left ventricle) require thicker muscular walls than the atria?

To generate sufficient hydrostatic pressure or force to pump blood through the arterial and capillary systems
(The atria have only to receive blood and pump it into the ventricles.)

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9 The heart is a remarkable organ. It begins beating very early on in the life of the embryo, and in man continues pumping, on average, at 70 beats per minute for 70 years (or over 2.5×10^{10} times during an average lifespan). During this time the heart is constantly called upon to make adjustments in its energy production, and the rate may be very high during periods of prolonged or strenuous exercise when the heartbeat may reach 160–200 beats per minute. Such activity expends considerable amounts of energy and demands a highly adapted, reliable and durable structure.
What features in the electron micrograph of rat cardiac muscle shown in fig. 6 provide evidence of this astonishing activity?

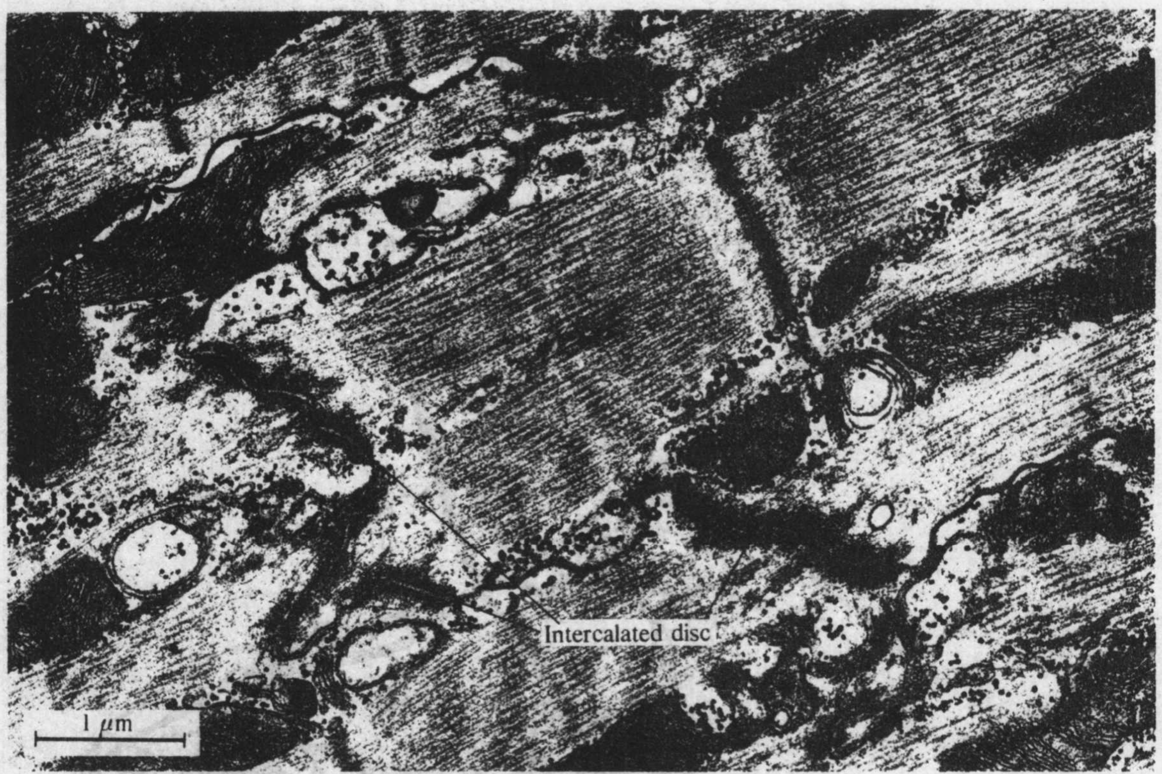

Fig. 6. An electron micrograph of rat cardiac muscle.

(*a*) The large and numerous mitochondria with closely packed cristae, pointing to the importance of oxidative phosphorylation and energy production.

(*b*) The presence of numerous glycogen granules and lipid droplets, acting as potential fuel supplies for oxidative phosphorylation.

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10 You will notice also regular intercalated discs (see Glossary) marking the point of contact between two entirely separate cardiac muscle cells, each with its own nucleus. Suggest two basic functions that are performed by the discs.

(i) They provide a strong mechanical link between cells, preventing their separation during contraction as well as providing anchorage points (note they always occur at the level of the Z-lines) for the contracting myofibrils of each cell. This is most important in providing motive force in prolonged alternating contraction–relaxation cycles.

(ii) The discs allow the communication between cells that is essential for facilitating the transmission of surface excitation.
