FOURTH EDITION

NEUROANATOMY TEXT AND ATLAS

JOHN H. MARTIN

McGraw Hill

Neuroanatomy Text and Atlas

Fourth Edition

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Preface

Neuroanatomy plays a crucial role in the health science curriculum by preparing students to understand the anatomical basis of neurology and psychiatry. Imaging the human brain, in both the clinical and research setting, helps us to identify its basic structure and connections. And when the brain becomes damaged by disease or trauma, imaging localizes the extent of the injury. Functional imaging helps to identify the parts of the brain that become active during our thoughts and actions, and reveals brain regions where drugs act to produce their neurological and psychiatric effects. Complementary experimental approaches in animals—such as mapping neural connections, localizing particular neuroactive chemicals within different brain regions, and determining the effects of lesions—provide the neuroscientist and clinician with the tools to study the biological substrates of disordered thought and behavior. To interpret this wealth of information requires a high level of neuroanatomical competence.

Since the third edition of *Neuroanatomy: Text and Atlas,* clinical neuroscience has become even more dependent on localization of function for treatment of disease. Electrophysiological procedures, such as deep brain stimulation (DBS) for Parkinson disease, target small regions within the basal ganglia. DBS, as this is called, is routine in many major medical centers. Interventional neuroradiology is a chosen approach for treating many vascular abnormalities, such as repair of arterial aneurysms. Surgery to resect small portions of the temporal lobe is the treatment of choice for many patients with epilepsy. Neurosurgeons routinely use high-resolution imaging tools to characterize the functions and even the connections of regions surrounding tumors, to resect the tumor safely and minimize risk of loss of speech or motor function. Each of these innovative approaches clearly requires that the clinical team have a greater knowledge of functional neuroanatomy to design and carry out these tasks. And this demand for knowledge of brain structure, function, and connectivity will only be more critical in the future as higher-resolution and more effective approaches are developed to repair the damaged brain.

Neuroanatomy helps to provide key insights into disease by providing a bridge between molecular and clinical neural science. We are learning the genetic and molecular bases for many neurological and psychiatric diseases, such as amyotrophic lateral sclerosis and schizophrenia. Localizing defective genes to particular brain regions and neural circuits helps to further our understanding of how pathological changes in brain structure alter brain function. And this knowledge, in turn, will hopefully lead to breakthroughs in treatments and even cures.

An important goal of *Neuroanatomy: Text and Atlas* is to prepare the reader for interpreting the new wealth of human brain images—structural, functional, and connectivity—by developing an understanding of the anatomical localization of brain function. To provide a workable focus, this book is largely restricted to the central nervous system. It takes a traditional approach to gaining neuroanatomical competence: Because the basic imaging picture is a two-dimensional slice through the brain, the locations of structures are examined on two-dimensional myelin-stained sections through the human central nervous system.

What is new for the fourth edition of *Neuroanatomy: Text and Atlas?* All chapters have been revised to reflect advances in neural science since the last edition. In addition to full color illustrations, there are many new features:

- Chapters begin with a clinical case to illustrate the connections and function of the key material. Some of these cases are specialized and not apt to be seen in routine practice. They were chosen to show how human behavior can change in remarkable ways following damage to a localized brain region; sometimes a very small region.
- Chapters end with a series of multiple choice review questions.
- Material on central nervous system development is now included in the relevant individual chapters rather than a single development chapter.
- There are separate chapters on touch and pain.

Designed as a self-study guide and resource for information on the structure and function of the human central nervous system, this book can serve as both text and atlas for an introductory laboratory course in human neuroanatomy.

For over 23 years, both at Columbia University's College of Physicians and Surgeons and now at the City University of New York's Medical School, we use this book in conjunction with a series of neuroanatomy laboratory exercises during the neuroscience teaching block in the curriculum. Rather than presenting the material in a traditional lecture format, we have successfully taught neuroanatomy in a dynamic small group learning environment. Supplemented with use of brain models and specimens, neuroanatomy small group sessions complement neural science lecture material and round-out medical, graduate, and allied health science students' learning experience.

The organization of *Neuroanatomy: Text and Atlas* continues to parallel that of *Principles of Neural Science,* edited by Eric R. Kandel, James H. Schwartz, Thomas Jessell, Steven A. Siegelbaum, and A. James Hudspeth (McGraw-Hill). Like *Principles of Neural Science, Neuroanatomy: Text and Atlas* is aimed at medical students, and graduate students in neuroscience, biology, and psychology programs. The content of many of the chapters is geared to dental students, such as a chapter focus on the trigeminal system, as well as physical therapy and occupational therapy students by considering the motor systems in detail.

John H. Martin

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Guide to Using This Book

Neuroanatomy: Text and Atlas takes a combined regional and functional approach to teaching neuroanatomy: Knowledge of the spatial interrelations and connections between brain regions is developed in relation to the functions of the brain's various components. The book first introduces the major concepts of central nervous system organization. Subsequent chapters consider neural systems subserving particular sensory, motor, and integrative functions. At the end of the book is an atlas of surface anatomy of the brain and myelin-stained histological sections, and a glossary of key terms and structures.

Overview of Chapters

The general structural organization of the mature central nervous system is surveyed in Chapter 1. This chapter also introduces neuroanatomical nomenclature and fundamental histological and imaging techniques for studying brain structure and function. The three-dimensional shapes of key deep structures are also considered in this chapter. The functional organization of the central nervous system is introduced in Chapter 2. This chapter considers how different neural circuits, spanning the entire central nervous system, serve particular functions. The circuits for touch perception and voluntary movement control are used as examples. The major neurotransmitter systems are also discussed.

Central nervous system vasculature and cerebrospinal fluid are the topics of Chapter 3. By considering vasculature early in the book, the reader can better understand why particular functions can become profoundly disturbed when brain regions are deprived of nourishment. These three chapters are intended to provide a synthesis of the basic concepts of the structure of the central nervous system and its functional architecture. A fundamental neuroanatomical vocabulary is also established in these chapters.

The remaining 13 chapters examine the major functional neural systems: sensory, motor, and integrative. These chapters reexamine the views of the surface and internal structures of the central nervous system presented in the introductory chapters, but now from the perspective of the different functional neural systems. As these latter chapters on functional brain architecture unfold, the reader gradually builds a neuroanatomical knowledge of the regional and functional organization of the spinal cord and brain, one system at a time.

These chapters on neural systems have a different organization from that of the introductory chapters: Each is divided into two parts, functional and regional neuroanatomy. The initial part, on functional neuroanatomy, considers how the brain regions that comprise the particular neural system work together to produce their intended functions. This part of the chapter presents an overall view of function in relation to structure before considering the detailed anatomical organization of the neural system. Together with descriptions of the functions of the various components, diagrams illustrate each system's anatomical organization, including key connections that help to show how the particular system accomplishes its tasks. Neural circuits that run through various divisions of the brain are depicted in a standardized format: Representations of myelin-stained sections through selected levels of the spinal cord and brain stem are presented with the neural circuit superimposed.

Regional neuroanatomy is emphasized in the latter part of the chapter. Here, structures are depicted on myelin-stained histological sections through the brain, as well as magnetic resonance images (MRIs). These sections reveal the locations of major pathways and neuronal integrative regions. Typically, this part examines a sequence of myelin-stained sections ordered according to the flow of information processing in the system. For example, coverage of regional anatomy of the auditory system begins with the ear, where sounds are received and initially processed, and ends with the cerebral cortex, where our perceptions are formulated. In keeping with the overall theme of the book, the relation between the structure and the function of discrete brain regions is emphasized.

Emphasis is placed on the close relationship between neuroanatomy and neuroradiology especially through use of MRI scans. These scans are intended to facilitate the transition from learning the actual structure of the brain, as revealed by histological sections, to that which is depicted on radiological images. This is important in learning to "read" the scans, an important clinical skill. However, there is no substitute for actual stained brain sections for developing an understanding of three-dimensional brain structure.

Atlas of the Central Nervous System

This book's atlas, in two parts, offers a complete reference of anatomical structure. The first part presents key views of the surface anatomy of the central nervous system. This collection of drawings is based on actual specimens but emphasizes common features. Thus, no single brain has precisely the form illustrated in the atlas. The second part of the atlas presents a complete set of photographs of myelin-stained sections through the central nervous system in three anatomical planes.

With few exceptions, the same surface views and histological sections used in the chapters are also present in the atlas. In this way, the reader does not have to cope with anatomical variability and is thus better able to develop a thorough understanding of a limited, and sufficiently complete, set of materials. Moreover, brain views and histological sections shown in the chapters have identified only the key structures and those important for the topics discussed. In the atlas, all illustrations are comprehensively labeled as a reference. The atlas also serves as a useful guide during a neuroanatomy laboratory.

Didactic Boxes

Selected topics that complement material covered in the chapters are presented in boxes. In many of the boxes, a new perspective on neuroanatomy is presented, one that has emerged only recently from research. The neuroscience community is enthusiastic that many of these new perspectives may help explain changes in brain function that occur following brain trauma or may be used to repair the damaged nervous system.

Clinical Cases

Each chapter begins with a clinical case, chosen to highlight a fascinating clinical feature of the neural system discussed in the chapter. Whereas some of these cases are rare and not apt to be seen in routine medical practice, they show how perception, motor behavior, or personality and emotions can change after a stroke or tumor damages the brain, or how brain structure and function change after a selective gene mutation. The case description is followed by an explanation of what structures and neural systems are damaged that produce the neurological signs. Questions are posed that can be answered on the basis of reading the case explanations and the chapter text. Detailed answers are provided at the end of the book.

Study Questions

Each chapter ends with a set of study questions. Answers are provided at the end of the book. A brief explanation of the more integrative and difficult questions also is provided.

Glossary

The glossary contains a listing of key terms and structures. Typically, these terms are printed in boldface within the chapters. Key terms are defined briefly in the context of their usage in the chapters. Key structures are identified by location and function.

Additional Study Aids

This book offers three features that can be used as aids in learning neuroanatomy initially, as well as in reviewing for examinations, including professional competency exams:

- Summaries at the end of each chapter, which present concise descriptions of key structures in relation to their functions.
- A glossary of key terms.
- The atlas of key brain views and myelin-stained histological sections, which juxtapose unlabeled and labeled views. The unlabeled image can also be used for self-testing, such as for structure identification.

These study aids are designed to help the reader assimilate efficiently and quickly the extraordinary amount of detail required to develop a thorough knowledge of human neuroanatomy.

Box Features

Contents

I

THE CENTRAL NERVOUS SYSTEM

Chapter 1

Organization of the Central Nervous System

CLINICAL CASE | Alzheimer Disease

A 79-year-old man has become forgetful, often misplacing items at home, and sometimes is confused when paying for his groceries. His family reports that his forgetfulness seems to be getting worse. On neurological examination, he reports the correct date and knows where he is and why he is there; he has normal speech. However, he is unable to recall the names of three unrelated words 5 minutes after correctly repeating them. When asked to perform simple addition and subtraction, he is slow and has difficulty. His mental status was further evaluated, which revealed additional cognitive impairment. He was diagnosed with Alzheimer disease, based on his neuro-psychiatric examinations and brain imaging studies.

Figure 1–1 shows, side by side, a photograph of a brain from a person that had Alzheimer disease (A1) and a normal brain (B1). Magnetic resonance images (MRIs) are presented below (A2–5; B2–5). The appearance of brain slices will be explored further, beginning with Chapter 2, as we learn about the brain's internal structure. But we can take this opportunity to consider changes to the cortex and ventricular system as revealed on slices of the living brain. Parts 2–4 present a series of MRIs close to the transverse plane (see inset; also, Figures 1–16 and 1–17). On these images, white and gray matter appear as different shades of gray and cerebrospinal fluid, black. Cranial fatty substances (for example, skin and in the bony orbits) are white. Note how the ventricles are thin in the healthy brain (right column), but dilated in the diseased brain (left column).

The hippocampal formation (Figure 1-10A; see Chapter 16) also becomes atrophic in Alzheimer disease. This is seen in the coronal MRIs in Figure 1–1. The generalized cortical atrophy and ventricular enlargement are also apparent on the transverse MRI.

You should try to answer the following questions based on your reading of the chapter and inspection of the images. Note that the description of key neurological signs that follow the questions also will provide the answers.

1. **Why is the ventricular system affected, even though it is a non-neuronal structure?**
2. **Are some brain areas more severely affected than others?**

—*Continued next page*

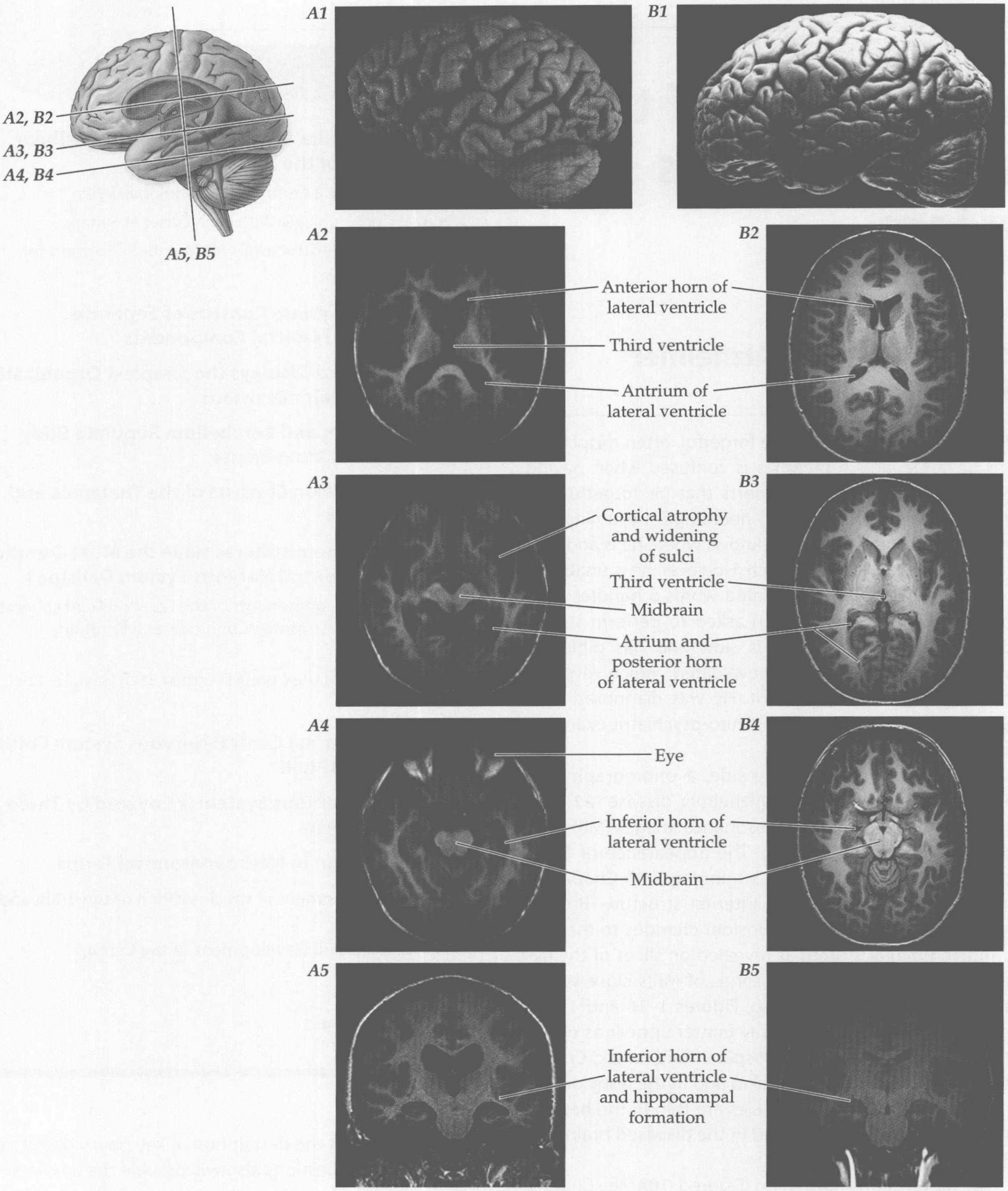

FIGURE 1–1 Brain (top) and MRIs (transverse plane, 2-4; coronal plane, 5) from a person with Alzheimer disease (***A***) and a healthy person (***B***). The brain views show generalized atrophy in Alzheimer disease. The MRIs (2-5) show cortical atrophy and ventricular enlargement. The MRIs are T1 images; brain tissues are shades of gray and cerebrospinal fluid, black. (**A1,** Image courtesy of Dr. Mony J de Leon [NYU School of Medicine], Dr. Jerzy Wegiel [Institute for Basic Research], and Dr. Thomas Wisniewski [NYU School of Medicine]; NIH Alzheimer's Disease Center P30 AG08051. **A2, A3, A4,** Images reproduced with permission from Dr. Frank Galliard, Radiopaedia. com. **A5,** Image courtesy of The Dementia Research Center, UCL Institute of Neurology.)