Strong and Elwyn's

HUMAN NEUROANATOMY

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PREFACE TO FOURTH EDITION

The First Edition of Strong and Elwyn's Human Neuroanatomy was published in 1943. Professor Adolph Elwyn, with the able assistance of his wife, Frances H. Elwyn, made further changes in both the text and illustrative materials of the Second and Third Editions which appeared in 1948 and 1953 respectively. The text material in the present revision was similarly rearranged, grafted, and pruned. Much of the text material in the third edition remains. Major changes were incorporated in Chapters I and XIII, while minor revisions were made in each of the remaining chapters. It is imperative that the student acquire an appreciation of the gross aspects of the brain and spinal cord, as well as knowledge of their blood supply, early in the course of study. Such information has been assembled in two new chapters (IV and V). The rhinencephalon and olfactory pathways were elevated to chapter status. Editorial surgery was undertaken optimistically in what appears to have been a futile effort to shorten the text material. Alterations were dictated largely by student use and comprehension of the text, in the lecture hall, laboratory, and subsequent clinical courses. Thus, a conscientious effort was made throughout this revision to maintain Professor Elwyn's original objective, namely, to keep this volume a "student textbook".

Neither space nor student time will permit the inclusion of all the many excellent contributions to neuroanatomy since the publication of the third edition. The field of neuroanatomy has continued to attract research interests of many disciplines. Investigators in neurohistology, neurophysiology, neurosurgery, neuropathology, neurochemistry, and neuropharmacology alone have made innumerable contributions in recent years. Each specialist has centered his disciplinary technics and often highly complex instruments upon the innermost secrets of the nerve cell. In the course of these ingenious studies the nerve cell has been probed, stimulated, irritated, injured, destroyed, cultured, irradiated, centrifuged, stained, homogenized and extracted. Neither the fetal nor the aged neuron has escaped scientific scrutiny. Increments in our knowledge of nerve cell structure and function is tremendously increased each year. Even a brief appraisal of such literature is beyond the scope of the present book. Recent information on some of the neural pathways of man and higher mammals have been placed in appropriate chapters of the present edition. References to the pertinent clinical literature have also been included.

The new student can be overwhelmed by the maze of nerve cells, nuclei, pathways and levels he is required to study. In an attempt to help him visualize this neuroanatomic material, 37 new illustrations have been added. Twenty-three are in color. The highly schematic, and often greatly enlarged, diagrams of major nervous pathways were designed to provide visual continuity through different levels of the central and peripheral nervous system. Schematic lesions at the end of Chapter XIII provide a means for the student to correlate the nerve pathways with their clinical significance. The beautifully stained Weigert preparations, through crucial levels of the spinal cord and brain stem, have been retained as text figures rather than incorporated in an Atlas at the end of the book.

All of the illustrations used for the first time in this revision were prepared by

Marjorie Stodgell, head of the Medical Art Department, Hahnemann Medical College and Hospital. Her skill, patience and artistic contributions are deeply appreciated. I am indebted to all my colleagues in the Department of Anatomy for their hearty cooperation and encouragement; to Martha Q. Smythe for valuable editorial help; to Irene Gamerman for her capable technical assistance with the manuscript; to Drs. E. H. Polley and G. S. Crouse who read some of the chapters; to Dr. Ray S. Snider of Northwestern University and Dr. Malcolm Carpenter of Columbia University who offered many constructive suggestions; to Dr. Clement Fox of Marquette University and Dr. Charles Noback of Columbia University for their generous loan of neurologic materials. Many colleagues of other teaching institutions have offered invaluable suggestions and their interest is gratefully acknowledged. Time imposed severe limitations upon the present edition. Many of the recommendations were omitted due to this factor alone.

It is a pleasure to express my personal appreciation to the Williams and Wilkins Company for their confidence, encouragement, and innumerable courtesies.

RAYMOND C. TRUEX

PREFACE TO FIRST EDITION

Neurology, more perhaps than any other branch of medicine, is dependent on an accurate knowledge of anatomy as a basis for the intelligent diagnosis and localization of neural disturbances. This book, the result of many years of neuro-anatomical teaching, is intended to supply this basic anatomical need, to give the student and physician a thorough and clear presentation of the structural mechanisms of the human nervous system together with some understanding of their functional and clinical significance. It is an attempt to link structure and function into a dynamic pattern without sacrificing anatomical detail.

The book is a human neuroanatomy sufficiently rich in content to obviate the necessity of constantly consulting larger anatomical texts. It may be conveniently divided into two parts. The first part (Chapters I–VIII) is concerned with the general organization and meaning of the nervous system, its embryology and histological structure, and with some fundamental neurological problems as they apply to man. This is followed by a discussion of the organization and segmental distribution of the peripheral nerve elements, including an analysis of the functional components of the spinal nerves and of the various receptors and effectors. If these earlier chapters are perhaps more extensive than in most other texts, it is due to the conviction that the book should be complete in itself, and also that a knowledge of these preliminaries is essential for an understanding of the complex machinery of the spinal cord and brain.

The second and larger part (Chapter IX–XX) is devoted to the architectonics of the central nervous system and may be regarded as "applied neuroanatomy." Special features of this part are the many fine photographs, both gross and microscopic, of the human brain and spinal cord, the great wealth of anatomical detail, and the discussion of the structural mechanisms in the light of clinical experience. While the individual portions of the nervous system are treated separately, an attempt has been made to achieve organic structural continuity by judicious repetition and overlapping and by constant reference to related topics already familiar to the student from previous chapters. The plan of exposition is substantially the same for each topic. The gross structure and relationships are concisely but thoroughly reviewed with the aid of clear and graphic illustrations. The internal structure is then presented in detail, usually based on a carefully graded series of fine and clearly labeled microphotographs of human material. At each level the student is familiarized with the exact location, extent and relationships of the various structures seen in the section. Finally the anatomical features of each part are reviewed more comprehensively as three-dimensional structural mechanisms, with a full discussion of their connections and clinical significance. We believe that this treatment will make the complicated structural details alive and interesting to the student. The illustrations are not segregated in the back of the book in the form of an atlas but are scattered in the text, in proper relation to the levels studied.

Besides the many original illustrations, a number of others selected from various and duly acknowledged sources have been completely redrawn and relabeled for the sake of clarity and simplicity. All the illustrations, whether original or borrowed, have been executed by Frances H. Elwyn to whose skill and patience

the authors are deeply indebted. We are also indebted to Dr. H. Alsop Riley for the use of several microphotographs; to Drs. R. C. Truex and Benjamin Salzer for the reading of several chapters; and especially to Dr. Otto Marburg for his many stimulating discussions and suggestions and for his critical reading of the chapters on the mesencephalon, diencephalon, and cerebral hemispheres. Thanks are also due to Rosette Spoerri for her competent help in preparing the manuscript and bibliography.

The authors cannot express too strongly their obligation to the publishers for their continuous courtesy and coöperation in all matters, and for their infinite patience in waiting for a manuscript long overdue.

Adolph Elwyn
Oliver S. Strong

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1

Origin and Composition of the Nervous System

In the never ending history of life, the human nervous system represents man's greatest heritage from the ancient past, the culmination of innumerable evolutionary changes. Through a continuous series of adaptations to environment and increasing functional needs, organisms developed more efficient nervous systems, capable of interpreting and responding to a variety of sensations. Man, possessing the ability to reason, has evolved the most elaborate neural mechanism of any living creature. The human system consists of a *central nervous system*, the brain and spinal cord; a *peripheral nervous system*, which includes the cranial and spinal nerves, and the *autonomic* or involuntary system. A brief survey of some representatives from the lower animals will emphasize their kinship to the mammals and provide a keener appreciation of this extraordinary system in man.

Microscopic unicellular animals are unique in that the protoplasm performs all the necessary life activities including irritability, motility and an adaptive behavior to the surrounding environment. It is well known that Paramecium can avoid mechanical obstacles, excessive temperatures and irritating chemicals by virtue of the rhythmic movement of surface cilia. The control center for the coordinated beating of the cilia is located near the gullet, and if this region is destroyed the animal loses control of all movements. Although the protozoa manifest the basic properties of the higher forms, they possess no specialized sensory or locomotor cells.

It is in the aquatic coelenterates that a primitive neural mechanism is first observed. As examples, the hydra, jelly fish and sea anemone have a layer of modified external cells (ectoderm) and an internal layer (endoderm) that lines a hollow digestive cavity (Fig. 1A). Slender sensory cells are found between the columnar epithelial cells, and the latter have fine contractile fibrils in their bases. In the jelly-like stratum between the two cell layers of the hydra are nerve cells whose processes communicate with the surface sensory cells, and also send fibrils to the contractile bases of the epithelial cells. Thus a network of nerve cells extends throughout the entire animal. The *nerve net* (Fig. 1B) is thought to consist of separate neural units so that a nerve impulse must pass across definite breaks at the junction of two nerve cells. Such junctions or *synapses* between two nerve cells are characteristic of more highly developed nervous systems. Synapses of higher forms are said to be polarized, or so constituted that a nerve impulse can pass across them in only one direction, and thus form specialized pathways. However, in the nerve net of the hydra it is possible for impulses to cross the synapses in either direction and there are no discrete pathways. Impulses travel slowly and in a diffuse manner over this primitive nervous agency, for there is little evidence of a "control center" or ganglionic brain.

Representing further development, the flat worms are characterized by body symmetry, a head with photosensitive spots and

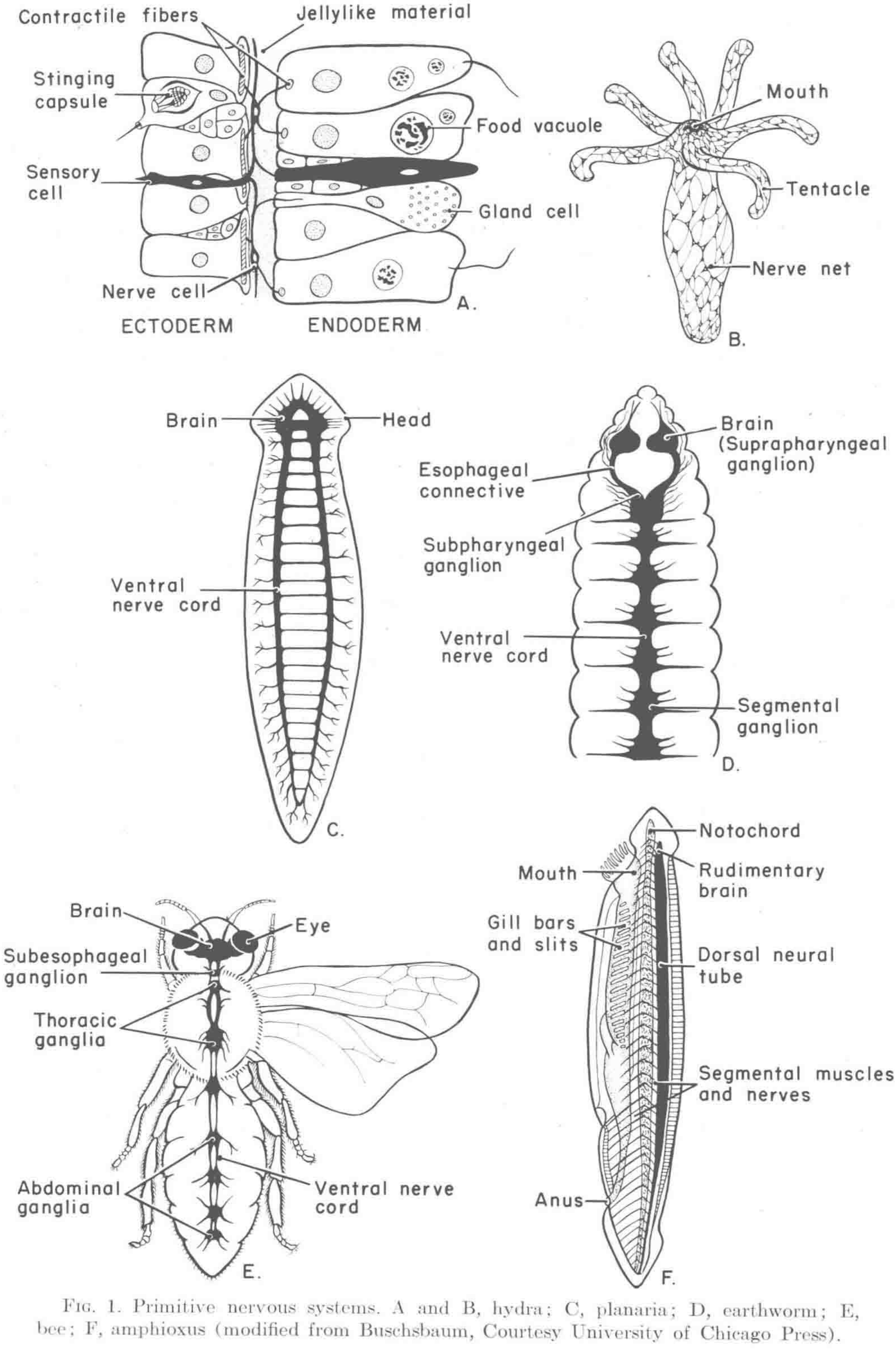

FIG. 1. Primitive nervous systems. A and B, hydra; C, planaria; D, earthworm; E, bee; F, amphioxus (modified from Buschsbaum, Courtesy University of Chicago Press).

other sense organs, the appearance of mesoderm with true muscle cells, and a more refined organization of tissues into organ systems. Planaria is an ideal example of this lowly phylum, for in the head the nervous tissue is concentrated into a bilobed mass called the brain, or head ganglion (Fig. 1C). Two strands or cords of nerve cells and fibers extend backward from the brain beneath the gastrovascular cavity, near the ventral surface of the animal. The brain and ladder-type nerve cords mark the first appearance of a central nervous system, although the nerve net of lower forms still persists. The brain is chiefly a sensory relay center that transmits impulses from the eyes and sense organs of the head region. The brain is not necessary for coordinated muscular activity, for a planaria deprived of its brain can still move along in a coordinated fashion. Because of its eyes, numerous sense organs, and centralized nervous system, this little animal manifests more rapid responses, independent locomotion, and a more varied behavior than does the hydra.

In adaptation to its subterranean life, the common earthworm has lost the prominent sense organs and eyes of the head region. At the same time the body segments have become streamlined as in other burrowing animals (Fig. 1D). The brain, or suprapharyngeal ganglion, remains essentially a sensory relay center for microscopic surface cells that are sensitive to light, touch, and probably chemicals. A worm deprived of this head ganglion shows little change in behavior and movement. A smaller subpharyngeal ganglion is interposed between the brain above, and a ventrally placed double nerve cord that extends to the posterior end of the animal. If the lower subpharyngeal ganglion is removed, a worm no longer eats and fails to burrow in a normal fashion. In the earthworm, each segmental ganglion of the nerve cord serves as a center which receives afferent impulses from sensory cells in the skin. Each ganglion also sends efferent impulses that coordinate the alternate contractions of well developed circular and longitudinal muscle layers. The intricate segmental neural apparatus of the earthworm presumably possesses all the components of a *simple reflex arc*, namely, the ability to respond segmentally and *involuntarily* to an appropriate stimulus. Larger nerve fibers within the ventral nerve cord extend over many segments and provide collateral branches to each of the segmental ganglia. Such giant fibers permit the longitudinal layers of muscle in all segments of the worm to contract simultaneously. This sudden contraction of the whole body is a stereotyped response that can be elicited by strong stimulation of any region. In such emergencies the simple reflexes of each segment becomes incorporated into a *mass response*, so that *intersegmental reflexes* take precedence over the local *segmental reflexes*. The coordination between anterior and posterior body segments is also evident to all who have observed the locomotion of an earthworm. The appearance and interplay of segmental and intersegmental reflexes in a centralized nervous system is of the utmost importance, for such simple reflexes form the neural basis of spinal cord activity in man. Of special significance is the nervous control of definitive muscle layers. Once this intimate relationship is established it becomes more elaborate and refined in higher forms.

The honey bee is included here as an illustrious example of the arthropod body plan (Fig. 1E). The individual body segments of lower forms are here incorporated into body regions—a head, thorax, and abdomen. The head now has movable mouth parts; simple and compound eyes capable of discerning light and movement; a pair of jointed antennae sensitive to touch and chemical odors. The thorax provides attachment for two pair of wings and three pair of jointed legs. The appearance of the head and thorax necessitated alterations in both muscular and nervous systems, namely, splitting of muscle layers into discrete muscle bundles, and a consolidation of neural elements into larger nerve ganglia adjacent to the major muscle masses (Fig. 1E). Synchronous wing movements and locomotion of jointed appendages are both attained by many of the insects through this refined *neuromuscular mechanism*. The brain has ceased to be a mere sensory relay center. Now a greater number of response patterns have been added and the bee has a measure of social and adaptive behavior as an integral part of instinctive behavior. All of the "specializations" in the organ systems attain their highest invertebrate development in the lowly arthropods, and they represent the peak of invertebrate evolution.

At this point it is desirable to recall the morphology of the primitive chordates. These unusual animals occupy a unique position midway between the invertebrates and the vertebrates. They all have, at some time in their life history, a cartilage-like bar, the *notochord*; a *tubular nervous system* located dorsal to the digestive tract; and pharyngeal gill bars and gill slits. Of the three sub-groups (amphioxus, tunicates, and acorn worms) amphioxus is perhaps the best known and the most like higher vertebrates (Fig. 1F). Although of questionable ancestry this animal is included because it illustrates advanced (vertebrate) and regressive (invertebrate) structural changes simultaneously. Hence it possesses a hollow, dorsally-placed neural tube with segmented musculature, but no definitive brain, eyes or special sense organs, and a very primitive digestive tract. Amphioxus also has more gill slits and gill bars than fish of higher forms, yet it has no cranial nerves or paired fins.

By a gradual process of centralization a spinal cord was thus fashioned from the primitive nerve net. This spinal cord in higher animals constitutes the primitive and most caudal portion of the central nervous system. The fact that the spinal cord developed anatomically in conjunction with, and assumed functional control over, the segmental muscles of the trunk is again emphasized.

In the lower vertebrates (e.g., lamprey eel) the sensory fibers are collected into separate bundles that course between the myotomes to enter the dorsal surface of the spinal cord (Fig. 2A). Motor nerve cells located in the gray matter of the spinal cord send their processes (*axons*) out through the ventral surface of the spinal cord as a ventral motor nerve. Each motor nerve enters the medial surface of the corresponding myotome and immediately breaks up into smaller branches. In this way the *dorsal sensory* and *ventral motor* nerves alternate with each other as they enter and leave the spinal cord. In all higher vertebrates the sensory and motor fibers are consolidated into a single nerve trunk, serving each segment of the cord.

The bipolar sensory nerve cells of the invertebrate are scattered in the periphery near the receptor endings (Figs. 1A; 3A, C). This arrangement still persists in some cranial nerves of the vertebrates (Fig. 3B, D). However, the *sensory* cells of all spinal nerves have migrated toward the spinal cord in most vertebrates and man (Fig. 3E). The bipolar sensory cells have become unipolar neurons (Figs. 80, 129) and these assembled masses of nerve cells outside the central nervous system form the dorsal root ganglia of the spinal nerves (Fig. 2B).

The simple relationship between myotome and ventral motor nerve is continued in the vertebrates. Each spinal nerve divides into a *dorsal primary ramus* to provide sensory and motor fibers to the integument and muscles of the back, and a larger *ventral primary ramus* to provide like fibers to the skin and muscles of the ventrolateral trunk (Fig. 2B). The "cord segment-spinal nerve-myotome" distribution is repeated bilaterally for each segment of the body, proceeding from the cranial to the caudal end of the spinal cord. Some animals have only