Basic Biology Course

10 Nerves and Muscle

BASIC BIOLOGY COURSE
UNIT 4
COMMUNICATION BETWEEN CELLS

BOOK 10

Nerves and Muscle

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University of Sussex

ERRATA

TRIBE BASIC BIOLOGY BK 10

p 144 Fig 25(e) For 1 Sarcomere read 2 Sarcomeres.
On the Labelling, for M read Z. The scale for the A-band changes accordingly.

p 145 Line 9 For A-band read H-band.
p 150 The positions of the tables in frame 66 and 67 should be reversed.
p 164 Last line. For 50-60 nm read 5-6 nm.

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Foreword

The tenth book in this series examines a major aspect of communication between cells; namely, how nerve impulses bring about co-ordination and control of muscular movements. In this respect, it forms a unit with Book 11 which, in its turn, deals with communication by hormones.

In both books, we have of necessity had to be very selective with the examples chosen in these extremely complex and yet rapidly expanding fields of biological research. Nevertheless, by exploring a few aspects in some depth, we have endeavoured to provide a sound conceptual basis for an understanding of the main anatomical structures and physiological processes going on within living organisms, with particular emphasis on vertebrate systems. To achieve this understanding we have concentrated on the presentation of ideas by a questioning approach, so that you, the student, have the opportunity to make observations on structures, to perceive the problems, and analyse some of the experimental data, that have challenged scientists over the last two centuries.

Brighton, Sussex, 1976

M.A. Tribe
M.R. Eraut

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In particular we would like to thank:
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Mr J. Fulthorpe, Muscular Dystrophy Research Unit, Newcastle General Hospital (Part I, fig. 27(*a*))
Dr A.R. Lieberman, Dept of Anatomy and Embryology, University College, London (Part I, figs. 18(*a*), 19 and 54; slides 1 and 12)
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Dr M. Stacey and Professor D. Barker, Zoology Dept, University of Durham (slides 27 and 28)
Mrs S. Webb, School of Biological Sciences, University of Sussex (Part II, fig. 22)

Contents

Introduction

Preknowledge requirements

This book assumes a knowledge of cell and membrane structure; diffusion; osmosis; and active transport as outlined in Books 2 and 5 of this series (*Electron Microscopy and Cell Structure* and *Cell Membranes*). It also assumes a basic understanding of Ohm's Law, such as would be required for the Ordinary Level General Certificate of Education in Physics.

Objectives

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

(1) Briefly describe the structure of motor and sensory neurons and their organization within the spinal cord.
(2) Describe the nerve pathway involved in a simple reflex action.
(3) Give a general description of the organization of the vertebrate nervous system with respect to:
   (*a*) functions involving voluntary and involuntary responses;
   (*b*) structure and position in the body.
(4) Show evidence of understanding how chemical and electrical gradients across cell membranes can lead to the establishment of a potential difference across the membrane.
(5) Analyse and correctly interpret oscilloscope recordings showing generator potentials, action potentials, excitatory and inhibitory post-synaptic potentials (EPSPs and IPSPs) and end plate potentials in nerves and muscle.
(6) Present evidence to show that a nerve action potential is an all-or-none event.
(7) Present evidence to show how the resting membrane potential is restored after an action potential.
(8) Explain how, as a result of (6) and (7) above, the nerve message is coded to produce varying responses in effector organs.
(9) Present evidence which favours a diffusion process and chemical excitation at synapses and motor end plates.
(10) Describe the structure of muscle, especially vertebrate skeletal muscle.
(11) Present evidence to support the sliding filament hypothesis of muscle contraction.
(12) Present evidence to show how the contractile mechanism is put into action as a result of an action potential in the muscle cell membrane.
(13) Predict and correctly interpret the effects of Ca^{2+}, Mg^{2+} and ATP on both glycerinated muscle fibres and fresh muscle.
(14) Correctly interpret data concerned with isometric or isotonic contraction of muscle.
(15) Explain how the mechanism of transmission of a nerve impulse and activation of muscle fibres is brought about by:
   (*a*) a series of *long-term*, slow reactions which prepare the pathway of conduction and the region of contraction by using energy from cellular respiration to lower the entropy of these regions, thus producing a store of potential energy ready to be used in nerve and muscle activity;

(*b*) the triggering, by a stimulus, of a series of *short-term* events which proceed in sequence along this pathway, deriving their energy from a small part of the store built up by the long-term processes and resulting in response of the effector organ.

Instructions on working through the book

The first section of the book is an illustrated descriptive account of the organization of the mammalian nervous system. You are merely required to read this section and refer back to it when necessary.

The remainder of the book is programmed, with questions and answers arranged sequentially down the page. You are provided with a masking card and a student response booklet. Cover each page in turn, and 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 your response booklet. Then *check* your answer with the answer given. If your answer is essentially correct, move the masking card down 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 the question, make a note of it and consult your tutor. The single thick line

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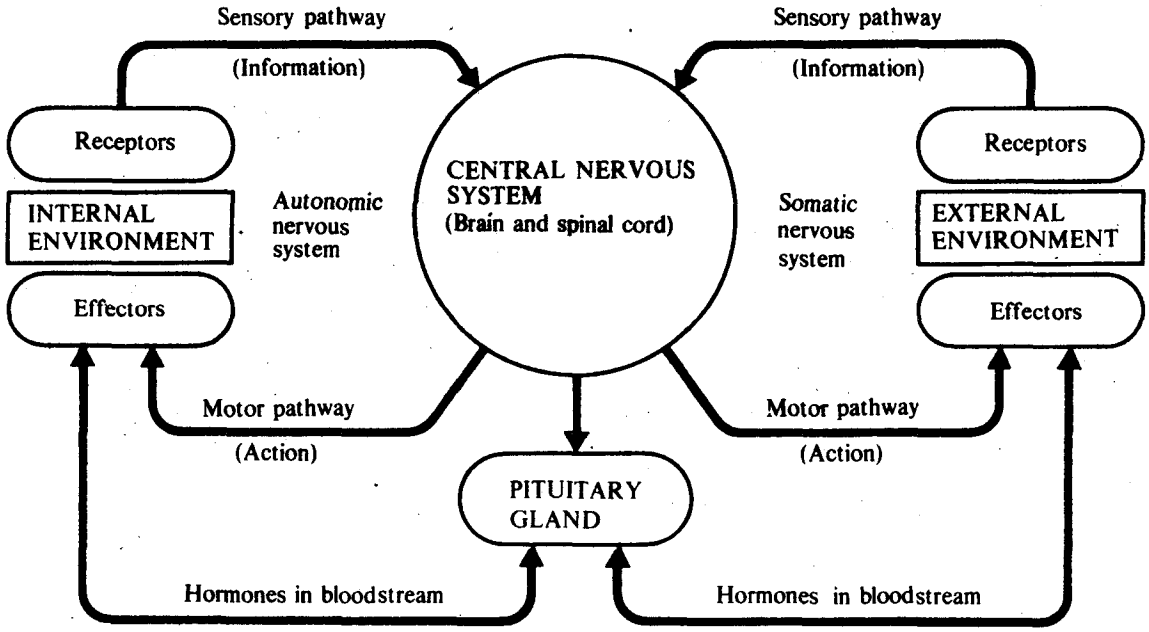
is a demarcation between one frame and the next. Occasionally you will find some frames without a question. Some of these will be 'Intermissions' or 'Summaries'; they are convenient stopping and starting points in the programme, since it is unlikely that you will have time to read through the whole book in one session. Always read the appropriate Intermission or Summary before going on to a new section. Additional stopping points are marked by thick double lines.

Part I Nerves

Introduction

It is an advantage for any organism to be able to monitor and act upon changes both in the external environment and in its own internal environment. In both cases receptors are necessary to detect the changes and since these changes will be of different kinds they will require different receptors. Secondly, if action is to be taken, an effector organ, such as a muscle or hormonal gland, will need to be stimulated into activity. Co-ordination of all these activities is best achieved through a centralized control system which can monitor all the activities going on and make decisions about the actions necessary. The situation in mammals is summarized below:



Nerve cells or NEURONS of different types are the major means by which rapid communication is effected and indeed by which information is interpreted, sorted and stored (memory). Communication is also possible by hormones (chemical messengers transported in the bloodstream). Hormone action is, however, slower, producing a more generalized and longer-lasting effect; and this aspect of communication and control is dealt with in Book 11 (*Hormones*).

The main purpose of this book is to examine the structure of some neurons, especially those involved in sensory and motor pathways which lead to and from the central nervous system. The book gives special attention to the mechanisms by which neurons conduct rapid signals, but since we are concerned primarily with principles rather than detail, we have not attempted to delve deeply into the different functions of the somatic and autonomic nervous systems. Instead we have concentrated on pathways in the somatic peripheral and central nervous systems to illustrate our theme.

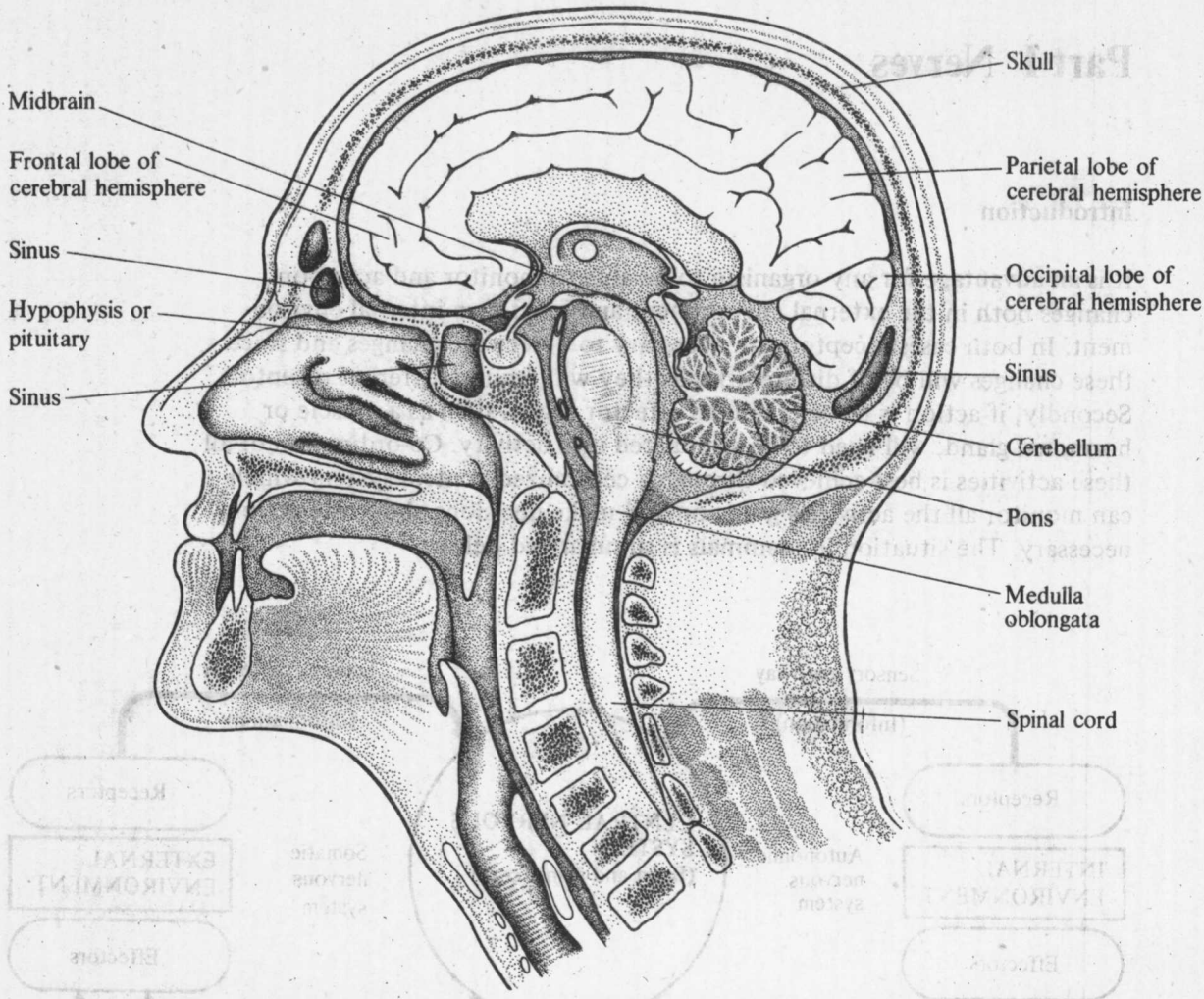
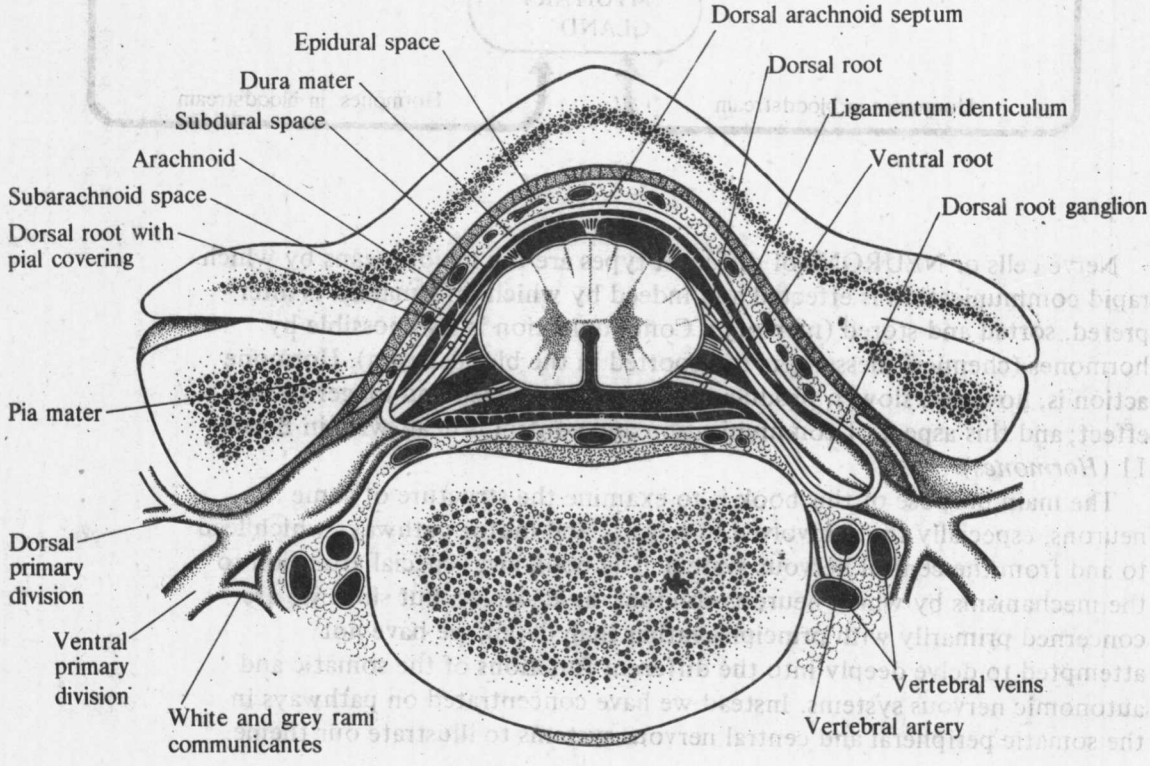


Fig. 1. Median sagittal section of the head showing the relation of the brain to the cranium. The spheroid bone is shown in transparency, and through it the terminal lobe may be seen.

Fig. 2. Cross-section of the spinal cord in the spinal canal showing its meningeal coverings and the manner of exit of the spinal nerves.



The basic structure and organization of the mammalian nervous system

Before moving on to the programmed sections of the book, we need to spend just a little time examining the gross organization of the nervous system in order to provide an overall perspective on our theme of communication between cells.

For convenience of description *only*, we can subdivide the nervous system as follows:

The central nervous system
- Brain
- Spinal cord

The peripheral nervous system
- Cranial nerves
- Spinal nerves
- Receptors

The autonomic nervous system
- Sympathetic trunk
- Visceral nerves
- Peripheral ganglia
- Receptors

(Remember, however, that these systems *function as an integrated whole.*)

The components of the CENTRAL NERVOUS SYSTEM (CNS) are housed in the head and spine, where they are protected by the bony skull and the spinal vertebrae respectively. Additional protection is afforded by the MENINGES (protective coverings), lying internal to the bony parts but external to the delicate nervous tissue. Between the nervous tissue and the meninges is to be found a cushioning fluid, the cerebrospinal fluid. Figs. 1 and 2 show respectively a medial cross-section of the head to emphasize the relation between the brain and the skull; and a cross-section of the spinal cord revealing the meningeal coverings and the manner of exit of the spinal nerves between the vertebrae. The brain and the spinal cord both have extensive blood supplies, as can be seen from fig. 3 overpage.

Fig. 4(*a*), (*b*), (*c*) and (*d*) are diagrammatic representations of the human brain. (*a*) is from below (ventral view), (*b*) from above (dorsal view), (*c*) is a median cross-sectional view and (*d*) is a section view at right-angles to (*c*) in the region of the hypothalamus. For the moment don't be unduly worried about the detailed labels and names. The diagrams should be used like a map, familiarity with names and places coming with use!

Closer examination of fig. 4 reveals that the brain consists of three major sections: (i) the *forebrain*, which includes among its important parts the cerebral hemisphere and olfactory bulbs; (ii) the *midbrain*, of which the pituitary, optic tract and thalami (particularly the hypothalamus) are conspicuous; and (iii) the *hindbrain* which includes the pons, cerebellum and medulla oblongata, the medulla oblongata eventually becoming continuous with the spinal cord.

Nerve trunks (comprising parts of many nerve cells, as we shall see later) emerge between the vertebrae, and run from the spinal cord through the two major cavities of the body – the thoracic (chest) and abdominal (gut)

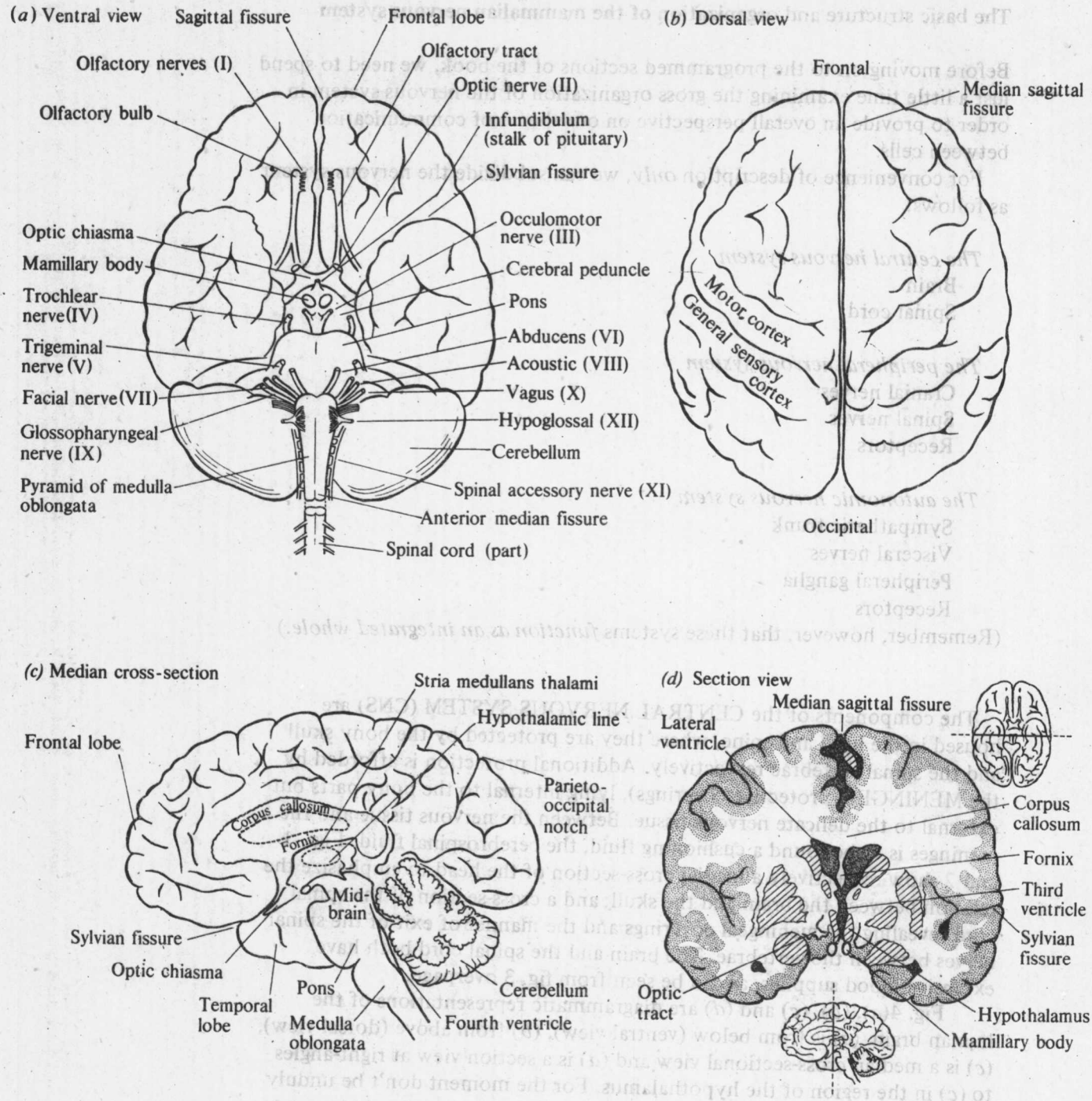


Fig. 4. Diagrammatic representations of the brain. The roman numerals denote the roots of the 12 cranial nerves.

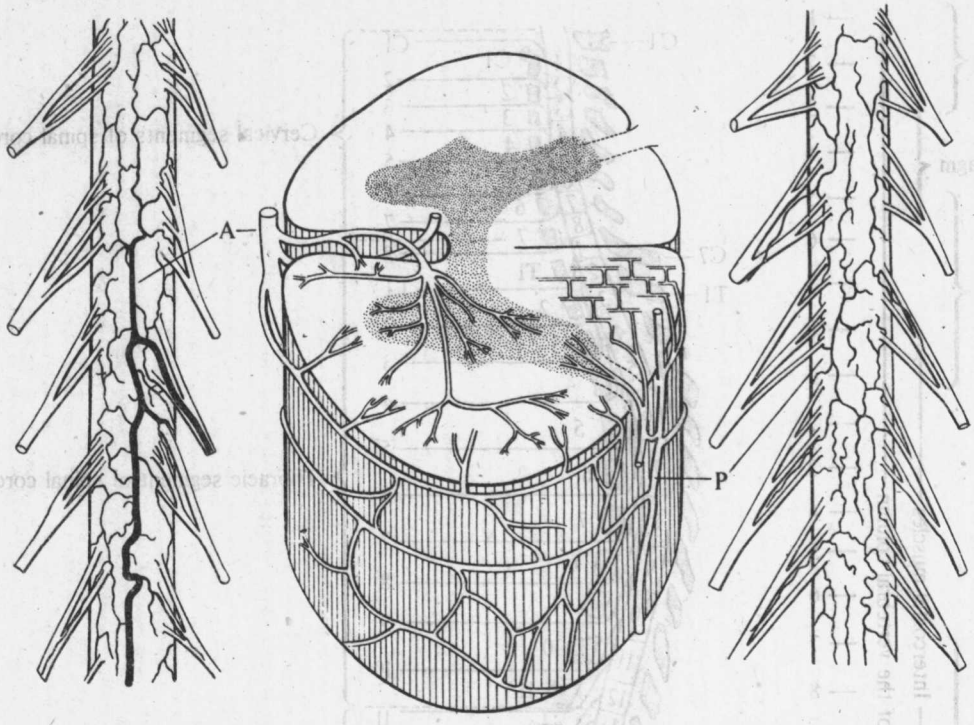


Fig. 3. Arterial supply of the spinal cord. To the left of the central figure is shown an anterior (ventral) view of the low thoracic segments of the spinal cord, and to the right a posterior (dorsal) view, each with arteries injected. The contributing vessels passing to the anterior spinal artery (A) and to the posterior spinal artery (P) along the spinal nerve roots vary markedly in size. In the middle figure the separate branches of the anterior median fissure to the spinal grey matter are shown. (After S.W. Ranson & S.L. Clark. *Anatomy of the Nervous System*, 10th edn. © W.B. Saunders & Co., Philadelphia.)

cavities to: (i) organs lying within these cavities; (ii) the muscles controlling skeletal movements of the body; and (iii) glands at the skin surface.

Some of these aspects are depicted diagrammatically in fig. 5. The diagram also indicates those localities that are served by various segments of the spinal cord with respect to the voluntary actions of the body, such as movement, balance and posture. That part of the nervous system responsible for these activities is called the SOMATIC nervous system.

The origins of the other major component of the peripheral nervous system, the CRANIAL nerves, can be seen if you look back again at fig. 4(*a*). There are 12 pairs of cranial nerves (numbered by roman numerals): some are highly specialized nerve tracts, such as the optic nerves (II), the olfactory tracts (I) and the auditory or acoustic nerves (VIII); others, like the vagus (X) have many branches and innervate a variety of organs.

Continuous with, and inextricable from, these two major subdivisions of the nervous system, is the autonomic nervous system, responsible for innervating and controlling certain muscles, organs and glands on an 'involuntary' basis. There are two components, the PARASYMPATHETIC component and the SYMPATHETIC component, the sympathetic component being 'sandwiched' between the two 'slices' of the parasympathetic component. The situation is depicted diagrammatically in fig. 6, where in general terms you can see that the sympathetic nerves prepare the body for 'emergency' situations, particularly by increasing heart-beat, ventilation of the lungs and secretion of adrenalin; whereas the parasympathetic nervous supply (having its origins in the cranial and sacral ends of the CNS) reverses the effects of

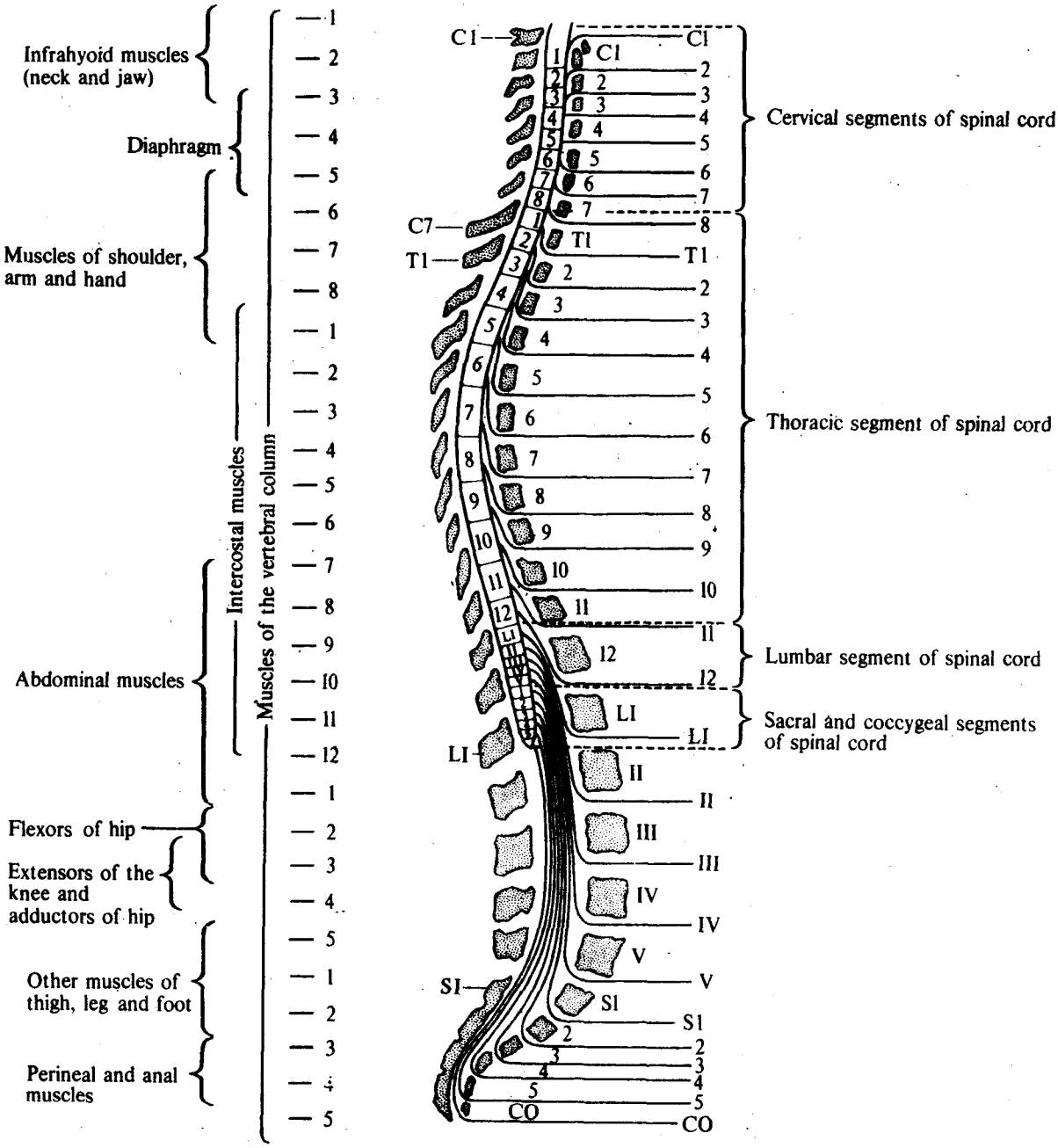


Fig. 5. Diagram showing the level of the various segments of the spinal cord with reference to the vertebrae, with a table showing the distribution of the fibres of the several ventral roots (i.e. the spinal nerve roots corresponding to the various vertebra of the spine). C, cervical; T, thoracic; L, lumbar; S, sacral; CO, coccygeal. (After S.W. Ranson & S.L. Clark. *Anatomy of the Nervous System*, 10th edn. © W.B. Saunders & Co., Philadelphia.)

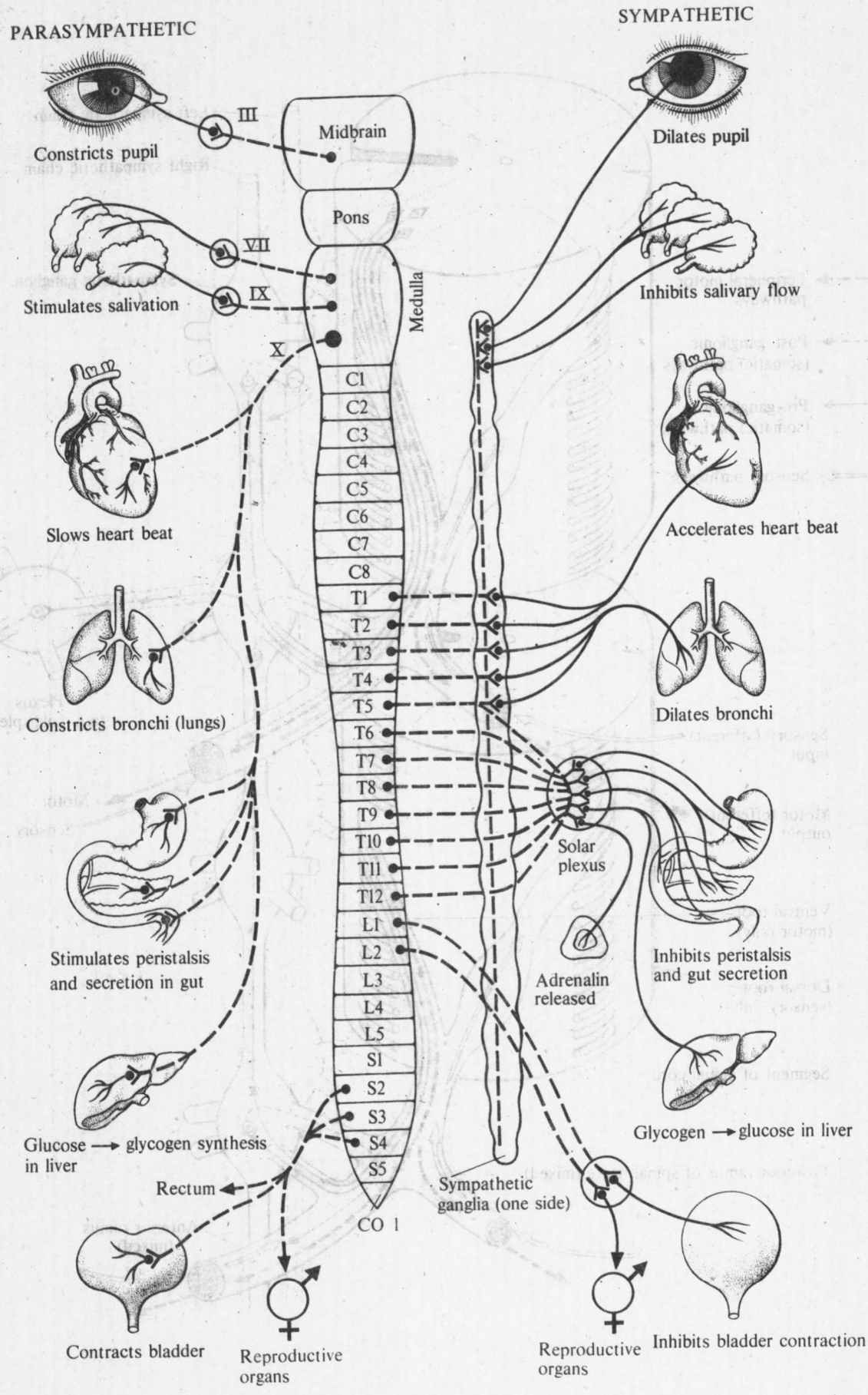


Fig. 6. C, cervical; T, thoracic; L, lumbar; S, sacral; CO, coccygeal.

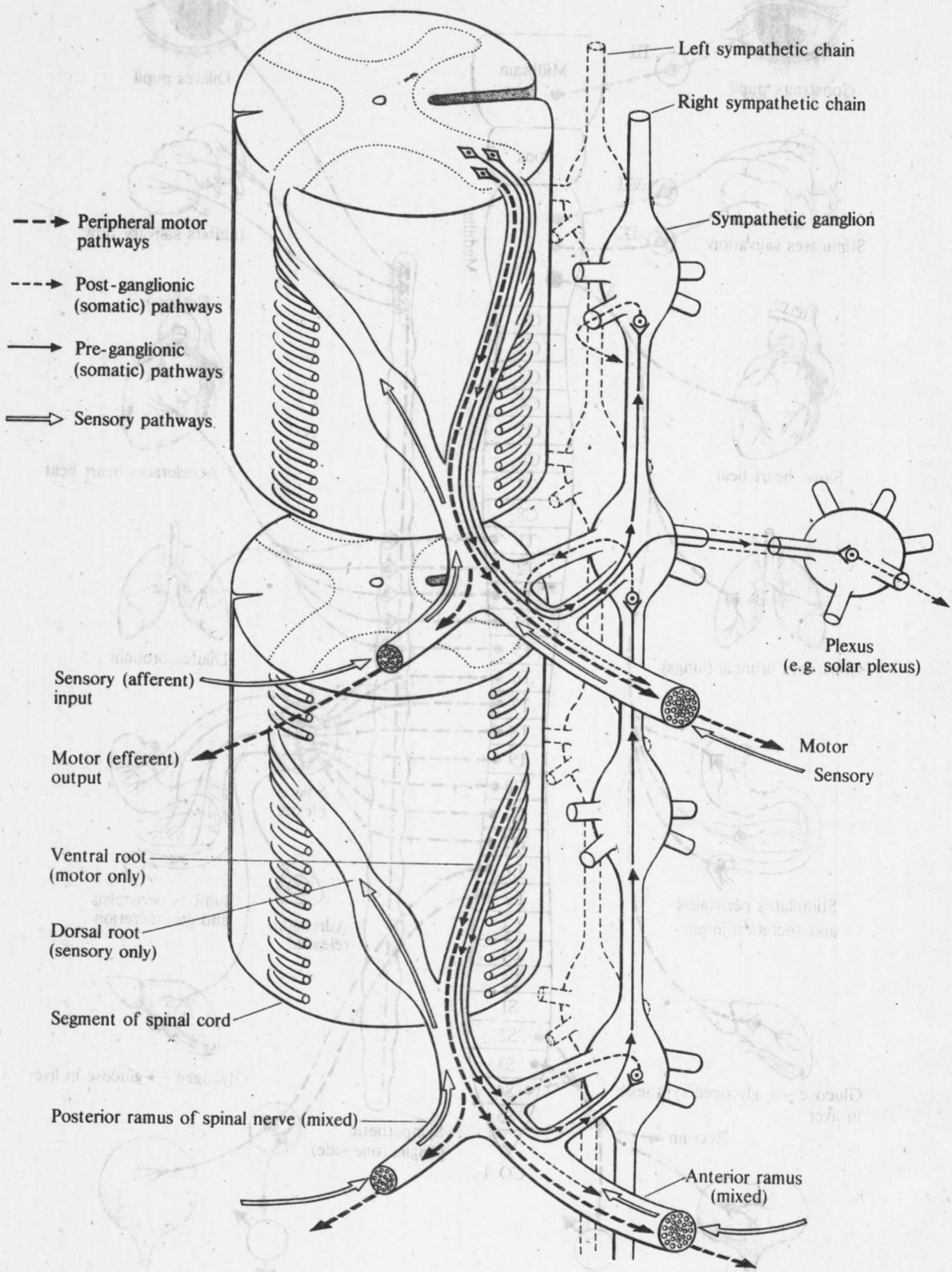


Fig. 7. Diagram to show the relationship between the spinal cord and sympathetic ganglia.

sympathetic stimulation. Pre-ganglionic nerve pathways (i.e. those passing from the CNS and synapsing in ganglia outside it) are shown as dashed lines, post-ganglionic pathways (i.e. those innervating specific organs from ganglia lying outside the CNS) are solid lines.

To avoid cluttering the diagram, some facets of autonomic control are not shown here – you might note, however, that organs like blood vessels, sweat glands and hair follicles in the skin, external genitalia, etc. also have an autonomic nerve supply.

Finally, we should emphasize again that the various subdivisions do function as an integrated unit; and whereas we can delineate the autonomic nervous system, for example, from the peripheral system on the grounds of special ganglia (nerve 'exchange and relay' centres) *outside* as well as inside the CNS, we find ultimately that most nerves which enter (sensory input) and leave (motor output) the CNS are 'mixed' nerves, i.e. they contain pathways associated with both peripheral and autonomic nerve cells. This feature is shown in fig. 7.

We are now in a position to examine more about the details of the nerve cells or neurons that comprise the system. Refer back to this section, whenever you need to, since it has been designed to help your understanding of the organization of the nervous system, but we do not expect you to have grasped all the details at this stage.

This section is programmed so you will require your masking card. You will also need a slide projector and colour slides 1–12.