A TEXT-BOOK OF

NEURO-ANATOMY

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PREFACE TO THE FOURTH EDITION

THE understanding of human behavior, adjustments of the body as a whole or of its parts to factors in its external and its internal environment and the regulation of vital processes through neural mechanisms, like the intelligent diagnosis and localization of neural disturbances, depends on accurate knowledge of the anatomy and physiology of the nervous system. This book is designed to set forth such knowledge in an orderly manner and without too great detail. Its purpose is to provide a comprehensive account of the anatomy of the human nervous system with sufficient physiological data to link structure and function into a dynamic pattern.

In the preparation of the present volume, the author has constantly had in mind the difficulties which the student encounters in his first attempts to gain some knowledge of the anatomy and physiology of the nervous system. The anatomical structure of the human brain and spinal cord is somewhat intricate, but the fundamental plan of structure in the vertebrate nervous system is relatively simple. An attempt has been made throughout this work to correlate anatomical data with the fundamental structural plan of the vertebrate nervous system and to discuss the anatomical structure of the parts of the human nervous system, without unnecessary details, in the light of our present knowledge of phylogenetic, anatomical and physiological relationships.

The material has been arranged with a view to giving the student an adequate concept of the nervous system as a whole early in the course and then to acquaint him with the simpler reflex and correlation mechanisms in the spinal cord and brain stem before taking up the long conduction pathways in their entirety and the higher subcortical and cortical mechanisms. The conduction pathways are studied from the point of view of their specific functions, *i. e.*, every central pathway is considered in its functional relationships to peripheral neurons and to any other central pathways which may be involved in the conduction of impulses to or from the highest center with which the pathway in question is functionally associated. The diencephalon, the corpus striatum and the cerebral cortex are discussed mainly from the viewpoint of their phylogenetic development and anatomical and functional relationships, as indicated by the results of the more recent anatomical, physiological, experimental and clinical studies. The autonomic nervous system is treated in a separate chapter based mainly on Chapters I to VI of the author's book, "The Autonomic Nervous System." An outline for laboratory study is included which is so arranged that it may be used in whole or in part, according to the time available and the aims and purposes of the instructor.

In preparing the fourth edition, the text has been thoroughly revised and parts of it rewritten. New data have been incorporated, but the text has not been materially extended. Many of the illustrations have been replaced by new ones which have been designed with a view to greater clearness and some additional ones have been introduced. Those of the transverse sections of the spinal cord, brain stem and basal ganglia have been worked out in greater detail and more adequately labeled with a view to greater usefulness in connection with the laboratory study of prepared sections.

Recent studies, many of them experimental, afford more complete and accurate accounts of both the anatomical and functional relationships particularly of the diencephalon and the corpus striatum than have been available hitherto. New data regarding the conduction pathways for visceral impulses, particularly the descending pathways, have been obtained. Experimental and clinical studies also afford new data regarding cortical projection areas, the connections of subcortical centers with the cerebral cortex and the importance of some of these centers in the extra-pyramidal projection system. Histological studies of the cerebral cortex also afford new data regarding the arrangement of the cortical neurons, the synaptic connections of afferent fibers within the cortex and the functional relationships of cortical neurons with one another.

The material used in the preparation of this book has been drawn from many sources, including text-books of anatomy and neuro-anatomy, atlases of the nervous system and original papers. Most of the chapters are accompanied by references to the literature, particularly original papers. These lists should not be regarded as complete. They have been included for the convenience of students who may be interested in collateral reading. A list of general references is included at the end of the text.

Most of the illustrations used in the present edition have been especially prepared for this book. Others have been borrowed from various sources. The latter are duly accredited. The author desires hereby to acknowledge the courtesy of all with whose permission illustrations have been used. He also wishes to acknowledge his indebtedness to Dr. Kermit Christensen for reading the manuscript, to Mr. P. A. Conrath for valuable assistance in the preparation of illustrations, to Mr. C. A. Richins for assistance in various ways and to the publishers for their continuous courtesy and coöperation.

A. K.

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NEURO-ANATOMY

CHAPTER I

EVOLUTION AND COMPARATIVE ANATOMY OF THE NERVOUS SYSTEM

General Considerations.—Successful living on the part of either plants or animals involves constant and adequate adjustment to external and internal factors; consequently, the ability to respond appropriately to environmental and internal stimuli is an essential capacity of the living organism. This capacity involves both sensitivity to energy manifestations of various kinds and the means of transmitting their effects from one part of the organism to another. Sensitivity, or irritability, and conductivity are fundamental properties of protoplasm which, in the simplest organisms, are possessed in nearly equal degree by all parts of the body. In all the higher organisms, these properties become intensified in certain parts of the body and reduced in others. In the higher animals, certain tissue elements are exceedingly sensitive to appropriate stimuli and possess the property of conductivity in a high degree, *i. e.*, certain cells have become specialized for the purposes of receiving impulses and conducting them. These cells constitute the nervous tissue which, in all metazoan animals except a few primitive groups, forms an organized nervous system.

In all the higher animals, including man, the nervous system is exceedingly complex in its organization, but is composed of cellular elements, the neurons, which are arranged according to a comparatively uniform plan. This plan is well exemplified in the simple spinal reflex arc of the vertebrates (Fig. 1), which, in its simplest form, consists of a sensory, or afferent, neuron and a motor, or efferent, neuron. The former, the cell body of which is located in the ganglion on the dorsal nerve root, extends from the integument into the gray matter of the spinal cord. The latter, the cell body of which is located in the gray matter of the spinal cord, extends from this site to the muscle fibers which it controls. In addition to neurons of these two classes, the spinal cord includes other neurons which serve to connect one part of its structure with another. Many of these so-called internuncial neurons are interpolated between sensory and motor neurons like those referred to above, and thereby serve not only to extend the courses of the reflex impulses but also to increase enormously the connections within the spinal cord. In the brain, the internuncial neurons not only serve to increase the neural interconnections but also afford the material basis for all psychic and mental operations.

Many invertebrate animals, even those as low in the phylogenetic series as the segmented worms, exhibit a plan of neuronal arrangement comparable to that exemplified in the simple reflex arcs of vertebrates. In the common earthworm, for example, the sensory neurons, the cell bodies of which are located in the integument, send their fibers into the ventral nerve cord, which is the central nervous organ. The motor neurons are similar to those in the vertebrates in that their cell bodies are located in the central nervous organ, from whence their fibers extend to the appro-

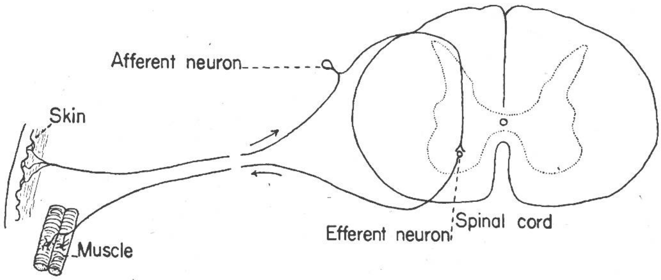

FIG. 1.—Diagram of a simple spinal reflex arc in a vertebrate animal.

priate musculature (Fig. 2). Interpolated neurons also are present in the ventral nerve cord of the earthworm, but, since the higher neural functions are but meagerly developed in this animal, their function, in contrast to that of interpolated neurons in the higher vertebrates, is limited mainly to neural intercommunication.

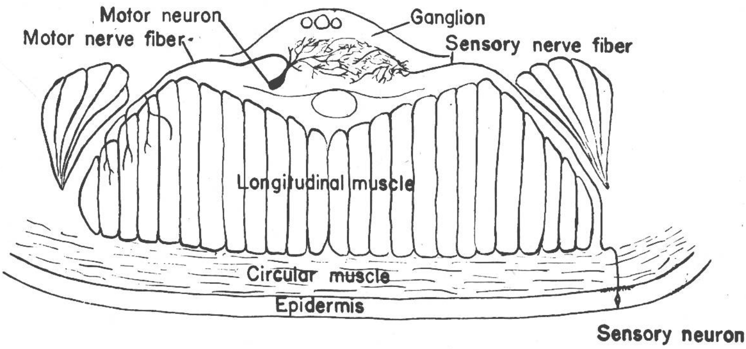

FIG. 2.—Diagrammatic transverse section of the ventral nerve cord and adjacent structures of the earthworm, showing the arrangement of the neurons in a simple reflex arc. (After Parker.)

Functional Factors in Neural Differentiation.—The uniformity in the plans of neuronal arrangement in the simpler reflex mechanisms, both in vertebrate and invertebrate animals, and the fundamental relationship of these mechanisms to the muscle tissue strongly suggest that the contractile function of the latter tissue and certain common functional requirements of animal organisms have played important rôles in the evolution of the nervous system. Even the simplest of the unicellular organisms whose reactions have been adequately studied show a more or less definite behavior pattern for every species. Among the more important factors in the establishment of such a pattern the following stand out prominently: (1) the stable protoplasmic organization of the species which is inherited by successive generations and (2) the reactions of this specific protoplasm to the stimulating influences which are present in the normal environment of the species and to which its protoplasmic organization enables it to respond in a physiological manner. Within its normal environment, every species responds only to those external influences which are adequate to stimulate its protoplasm, *i. e.*, those to which not only its receptive apparatus but its entire excitomotor mechanism has become attuned.

In the simpler ameboid organisms, there is no visible apparatus of excitomotor response, but the clearer ectoplasm is separated from the more granular endoplasm. With regard to the pattern of organization, this represents a permanent differentiation, but constituent substances of both the endoplasm and the ectoplasm pass freely from the one into the other. Since the pattern remains stable, although the substance is in a constant state of flux, it may be regarded as a dynamic pattern which probably plays a rôle in the transmission of excitations from the surface to the interior of the body. The reactions of ameboid organisms to various kinds of stimulation also give evidence of the propagation of excitations superficially in the ectoplasm. This layer obviously plays the major rôle in the excitomotor reactions.

Certain of the higher protozoa exhibit differentiation of the excitomotor apparatus in a relatively high degree. Such differentiation is particularly well marked in Diplodinium ecaudatum. The so-called neuromotor apparatus in this organism consists mainly of a band of tufted cilia (membranelles) around the mouth, which are sensory receptors and also actively motile, and a series of "neuromotor" strands which are connected with the bases of the cilia and converge into a central mass of protoplasm, the neuromotor mass or "motorium." Other neuromotor strands encircle the gullet and extend downward into the interior of the body, where they become associated with other and larger protoplasmic bands, termed retractor strands, which are highly contractile. These neuromotor and retractile strands contract in response to noxious stimuli acting on the sensorimotor apparatus for feeding and locomotion. Its main features, as seen in median section of the body, are illustrated in Figure 3.

The apparatus here described represents a well differentiated excitomotor mechanism, but without complete separation of the neuroid and contractile components. The retractor strands appear to be almost purely contractile, whereas the neuroid functions predominate in the neuromotor strands and the neuromotor mass. The anatomical arrangement of the neuromotor strands suggests that they are primarily conductors by means of which the activities of the motor organs are coördinated.

Similar neuromotor strands and a similar neuromotor mass also have been described in Paramecium (Rus, 1922). The results of experimental studies involving microdissection carried out on this organism support the assumption that the neuromotor strands subserve conduction and the neuromotor mass subserves coördination.

In excitomotor mechanisms of this type, as well as in the simpler ones of other protozoan species, the contractile organs of response are more highly differentiated than the neuroid organs. In some species the contractile elements are the only differentiated portions of the excitomotor apparatus hitherto recognized; consequently, the contractile organs of response must be regarded as among the first to assume definite form.

The same developmental sequence also obtains in metazoan animals.

In the sponges (Parker, 1919), the first stage in the cellular differentiation of the excitomotor apparatus is represented by well formed muscles without either nerves or sense organs.

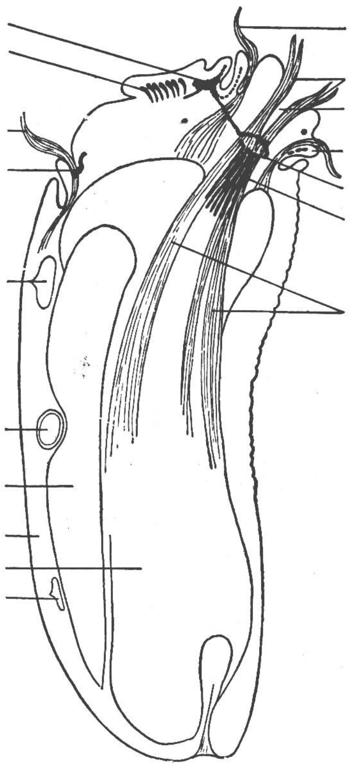

FIG. 3.—Diagrammatic longitudinal section of the Body of Diplodinium ecaudatum illustrating its neuromotor mechanism. (Modified from Sharp in Herrick's Neurological Foundations of Animal Behavior, courtesy of Henry Holt Company.)

In the fingered sponge, the osculum is encircled by a primitive ring of muscle tissue the contraction of which closes the aperture. This muscle, according to Parker, either is stimulated directly or the excitation is transmitted to it by simple protoplasmic conduction. Although devoid of sense organs and nerves, the reactions of the sponge nevertheless show slight coördination. On the basis of extensive experimental studies, Parker[1] concluded: "Sponges, then, represent that stage in evolution in which a primitive type of muscle tissue has made its appearance unaccompanied with nervous elements. . . . They mark the beginnings of the neuromuscular mechanism in that they possess the original and most ancient of its constituents, muscle, around which the remainder of the system is supposed subsequently to have been evolved."

This conclusion of Parker obviously must not be interpreted to mean that the muscles of sponges are pure contractile tissue, since an isolated pure contractile organ would be as useless as an isolated sense organ. The apparatus of response of necessity implies a receptive mechanism as

[1] Parker, G. H.: Elementary Nervous System, Philadelphia, J. B. Lippincott Company.