

Stanley Jacobson
Elliott M. Marcus
Stanley Pugsley

Neuroanatomy for the Neuroscientist

Third Edition

 Springer

Neuroanatomy for the Neuroscientist

Stanley Jacobson • Elliott M. Marcus
Stanley Pugsley

Neuroanatomy for the Neuroscientist

Third Edition

 Springer

Stanley Jacobson
Boston, MA, USA

Elliott M. Marcus
Jamaica Plain, MA, USA

Stanley Pugsley
South Abington Twp., PA, USA

ISBN 978-3-319-60185-4 ISBN 978-3-319-60187-8 (eBook)
DOI 10.1007/978-3-319-60187-8

Library of Congress Control Number: 2017945279

© Springer International Publishing AG 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*To Elliott M. Marcus, colleague,
friend, collaborator, superb neurologist,
and developer of neurosciences at Tufts
Medical School*

*To our wives: Avis Jacobson, Nuran Turksoy,
and Tricia Pugsley*

*To our children: Arthur Jacobson,
Robin Seidman, Erin Marcus, Robert Letson,
Gerard Pugsley, David Pugsley,
and Mark Pugsley*

*To our grandchildren: Ross Jacobson,
Jase Jacobson, Zachary Letson,
and Amelia Letson*

To our teachers, students, and colleagues

Preface

Elliott M. Marcus, M.D., was a friend and colleague for over 40 years, and he was the father of neurosciences at the Tufts University School of Medicine, and with his passing in 2011, we lost a dear friend, colleague, dynamic teacher, and an outstanding neurologist. This textbook is dedicated to his memory.

The purpose of this textbook is to enable a neuroscientist to discuss the structure and functions of the brain at a level appropriate for students at many levels of study including undergraduate, graduate, dental, or medical school level. It is truer in neurology than in any other system of medicine that a firm knowledge of basic science material, that is, the anatomy, physiology, and pathology of the nervous system, enables one to readily arrive at the diagnosis of where the disease process is located and to apply their knowledge at solving problems in clinical situations. The authors have a long experience in teaching neuroscience courses at the first- or second-year level to medical and dental students and to residents in which clinical information and clinical problem-solving are integral to the course.

Dr. Jacobson has taught neuroanatomy and gross anatomy for many years to medical and dental students at the Tufts University School of Medicine and an upper-level biology course on the central nervous system to undergraduates at Tufts University in Medford, MA, utilizing many of Dr. Marcus' cases to engage students. He also has used several movies on the brain developed in Hollywood to further involve students.

Dr. Marcus practiced neurology for 40 years, and he developed a case history of problem-solving sessions in the recent book *Integrated Neurosciences* by E.M. Marcus, S. Jacobson, and T. Sabin (Oxford University Press, 2014), and he also conducted a problem-solving seminar in which all medical students at the University of Massachusetts participate during their clinical neurology clerkship rotation. This provides students an opportunity to refresh their problem-solving skills and to review and update that basic science material essential for clinical neurology.

Dr. Pugsley is a senior neurosurgeon with extensive clinical and teaching experience. He trained in neurosurgery at the Tufts University School of Medicine. He observed that the inclusion of case history materials reinforces the basic science

subject matter learned by markedly increasing the interest of students in both basic and clinical science material. He has added many new cases and a neurosurgeon's prospective to disease.

In this third edition, decisions had to be made so that the size of the textbook remained within reasonable limits. Throughout this book, we have utilized clinical illustration and integrated the anatomical, neurological, and neurosurgery managed in most of today's neuroscience courses, and we have responded to many of the very worthwhile suggestions from our colleagues. The book contains the core topics concerned with the central nervous system and all chapters have been updated. We have divided this edition into five parts: (I) Introduction to the Central Nervous System (Chaps. 1–10); (II) The Systems (Chaps. 11–17); (III) Neuropathology, (Chap. 18) Vascular Diseases and (Chap. 19) Nonvascular Diseases; (IV) The Nonnervous Elements, (Chap. 20) Meninges, Blood Supply, Ventricular System, (Chap. 21) General Case Histories, Problem-Solving, and (Chap. 22) Movies on the Brain; and (V) Descriptive Atlas of the Brain and Spinal Cord (Chap. 23).

We have added in several chapters, in Chap. 19, representative cases of trauma and infectious diseases within the CNS to aid students in understanding disease processes with the central nervous system and, in Chap. 20, the meninges, blood supply, and ventricular system. We have included an atlas at the end of the spinal cord (Chap. 3), brain stem (Chap. 6), and diencephalon chapters (Chap. 8). We have maintained the atlas chapter 23 and 24 with Chapter 23 Descriptive Atlas of Gross Brain and Chapter 24-Descriptive Atlas –Myelin stained sections.

In Chap. 22, Movies on the Brain, we have added in the film on Concussion which is an important discussion of the effects of contact sports. We have also used several of these movies as an adjunct to our teaching; (1) Young Frankenstein directed by Mel Brooks has a wonderful scene introducing the CNS and (2) Little Shop of Horrors directed by Frank Oz features Steve Martin as a dentist, and this is a great introduction to the trigeminal nerve). There are many movies in the science fiction genre that are also useful for discussion, and Star Trek and its many episodes and its medical manual are at the top of our list!

A number of other topics including cell biology, cell physiology, embryology, gross anatomy, nerve, and muscle are usually covered in other courses, and the student should examine these topics in those courses. The anatomy of the peripheral nervous system and autonomic nervous system has been touched on briefly here but should be reviewed in one of the standard gross anatomy texts.

Most of the case histories utilized in the chapters have been drawn from the files of Drs. Marcus and Pugsley. For a number of the cases, our associates at the Geisinger Medical Center in Danville, PA, Tufts Medical Center, St. Vincent Hospital, Fallon Clinic, and the University of Massachusetts School of Medicine either requested our opinion or brought a given case to our attention and provided information from their case files. These individual neurologists and neurosurgeons are identified in the specific case histories. We are also indebted to the many referring physicians of those institutions. Medical house officers at St Vincent Hospital presented some of the cases to Dr. Marcus during morning report. In particular, our thanks are due to our associates in Worcester: Drs. Bernard Stone, Alex Danylevich,

Robin Davidson, Harold Wilkinson, and Gerry McGillicuddy. Drs. Sandra Horowitz, Tom Mullins, Steve Donhowe, Martha Fehr, and Carl Rosenberg provided clinical information from their files for some of the case histories. Our associates at the New England Medical Center Drs. John Sullivan, Sam Brendler, Peter Carney, John Hills, Huntington Porter, Thomas Sabin, Bertram Selverstone, Thomas Twitchell, C. W. Watson, and Robert Yuan likewise provided some of the clinical material. Dr. Milton Weiner at St Vincent Hospital was particularly helpful in providing many of the modern neuroradiological images. Dr. Sam Wolpert and Dr. Bertram Selverstone provided this material for the earlier version of the text. Dr. Val Runge from the Imaging Center at Texas A&M provided the normal MRIs. Dr. Anja Bergman (left-handed) had the patience to be our normal case, and the images from her brain form the normal MRIs in basic science chapters and atlas. Dr. Tom Smith and his associates in pathology provided much of the recent neuropathological material. Drs. John Hills and Jose Segarra provided access to neuropathological material for the earlier version of the text. Drs. Sandra Horowitz and David Chad provided critic of particular chapters.

Dr. Sarah B. Cairo, M.D., M.P.H., while still a medical student at Tufts Medical School developed the illustrated drawings that were used throughout the second edition of this book, and they will be used in this edition to illustrate the retina, pathways, levels of the spinal cord, levels of the brain stem, and levels of the thalamus.

Dr. Samuel Giles, MD, while a student at Tufts University School of Medicine, developed the Malaria and HIV/AIDS cases. He has continued to help us while he is training in Neurology at the University of Florida in Jacksonville.

Dr. Mary Gauthier Delaplane while a medical student at Boston University School of Medicine provided anatomical drawings illustrating the cranial nerves and the neuroembryology. Anne Que, Paul Ning, Tiffany Mellott, Elizabeth Haskins, and Tal Delman aided Dr. Delaplane. Dr. Marc Bard provided drawings for an earlier text, *An Introduction to the Neurosciences*, 1972, while a student at the Tufts University School of Medicine, and we have continued to utilize or have modified some of these illustrations. We have also borrowed with permission from other published illustrations. We have attempted to contact these original sources for continued permissions. We will acknowledge subsequently any sources that have been inadvertently overlooked. In many of the clinical chapters, various medications are recorded. Before utilizing these medications, the reader should check dosage and indications with other sources.

It is with great pleasure we extend our thanks to our publishers and particularly our editor Simina Calin for all her help. Special thanks to Michael J. Lukus, PA-C; Steven Toms, M.D.; and Michel Lacroix, M.D., for the advice and support in this endeavor. Any faults or errors are those of the authors, and we would therefore appreciate any suggestions or comments from our colleagues.

Boston, MA, USA
Jamaica Plain, MA, USA
South Abington Twp., PA, USA

Stanley Jacobson
Elliott M. Marcus
Stanley G. Pugsley

Contents

Part I Introduction to the Central Nervous System

1	Introduction to the Central Nervous System	3
1.1	The Neuron	4
1.2	The Nervous System	8
1.2.1	Peripheral Nervous System (Fig. 1.3)	9
1.2.2	Central Nervous System	9
	Bibliography	26
2	Neurocytology: Cells of the CNS	27
2.1	The Neuron	27
2.1.1	Dendrites	28
2.1.2	Soma	28
2.1.3	Golgi Type I and II Neurons	28
2.1.4	Dendritic Spines (Fig. 2.2)	29
2.1.5	Nucleus	35
2.1.6	Neuronal Cytoskeleton	38
2.1.7	Microtubules and Axoplasmic Flow	38
2.1.8	Neurofibrillary Tangles	41
2.2	Synapse	45
2.2.1	Synaptic Structure	45
2.2.2	Synaptic Types	45
2.2.3	Synaptic Transmission	46
2.2.4	Neurotransmitters (Table 2.3)	47
2.2.5	Modulators of Neurotransmission	47
2.2.6	Synaptic Vesicles (Fig. 2.16) (Table 2.4)	47
2.2.7	Effectors and Receptors	50
2.3	Supporting Cells of the Central Nervous System	50
2.3.1	Astrocytes (Figs. 2.6 and 2.14; Table 2.7)	51
2.3.2	Oligodendrocytes (Fig. 2.9)	53
2.3.3	Endothelial Cells	53

2.3.4	Mononuclear Cells: Monocytes and Microglia	53
2.3.5	Ependymal Cells (Fig. 2.20)	59
2.3.6	Supporting Cells in the Peripheral Nervous System	59
2.4	Response of the Nervous System to Injury	60
2.4.1	Degeneration	60
2.5	Regeneration	63
2.5.1	Peripheral Nerve Regeneration	63
2.5.2	Regeneration in the Central Nervous System	64
2.5.3	Neurogenesis in the Adult Brain Stem.	64
2.5.4	Nerve Growth Factors (NGF)	65
2.5.5	Glial Response to Injury	65
2.6	Blood–Brain Barrier.	66
2.6.1	Blood–Brain Barrier (Fig. 2.24).	66
2.6.2	Extracellular Space	67
	Specific References.	69
3	Neuroembryology and Congenital Malformations	73
3.1	Formation of the Central Nervous System.	73
3.2	Histogenesis.	76
3.2.1	Repair of Damaged Nervous System.	77
3.2.2	Growth Cone Guidance	78
3.2.3	Programmed Cell Death (PCD): Apoptosis.	78
3.2.4	Neuronal Death	79
3.2.5	Development of Blood Vessels in the Brain.	80
3.2.6	Ventricular System.	80
3.2.7	Formation of Peripheral Nervous System	81
3.2.8	Spinal Cord Differentiation	81
3.3	Brain Differentiation	85
3.3.1	Rhombencephalon (Hindbrain) > Pons, Medulla, and Cerebellum	85
3.3.2	Mesencephalon > Adult Midbrain.	86
3.3.3	Prosencephalon > Cerebral Hemispheres and Diencephalon.	86
3.3.4	Diencephalon	87
3.3.5	Cranial Nerves	88
3.3.6	Telencephalon	92
3.3.7	Primary Sulci	92
3.3.8	Development of the Cerebral Cortex.	94
3.4	Prenatal Development of the Cerebral Cortex	96
3.5	Changes in the Cortical Architecture as a Function of Postnatal Age.	99
3.6	Abnormal Development.	101
3.6.1	Malformations Resulting from Abnormalities in Growth and Migration with Incomplete Development of the Brain	101

- 3.6.2 Genetically Linked Migration Disorders 102
- 3.6.3 Environmentally Induced Migration Disorder:
Fetal Alcohol Syndrome 107
- 3.6.4 Malformations Resulting from Chromosomal
Trisomy and Translocation 108
- 3.6.5 Malformations Resulting from Defective Fusion
of Dorsal Structures 108
- 3.6.6 Malformations Characterized by Excessive Growth
of Ectodermal and Mesodermal Tissue Affecting
the Skin, Nervous System, and Other Tissues 109
- 3.6.7 Cutaneous Angiomas with Associated
Malformations of the Central Nervous System 110
- 3.6.8 Malformations Resulting from Abnormalities
in the Ventricular System 110
- Bibliography 111
- 4 Spinal Cord 113**
 - 4.1 Gross Anatomy 113
 - 4.1.1 Spinal Cord: Structure and Function 114
 - 4.1.2 Nerve Roots 114
 - 4.1.3 Gray Matter 116
 - 4.2 Interneurons 122
 - 4.3 Central Pattern Generators 122
 - 4.4 Segmental Function 123
 - 4.4.1 Motor/Ventral Horn Cells 123
 - 4.4.2 Sensory Receptors 124
 - 4.4.3 Stretch Receptors 125
 - 4.5 Nociception and Pain 128
 - 4.5.1 Modulation of Pain Transmission 129
 - 4.6 White Matter Tracts 131
 - 4.6.1 Descending Tracts in the Spinal Cord 131
 - 4.6.2 Ascending Tracts in the Spinal Cord 134
 - 4.6.3 The Anterolateral Pathway 134
 - 4.7 Upper and Lower Motor Neurons Lesions 138
 - 4.7.1 Upper Motor Neuron Lesion (UMN). 139
 - 4.7.2 Lower Motor Neuron Lesion 140
 - 4.8 Illustrative Spinal Cord Case Histories 140
 - 4.9 Illustrative Non-spinal Cord Cases with Involvement
of Specific Peripheral Nerves: Case Histories 4.8–4.10 147
 - 4.10 Carpal Tunnel Syndrome 147
 - Bibliography 153
- 5 Brain Stem: Gross Anatomy 155**
 - 5.1 Gross Anatomical Divisions 155
 - 5.1.1 Sites of Transition 156

5.2	Relationship of Regions in the Brain to the Ventricular System: Fig. 5.2	157
5.3	Gross Anatomy of Brain Stem and Diencephalon	158
5.3.1	Anterior Surface of Gross Brain Stem: Fig. 5.3.	158
5.3.2	Posterior Surface of Brain Stem and Diencephalon: Fig. 5.4	160
5.4	Arterial Blood Supply to the Brain Stem and Diencephalon (Fig. 5.5).	165
5.4.1	Medulla	165
5.4.2	Pons	166
5.4.3	Midbrain.	167
5.4.4	Diencephalon	167
	Bibliography	167
6	Brain Stem Functional Localization	169
6.1	Introduction to the Brain Stem.	169
6.2	Differences Between the Spinal Cord and Brain Stem	171
6.3	Functional Localization in Brain Stem Coronal Sections and an Atlas of the Brain Stem	172
6.3.1	Medulla	173
6.3.2	Pons-Blood Supply: Basilar Artery and Its Branches	180
6.3.3	Midbrain Blood Supply: Basilar Arteries and Posterior Cerebral Arteries.	185
6.4	Midbrain Tectum	187
6.5	Midbrain Tegmentum.	187
6.6	Superior Colliculus	189
6.6.1	Midbrain Tegmentum.	189
6.6.2	Blood Supply: Posterior Cerebral Arteries	189
6.7	Superior Colliculus Tectum	189
6.8	Superior Colliculus Tegmentum	190
6.8.1	Superior Colliculus Ventricular Zone	190
6.9	Functional Centers in the Brain Stem	193
6.9.1	Reticular Formation	193
6.9.2	Respiration Centers	195
6.9.3	Cardiovascular Centers	196
6.9.4	Deglutition	196
6.9.5	Vomiting.	197
6.9.6	Emetic Center.	197
6.9.7	Coughing	198
6.9.8	Taste	198
6.10	Localization of Dysfunction in the Cranial Nerves Associated with the Eye (Table 6.8)	200
6.11	Localization of Disease Processes in the Brain Stem	200
6.11.1	Exercise to Identify the Tracts and Nuclei in the Brain Stem (Figs. 6.10–6.14).	201
	Bibliography	204

7 The Cranial Nerves 205

7.1 How the Cranial Nerves Got Their Numbers. 205

7.2 Functional Organization of Cranial Nerves 207

7.3 The Individual Cranial Nerves 211

7.3.1 Cranial Nerve I, Olfactory (Fig. 7.4),
Special Sensory/Special Visceral Afferent. 211

7.3.2 Cranial Nerve II, Optic (Fig. 7.5), Special
Somatic Sensory. 213

7.3.3 Cranial Nerve III, Oculomotor (Fig. 7.6),
Pure Motor (Somatic and Parasympathetic, Only III) 215

7.3.4 Cranial Nerve IV, Trochlear (Fig. 7.6), Pure Motor. 216

7.3.5 Cranial Nerve VI, Abducens (Fig. 7.6), Pure Motor 216

7.3.6 Cranial Nerve V, Trigeminal (Fig. 7.7),
Mixed Nerve (Sensory and Motor
but No Parasympathetic) 217

7.3.7 Cranial Nerve VII, Facial (Fig. 7.8), Mixed Nerve
(Sensory, Motor, Parasympathetic) 219

7.3.8 Cranial Nerve VIII, Vestibulocochlear (Fig. 7.9),
Pure Special Somatic Sensory 222

7.4 Auditory Pathway 223

7.4.1 Cranial Nerve IX, Glossopharyngeal (Fig. 7.13),
Mixed (Sensory, Motor, Parasympathetic):
Nerve to Third Pharyngeal Arch 228

7.4.2 Cranial Nerve X, Vagus (Fig. 7.14),
Mixed (Sensory, Motor, Parasympathetic),
and Longest Cranial Nerve 229

7.4.3 Cranial Nerve XI, Spinal Accessory (Fig. 7.15),
Pure Motor: Somatic and Visceral 231

7.4.4 Cranial Nerve XII, Hypoglossal (Fig. 7.16):
Pure Motor Nerve 232

7.5 Cranial Nerve Dysfunction 233

7.6 Cranial Nerve Case Histories. 236

Bibliography 240

8 Diencephalon 241

8.1 Overview 241

8.2 Functional Organization of Thalamic Nuclei (Table 8.1) 245

8.2.1 Sensory and Motor Relay Nuclei:
The Ventrobasal Complex and Lateral Nucleus. 245

8.2.2 Limbic Nuclei: The Anterior, Medial, Lateral
Dorsal, Midline, and Intralaminar Nuclei (Fig. 8.4) 248

8.2.3 Specific Associational: Polymodal/Somatic Nuclei,
the Pulvinar Nuclei (Fig. 8.5) 249

8.2.4 Special Somatic Sensory Nuclei: Vision and Audition,
the Lateral Geniculate and Medial Geniculate Nuclei
of the Metathalamus (Fig. 8.5): The Special Somatic
Sensory Cranial Nerves Are Cranial Nerves II and VIII 251

8.2.5	Nonspecific Associational	252
8.3	White Matter of the Diencephalon	253
8.4	Relationship Between the Thalamus and the Cerebral Cortex (Figs. 8.7 and 8.8)	255
8.5	Subthalamus (Fig. 8.3)	259
8.6	Thalamic Atlas Figs. 8.10, 8.11, and 8.12	261
8.7	Level: Midbrain, Diencephalic Junction (Fig. 8.10)	262
8.8	Level: Midthalamus (Fig. 8.11)	264
8.9	Level: Anterior Tubercle of Thalamus (Fig. 8.12)	266
	Bibliography	267
9	Hypothalamus, Neuroendocrine System, and Autonomic Nervous System	269
9.1	Hypothalamus	269
9.1.1	Hypothalamic Nuclei	269
9.1.2	Afferent Pathways	273
9.1.3	Efferent Pathways (Fig. 9.6)	273
9.1.4	Functional Stability	275
9.2	Neuroendocrine System, the Hypothalamus, and Its Relation to the Hypophysis	275
9.2.1	Hypophysis Cerebri	276
9.2.2	Hypothalamic–Hypophyseal Portal System	277
9.2.3	Hypophysiotrophic Area	278
9.2.4	Hormones Produced by Hypothalamus	279
9.2.5	Hormones Produced in Adenohypophysis (Fig. 9.12)	279
9.2.6	Case 9.1	282
9.2.7	Hypothalamus and the Autonomic Nervous System (Fig. 9.12)	284
9.2.8	Functional Localization	285
9.2.9	Water Balance and Neurosecretion (Fig. 9.7)	286
9.2.10	Hypothalamus and Light Levels: Optic Nerve Terminations in the Hypothalamus	287
9.2.11	Hypothalamus and Emotions	289
9.2.12	Hypothalamus and Light Levels	289
9.3	Autonomic Nervous System (Fig. 9.13)	290
9.4	Parasympathetic System (Craniosacral) (Fig. 9.13)	292
9.4.1	Cranial Nerves: III, VII, IX, and X	292
9.4.2	Sacral Segments S2–S4	292
9.5	Sympathetic System (Fig. 9.13)	293
9.6	Enteric Nervous System (Fig. 9.14)	294
	Bibliography	295
10	Cerebral Cortex Functional Localization	297
10.1	Anatomical Considerations	297
10.1.1	Cerebral Cortical Gray Matter	297
10.1.2	Cytology	299

- 10.2 Basic Design and Functional Organization of Cerebral Cortex 302
- 10.3 Fundamental Types of Cerebral Cortex 302
- 10.4 The Schema of the Fundamental Six-Layered Neocortices (Refer to Fig. 10.4) 303
- 10.5 Organization of the Neocortex (Fig. 10.6a). 304
 - 10.5.1 How the Brodmann Areas Got Their Numbers 307
- 10.6 Correlation of Neocortical Cytoarchitecture and Function 307
 - 10.6.1 Frontal Lobe (Figs. 10.8 and 10.9 and Table 10.1) 308
 - 10.6.2 Motor Areas 311
 - 10.6.3 Parietal Lobe (Figs. 10.9 and 10.10) 314
 - 10.6.4 Temporal Lobe (Figs. 10.6 and 10.8). 315
 - 10.6.5 Occipital Lobe (Figs. 10.8 and 10.9 and Table 10.4). 317
- 10.7 Subcortical White Matter Afferents and Efferents. 318
- 10.8 Afferent Inputs and Efferent Projections of the Neocortex 320
 - 10.8.1 Non-thalamic Sources of Cortical Input 321
- 10.9 Methods for the Study of Functional Localization in the Cerebral Cortex 322
 - 10.9.1 How Do We Study Function? 322
 - 10.9.2 How Do We Confirm the Location of the Pathology? 324
 - 10.9.3 Neurophysiology Correlates of Cortical Cytoarchitecture and the Basis of the Electroencephalogram. 325
- General Bibliography-Cerebral Cortical Organization. 327

Part II The Systems

- 11 Motor System, Movement, and Motor Pathways. 331**
 - 11.1 Cerebral Cortical Motor Functions 331
 - 11.1.1 Reflex Activity 331
 - 11.2 Concept of Central Pattern Generators 332
 - 11.3 Postnatal Development of Motor Reflexes 335
 - 11.4 Relationship of Primary Motor, Premotor, and Prefrontal Cortex. 336
 - 11.4.1 Functional Overview 336
 - 11.4.2 Primary Motor Cortex: Area 4 (Figs. 11.3 and 11.5). 338
 - 11.4.3 Areas 6, Premotor Cortex (Areas 6 and 8; Fig. 11.5) 341
 - 11.4.4 Dysfunction in the Premotor and Supplementary Motor Cortex 344
 - 11.4.5 Prefrontal Cortex (Areas 9, 10, 11, 12, 13, 14, and 46, Fig. 11.5). 348
 - 11.5 Disorders of Motor Development 349
 - 11.6 Studies of Recovery of Motor Function in the Human 350
 - 11.7 Cortical Control of Eye Movements-Frontal and Parietal Eye Fields. 351
 - 11.8 Major Voluntary Motor Pathways 354

- 11.8.1 Rubrospinal and Tectospinal Tracts (Fig 4.16; Table 4.2) 358
- References 358
- 12 Motor System II: Basal Ganglia 361**
 - 12.1 Clinical Symptoms and Signs of Dysfunction 368
 - 12.2 Specific Syndromes, Parkinson’s Disease, and the Parkinsonian Syndrome (Olanow and Tanner (1999) and Riley and Lang (2007)) 369
 - 12.3 Differential Diagnosis of Parkinson’s Disease 377
 - 12.4 Chorea, Hemichorea, and Hemiballismus: 378
 - 12.5 Hemichorea and Hemiballism 379
 - 12.6 Other Movement Disorders Associated with Diseases of the Basal Ganglia 384
 - Bibliography 386
- 13 Motor Systems III: The Cerebellum Movement and Major Fiber Pathways of the Cerebellum 393**
 - 13.1 Anatomic Considerations 393
 - 13.1.1 Subdivisions of the Cerebellum 393
 - 13.1.2 Longitudinal Divisions 394
 - 13.1.3 Transverse Divisions 395
 - 13.2 Cytoarchitecture of the Cerebellum 395
 - 13.3 Cerebellar Circuitry–Cerebellar Peduncles (Fig 13.4) 398
 - 13.3.1 Afferents 398
 - 13.3.2 Efferents 399
 - 13.4 Topographic Patterns of Representation in Cerebellar Cortex 401
 - 13.5 Functions of the Cerebellum and Correlations 401
 - 13.5.1 Regional Functional Correlations 401
 - 13.6 Effects of Disease on the Cerebellum 403
 - 13.7 Major Cerebellar Syndromes 404
 - 13.8 Syndrome of the Flocculonodular Lobe and Other Midline Cerebellar Tumors 404
 - 13.9 Syndrome of the Anterior Lobe 408
 - 13.10 Syndrome of the Lateral Cerebellar Hemispheres (Neocerebellar or Middle-Posterior Lobe Syndrome) 409
 - 13.10.1 Syndromes of the Cerebellar Peduncles 411
 - 13.11 Other Causes of Cerebellar Atrophy 412
 - 13.12 Vascular Syndromes of the Cerebellum 412
 - 13.13 Syndromes of Occlusion and Infarction 413
 - 13.13.1 Neurological Examination 415
 - 13.14 Cerebellar Degenerative Diseases 415
 - 13.14.1 Gene Mechanisms 416
 - 13.14.2 Olivopontocerebellar Atrophy (OPCA) 417
 - 13.15 An Overview of Tremors 418

- 13.16 Major Fiber Pathways of the Cerebellum 419
 - 13.16.1 Cerebellar Peduncles (Fig. 13.4) 419
 - 13.16.2 Spinocerebellar Tracts (Fig. 13.11) 420
 - 13.16.3 Cuneocerebellar Tract 422
- Bibliography 422
- 14 Somatosensory Functions and the Parietal Lobe 427**
 - 14.1 Postcentral Gyrus: Somatic Sensory Cortex
[Primary Sensory S-I] 427
 - 14.1.1 Neurological Examination 432
 - 14.2 Superior and Inferior Parietal Lobules 433
 - 14.2.1 Dominant Hemisphere in the Parietal Lobules 435
 - 14.2.2 Non-dominant Hemisphere in the Parietal Lobules 435
 - 14.3 Parietal Lobe and Tactile Sensation from the Body 440
 - 14.3.1 Tactile Sensation from the Body: Medial
Lemniscus (Fig. 14.5) 440
 - 14.3.2 Tactile Sensation from the Head: The Trigeminal
Nerve (Fig. 14.6) 442
- Bibliography 444
- 15 Visual System and Occipital Lobe 445**
 - 15.1 Structure of the Eye 445
 - 15.2 Photoreceptor Layer: Rods and Cones 450
 - 15.2.1 Optic Nerve 452
 - 15.2.2 Blind Spot 453
 - 15.3 Visual Pathway (Figs. 15.4 and 15.5a–c) 453
 - 15.3.1 Retina and Visual Fields 453
 - 15.4 Occipital Lobe 459
 - 15.4.1 Areas in the Occipital Lobe: 17, 18, and 19 (V1–V5) 459
 - 15.4.2 Parallel Processing in the Visual Cortex 459
 - 15.5 Perceptual Pathways: Color Vision 462
 - 15.5.1 Effects of Stimulation of Areas 17, 18, and 19 464
 - 15.6 Summary 464
 - 15.6.1 Effects of Lesions in the Occipital Visual Areas 464
 - 15.6.2 Occipital Lobe and eye Movements 466
 - 15.7 Visual Field Deficits Produced by Lesions
in the Optic Pathway 466
 - 15.7.1 Case Histories: Examples with Lesions
in the Visual System 467
 - 15.7.2 Lesions in Occipital Cortex Result: Congruous
Homonymous Hemianopsia 472
- Bibliography 475
- 16 The Limbic System, Temporal Lobe, and Prefrontal Cortex 477**
 - 16.1 Olfactory System 478
 - 16.2 Limbic System 483

- 16.2.1 Subcortical Structures (Table 16.2) 483
- 16.2.2 Cortical Structures in the Limbic System 485
- 16.3 Principal Pathways of the Limbic System 497
- 16.4 Role of the Temporal Lobe in Learning and Memory 499
- 16.5 The Role of the Prefrontal Granular Areas and Emotions 514
- 16.6 Functional Neurosurgery 516
- 16.7 The Limbic Brain as a Functional System 520
- Temporal Lobe References 521
- 17 Higher Cortical Functions 531**
 - 17.1 Cerebral Cortex and Disturbances of Verbal Expression 531
 - 17.2 Cerebral Dominance 532
 - 17.3 Aphasia: Dominant Hemispheric Functions 534
 - 17.3.1 Nonfluent Aphasias 538
 - 17.3.2 The Fluent Aphasias 544
 - 17.4 Non-dominant Parietal Hemisphere Functions 550
 - 17.5 Role of the Corpus Callosum in the Transfer of Information 550
 - General or Historical References 551

Part III Neuropathology

- 18 Cerebral Vascular Disease 557**
 - 18.1 Occlusive Cerebrovascular Disease 558
 - 18.2 Clinical Correlates of Vascular Territories: Syndromes 559
 - 18.3 Intracerebral Hemorrhage 571
 - 18.4 Subarachnoid Hemorrhage (SAH) 572
 - 18.5 Common Sites of Saccular Aneurysms (Fig. 18.7), Table 18.1 572
- 19 Neuropathology, Nonvascular: Trauma, Neoplasms, and Communicable Diseases 577**
 - 19.1 Neuropathology Due to Trauma 577
 - 19.1.1 Complications of Skull Fractures 577
 - 19.1.2 Concussions 578
 - 19.1.3 Contusions and Lacerations 579
 - 19.1.4 Extradural Hematomas and Subdural Hematomas 581
 - 19.1.5 Traumatic Brain Injury/TBI 588
 - 19.1.6 Metastatic Lesions to the Brain 592
 - 19.1.7 Meningioma: Tumors in the Coverings of the Brain 593
 - 19.1.8 Glioma: Tumors Intrinsic to the Brain 594
 - 19.1.9 Pituitary Tumor 595
 - 19.2 Neuropathology Due to Communicable Diseases 596
 - Reference 598

Part IV The Nonnervous Elements

- 20 Non-nervous Elements in the CNS 601**
 - 20.1 Skull 601

- 20.2 Meninges: Coverings of the Brain 602
- 20.3 Blood Supply to the Brain 605
 - 20.3.1 Arterial Blood Supply Figs. 20.6, 20.7, 20.8, 20.9, 20.10, and 20.11 605
- 20.4 Venous Drainage of the Brain, Head, and Neck (Fig. 20.13) 610
- 20.5 Ventricular System: Figs. 20.14 and 20.15 613
- 20.6 Cerebrospinal Fluid 615
- 20.7 The Glymphatic System and Drainage from the Brain 616
- 20.8 Glands Associated with the Brain 616
- Reference 617
- 21 Case History Problem Solving** 619
- 22 Movies on the Brain** 647
 - 22.1 Neuroanatomists, Anatomists, Neurosurgeons, and Neurologists 647
 - 22.2 Developmental Disorders 648
 - 22.3 Spinal Cord/Brain Stem Disorders 649
 - 22.4 Disorders of Motor Systems and Motor Control 651
 - 22.5 Cerebral Cortex 652
 - 22.6 Limbic System 653
 - 22.7 Cerebrovascular Disease 654
 - 22.8 Brain Trauma 655
 - 22.9 Brain Tumors and Increased Intracranial Pressure 656
 - 22.10 Infections 657
 - 22.11 Toxic and Metabolic Disorders 658
 - 22.12 Disorders of Myelin 661
 - 22.13 Seizures and Epilepsy 661
 - 22.14 Coma 662
 - 22.15 Memory 663

Part V Atlas

- 23 Descriptive Atlas** 667
 - 23.1 Gross Brain Sections: Coronal and Horizontal Sections 667
 - 23.2 Gross Brain: Lateral Surface (Fig. 23.1) 668
 - 23.3 Gross Brain: Medial Surface (Fig. 23.2) 669
 - 23.4 Gross Brain Slices: Coronal (Figs. 23.3–23.9) 670
 - 23.5 Gross Brain Slices Horizontal (Fig. 23.10) 677
- 24 Myelin-Stained** 679
 - 24.1 Myelin-Stained Coronal Brain Sections (Figs. 24.1, 24.2, 24.3, 24.4, 24.5, 24.6, and 24.7) 679
 - 24.2 Myelin-Stained Horizontal Sections (Figs. 24.8, 24.9, 24.10, and 24.11) 685
 - 24.3 Myelin-Stained Sagittal Sections (Figs. 24.12 and 24.13) 689

Part I
Introduction to the Central Nervous
System

Chapter 1

Introduction to the Central Nervous System

Abstract The brain and spinal cord form the central nervous system. The brain is the part of the central nervous system that is housed in the cranium/skull. It consists of the brain stem, diencephalon, cerebellum, and cerebrum. At the foramen magnum, the highest cervical segment of the spinal cord is continuous with the lowest level of the medulla of the brain stem. The spinal nerves from the sacral, lumbar, thoracic, and cervical levels of the spinal cord form the lower part of the peripheral nervous system and record general sensations of pain, temperature touch, and pressure. The 12 cranial nerves attached to the brain form the upper part of the peripheral nervous system and record general sensations of pain, temperature touch, and pressure, but in addition we now find the presence of the special senses of smell, vision, hearing, balance, and taste. The blood supply to the brain originates from the first major arterial branches from the heart insuring that over 20% of the entire supply of oxygenated blood flows directly into the brain.

Keywords Neuron • Glia • Spinal cord • Brain • Brain stem • Cerebellum • Diencephalon • Basal ganglia • Cerebrum • Lobes of the cerebrum • Cases

Homo sapiens evolved into the modern human in southern Africa for millions of years. About 100,000–60,000 years ago, they struck out and spread initially along the continental coast throughout Africa, into the Middle East, Europe, the Indian subcontinent, and the rest of Asia and finally crossed the land bridge from Asia into North America and then down into South America (the Out of Africa theory). The evidence for this comes partly from dating bones to specific periods, but also from genetics. As you move further away from Africa, across Asia, and then the Americas, the genetic diversity of indigenous populations drops. This implies that the source of these populations was in Africa and gradually lost diversity as it expanded.

Human beings enter the world naked but equipped with a nervous system that, with experience, is ready to function in almost any environment.

One word summarizes the function of the nervous system: “reaction.” The central nervous system (brain and spinal cord) monitors and controls the entire body by its peripheral divisions, which are distributed to all the muscles, organs, and tissues. The brain has an advantageous site in the head and above the neck, which can move in about a 140° arc. Close to the brain are all of the specialized sense organs, which permit us to see, smell, taste, and hear our world. The central nervous system is protected by fluid-filled membranes, the meninges, and surrounded by the bony skull and vertebrae.

1.1 The Neuron

The basic conducting element in the nervous system is the nerve cell, or neuron (Fig. 1.1). A neuron has a cell body, dendrite, and axon. The cell body contains many of the organelles vital to maintain the cell structure and function, including the nucleus and nucleolus, and is considered the tropic center of the nerve cell. The dendrites extend from the cell body and increase the receptive surface of the neuron. The axon leaves the cell body and connects to other cells. Axons are covered by a lipoproteinaceous membrane called *myelin* that insulates the axons from the fluids in the central nervous system. The site of contact between the axon of one nerve cell and the dendrites and cell body of another neuron is the *synapse* (see Chap. 2). The cells in the nervous system are classified based on their shapes: unipolar, bipolar, and multipolar (Fig. 1.1; Table 1.1). In the central nervous system, the nerve cells are supported by glia and blood vessels; in the peripheral nervous system, they are supported by satellite cells, fibroblasts, Schwann cells, and blood vessels.

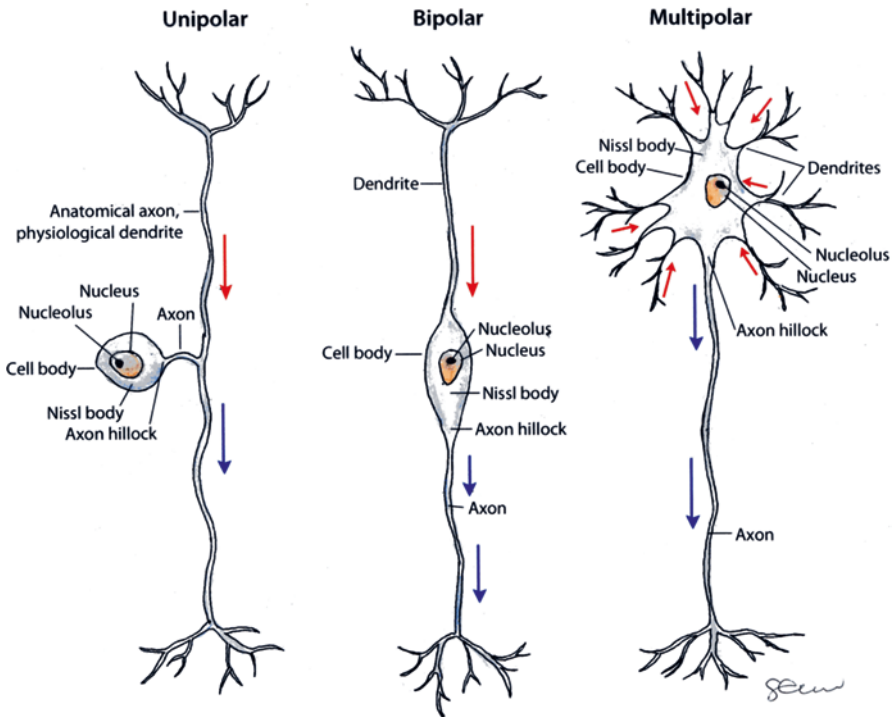


Fig. 1.1 Types of neurons in the central nervous system. The cells in the nervous system are classified based on their shapes: unipolar, bipolar, and multipolar. The input (red) reaches the dendrites of each cell and is then transported (blue) into the axon where it connects to the next neuron via a synaptic interruption

Table 1.1 Types of neurons in the nervous system

Neuronal type	% of neurons	Location
Unipolar 0.05	0.5	– Dorsal root ganglia of the spinal cord
		– Cranial nerve ganglia of the brain stem
		– Mesencephalic nucleus of CN V in the midbrain
Bipolar	0.05	Retina, inner ear, taste buds
Multipolar:		
– Peripheral	– 0.1	– Autonomic ganglia
– Central	– 99.8	– Brain and spinal cord

There are three basic categories of neurons:

1. Receptors. These neurons bring the information into the CNS, and these cells form either the ganglia of the spinal dorsal roots (at spinal cord levels C1–S5) and ganglia of the cranial nerves which have general sensory functions (CNs V, VII, IX, and X) or the ganglion cells associated with the special senses of olfaction (CN I), vision (CN II), hearing and balance (CN VIII), and taste (CNs VII, IX, and X).

Ganglia. *Sensory ganglia* are found outside the central nervous system and contain the first-order neurons in the sensory systems, and they are the dorsal root ganglia on the 32 segments of the spinal cord and the sensory ganglia on cranial nerves, V, VII, VIII, IX, and X. They also form the primary cell bodies in the special senses associated with CN I (olfaction); II (vision); VII, IX, and X (taste); and VIII (hearing and balance).

Motor/autonomic ganglia are found throughout the body, and they are either sympathetic or parasympathetic. The sympathetic ganglia originate from thoracolumbar levels T1–L2, while the parasympathetic ganglia originate from cranial nerves III, VII, IX, and X, which control many glands, smooth muscles, and cardiac muscles.

The sympathetic ganglia (thoracolumbar locations) are located in paravertebral chains alongside the vertebrae at T1–L2.

The parasympathetic ganglia (craniosacral – CN – III, VII, IX, and X; spinal cord sacral levels) are mostly terminal as they are located in close proximity to most of the structures they innervate with the exception of the maxillary glands that are distant from the ganglia.

2. Effectors. The ventral horn cells – the motor cranial nerve nuclei (CNs III–VII, IX, X, XI, and XII) – and motor division of the autonomic nervous system form the effectors which innervate the three types of muscles in our bodies: skeletal, smooth, and cardiac.
3. Interneurons. These are the vast majority of the neurons in the central nervous system. The areas in the central nervous system that contain high numbers of neuronal cell bodies are called *gray matter*, while the regions that contain primarily myelinated axons are called *white matter*. Neurons are organized into ganglia, nuclei, or layered cortices.

Table 1.2 Sensory receptors

Class of receptor	Function	Location
Chemoreceptors	– Taste	– Taste buds on the tongue
	– Smell	– Olfactory mucosa in the nose
Mechanoreceptors	– Balance	– Inner ear – semicircular canals
	– Sound	– Inner ear – cochlea
	– Tactile discrimination and pressure	– Skin, muscle, tendons, joints
Nociceptor	Pain	Free nerve endings in the skin and organs
Thermoreceptor	Temperature	Skin, tissues, and organs

Nuclei. Throughout the brain and spinal cord, there are groupings of neurons with a common function; these are the nuclei. They are found throughout the spinal cord (ventral and dorsal horn), brain stem (cranial nerve nuclei, reticular formation), diencephalon (nuclei of the thalamus, hypothalamus, subthalamus, and metathalamus), basal ganglia (caudate, putamen, globus pallidus, substantia nigra), and cerebral cortex (amygdaloid nuclei).

Lamina. In the cerebral cortex, cerebellar cortex, and superior colliculus, the gray matter is on the surface and organized anatomically into horizontal columns and physiologically into vertical columns permitting a nearly infinite number of interconnections.

The senses. Aristotle distinguished five senses: hearing, sight, smell, taste, and touch. Modern neuroscience, however, includes the *five special senses* (balance, vision, hearing, taste, and smell) and the *four general senses* (pain, temperature, touch, and pressure). Humans have evolved a series of specialized receptors for each of these different sensory functions (Table 1.2). The special sensory apparatuses are found in the head: the eye and its protective coverings and muscles, the membranous labyrinth in the temporal bone for hearing and balance, the nose with olfactory receptors, and the tongue with taste buds. The *receptors for general sensation* (mechanoreceptors, nociceptors, and thermoreceptors) are located primarily in the body's largest organ, the skin. Certain areas, e.g., the lips, fingers, feet, and genitalia, have a proliferation of the tactile mechanoreceptors. Everywhere except on the soles and palms we have hair, which is an important tactile receptor but is continually being depleted by our concern for grooming. The pain receptors, or free nerve endings in the skin, are located throughout the body, but probably more receptors are in the skin over the face, lips, hands, and feet and then over the rest of the body. As you review the receptors in Table 1.2, sense on your own body how the soles are especially good for feeling pressure and placing the body safely in light or darkness and the fingers and face are sensitive to touch and temperature. Remember that we have only discussed the skin receptors so far, which respond to external stimuli. However, there are also similar receptors within the respiratory, cardiovascular, endocrine, gastrointestinal, and urogenital systems that monitor our internal milieu.

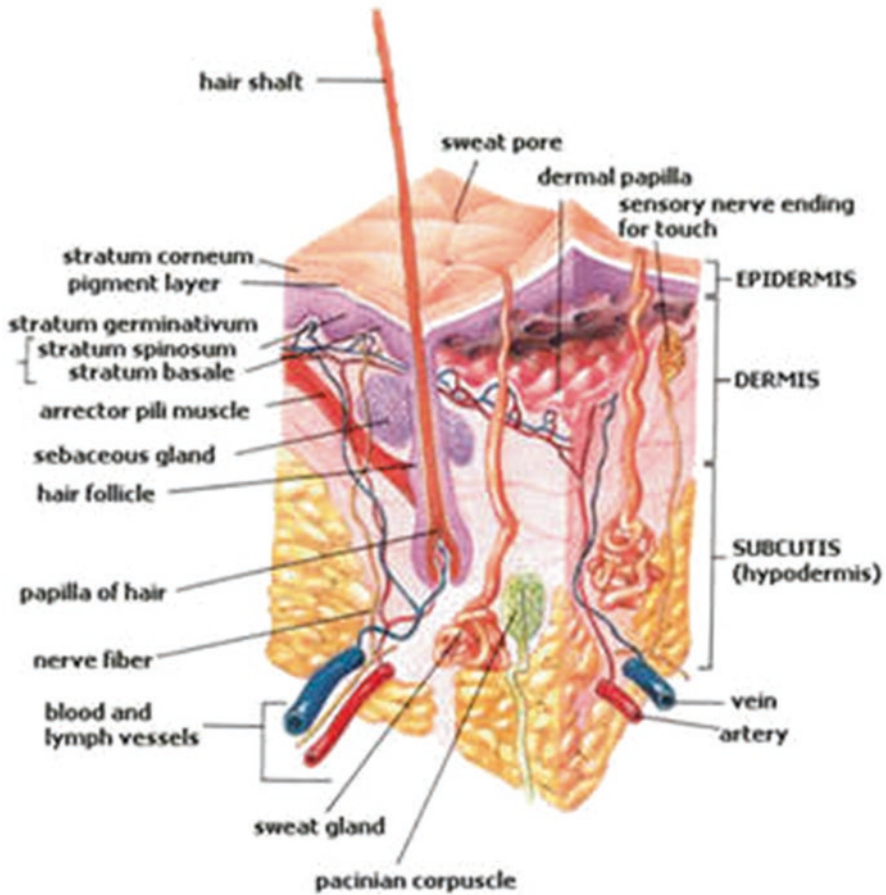


Fig. 1.2 Hairy skin showing the epidermis, dermis, and hypodermis. The blood vessels, lymph vessels, sweat glands, hair follicle, Pacinian tactile receptor, and free nerve endings (for pain) are also demonstrated (from Human free [science.org](https://www.science.org))

Muscles. The $640 \pm$ muscles in the body form the bulk of the body and consist of three different functional and histological entities: *skeletal*, *smooth*, and *cardiac*. Skeletal muscles are found in the head, neck, arms, legs, and trunk and permit us to undertake voluntary movements. Smooth, or unstriated, muscles are found in the viscera, blood vessels, and hair follicles. Cardiac muscles form the auricles and ventricles of the heart.

Each muscle group has a specialized nerve ending that permits the impulse carried down to the motor nerve via a peripheral nerve to stimulate the muscle through release of a specific chemical. Contraction of the three muscle groups in response to sensory information originates from the central nervous system via the efferent/motor peripheral nerves.

Sensory receptors. The general and special sensory receptors in the skin (Fig. 1.2) provide the *afferent* nerves that carry sensory information to the spinal cord and brain. The brain analyzes the sensory input before the muscles, which are controlled

by the efferent nerves carrying information from the brain or spinal cord, and makes a response. These integrative functions of the central nervous system form the bulk of the discussion in this book.

1.2 The Nervous System

The nervous system consists of a peripheral and central division (Fig. 1.3). The central nervous system (brain and spinal cord, Fig. 1.3) is surrounded by fluid-filled membranes (meninges with CSF), and the brain is further protected in the bony

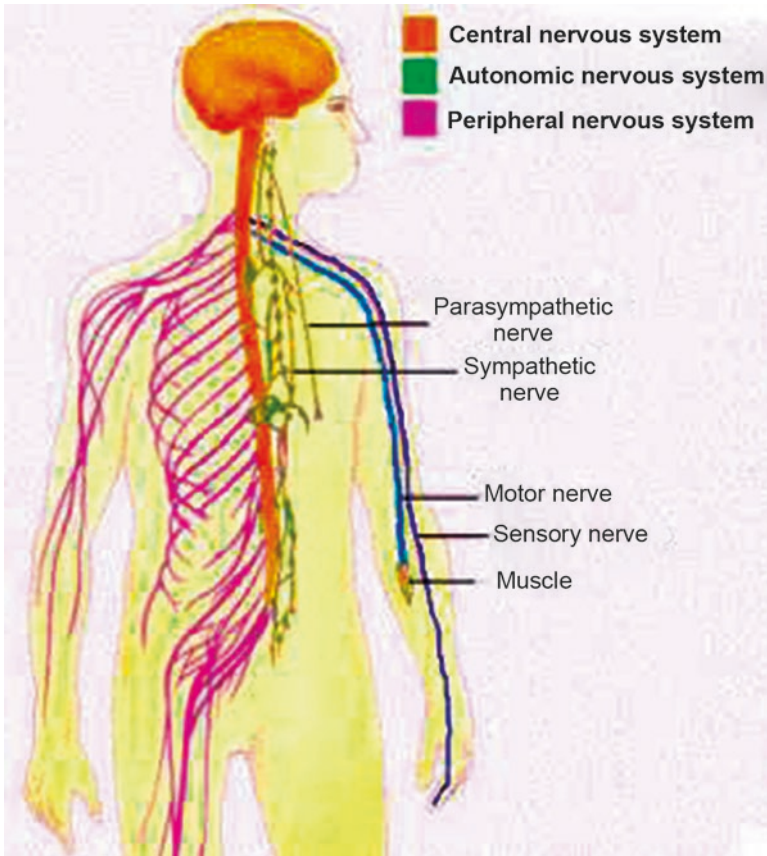


Fig. 1.3 Human nervous system (from Wikipedia 2016)

skull, while the spinal cord is housed in the bony vertebrae. In contrast, the peripheral nervous system that brings information from and to the central nervous system lacks a bony covering, but is protected by the fascia, skin, muscles, and organs where it distributes. Sensory information enters the central nervous system through the afferent divisions of the peripheral nerves.

1.2.1 Peripheral Nervous System (Fig. 1.3)

Peripheral nerves are found everywhere in the body: skin, muscles, organs, and glands. Peripheral nerves originate from either the spinal cord or the 12 cranial nerves associated with the brain. The peripheral nervous system is divided into a somatic and a visceral division. The *somatic division* innervates the skin and skeletal muscles in the body. The visceral, or *autonomic division*, innervates the cardiac muscles of the heart and the smooth muscles and receptors in the blood vessels and gastrointestinal, respiratory, urogenital, and endocrine organs. The details of the peripheral nervous system are usually taught as part of gross anatomy, so the student may want to review an anatomy text.

1.2.2 Central Nervous System

The central nervous system consists of the spinal cord and brain. The spinal cord has 32 segments, while the brain consists of the brain stem, cerebellum, diencephalons, and cerebrum. In Fig. 1.3, we show an isolated entire human CNS, while in Fig. 1.4, we demonstrate the CNS in situ. Attached to all of the 32 segments of the spinal cord and the brain stem are the sensory ganglia that form the first link in the sensory system and bring the sensory information into the central nervous system. Motor axons exit from each of the 32 segments of the spinal cord and all levels of the brain stem and connect the central nervous system to all muscles and organs in the body. In the spinal cord, much of the brain stem, and diencephalon, the neurons are organized into nuclei, while in the superior colliculus of the brain stem, cerebellum, and cerebrum, the neurons are organized anatomically into layers and functionally into vertical columns.

1.2.2.1 Spinal Cord (Fig. 1.5)

The spinal cord, Chap. 4, is that portion of the central nervous system that lies in the vertebral canal from the upper border of the atlas (first cervical vertebrae) to the lower border of the first lumbar vertebrae in the adult (or third lumbar vertebrae in the neonate). The spinal cord has 32 segments divided into five regions – cervical, thoracic, lumbar, sacral, and coccygeal – and these regions innervate specific regions

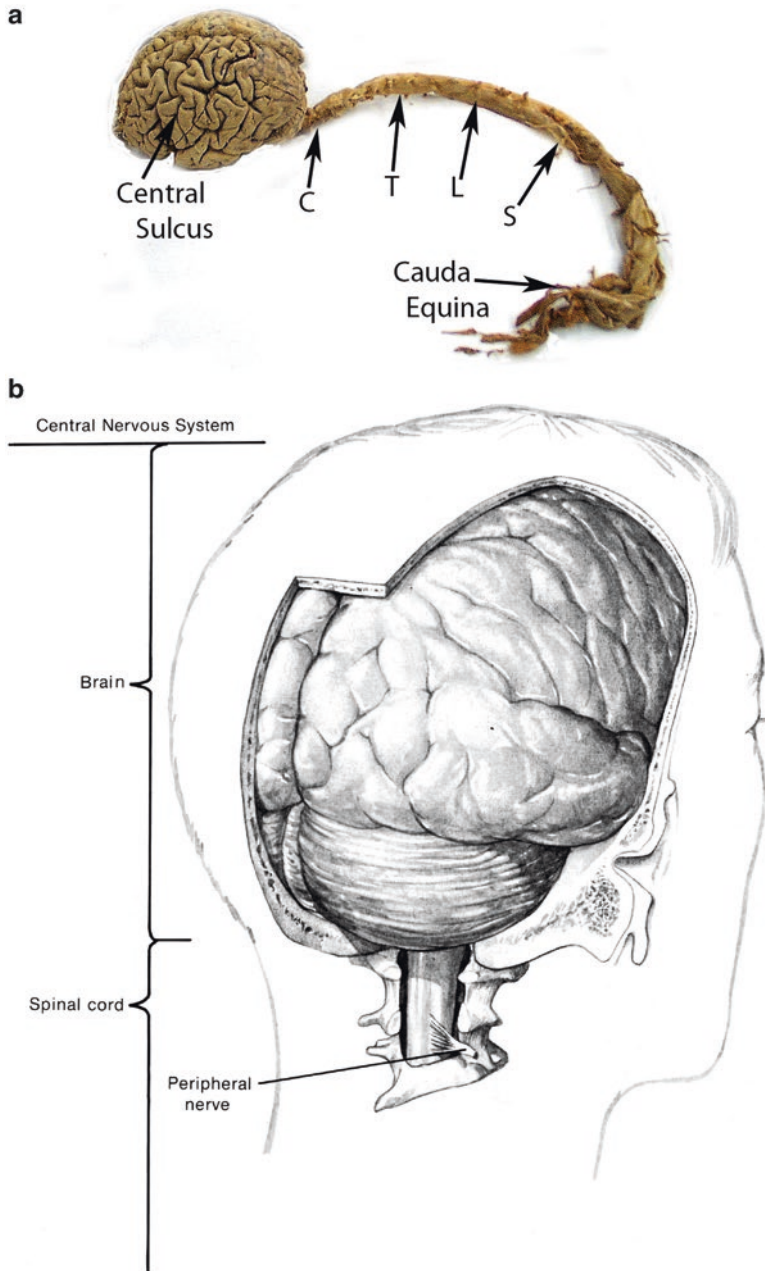
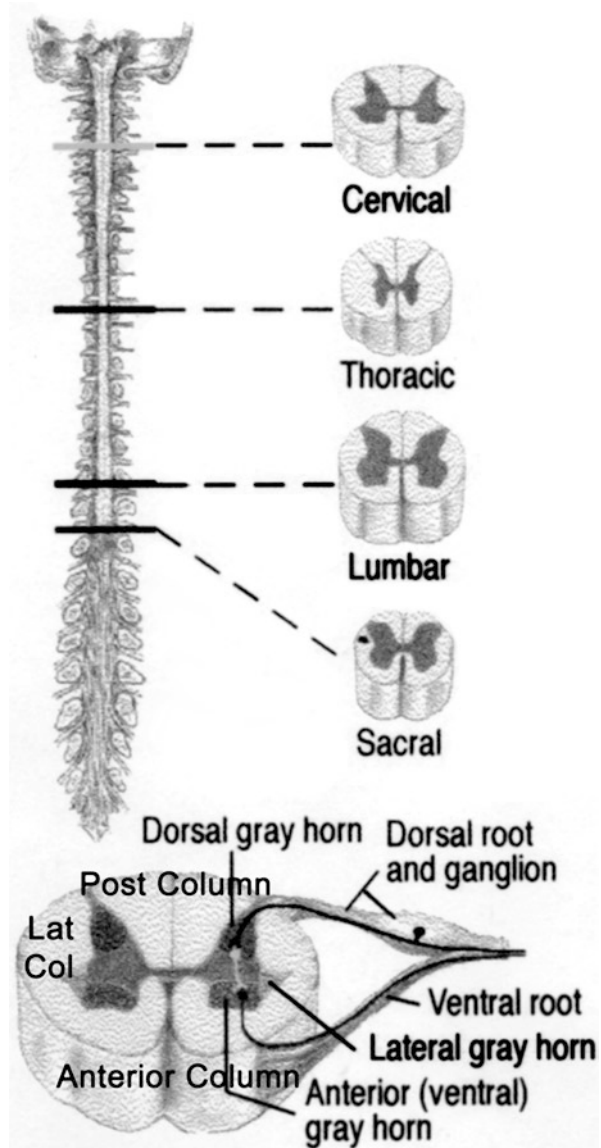


Fig. 1.4 Central nervous system. In (a) a human CNS (brain and spinal cord) is shown, while in (b) the brain and spinal cord are shown in situ in the skull. From an Introduction to Neurosciences, Curtis, Jacobson, Marcus. Saunders 1974

Fig. 1.5 Spinal cord



in the neck and upper extremity (cervical segments), thorax and abdomen (thoracic levels), anterior leg and thigh (lumbar segments), and buttock and posterior leg and thigh (lumbar segments). This ordered relationship between the spinal cord and body produces a somatotopic organization throughout the central nervous system.

In the spinal cord, the parenchyma is organized simply into columns of gray (location of neuronal cell bodies) and white matter (location of axons covered with myelin) with the gray matter centrally placed and surrounded by the white matter.

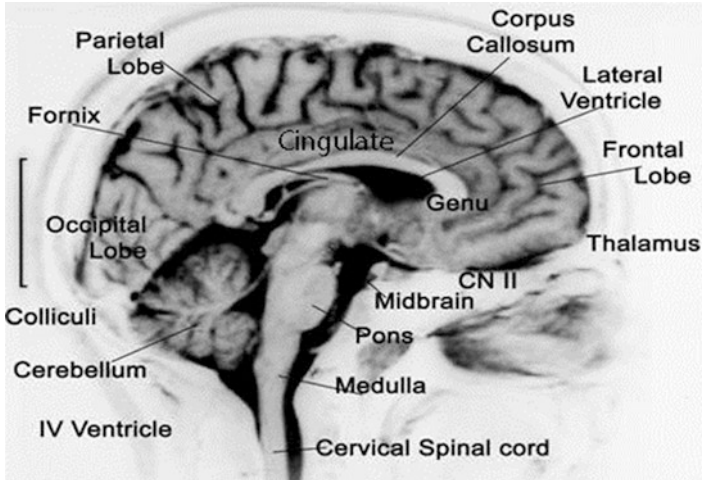


Fig. 1.6 The brain. MRI sagittal plain T2

This organization is not evident as one looks at isolated cross sections, but when these sections are reconstructed serially, this columnar organization in the gray and white matter is apparent. The columns of gray matter in the spinal cord appear in the shape of a butterfly and are called horns and are divided into a dorsal sensory horn, a ventral motor horn, intermediate zone, and commissural region. The largest neuronal cell bodies are found in the ventral horn (*ventral horn cells*), whose axons form the efferent division of the peripheral nervous system and innervate the skeletal muscles (Fig. 1.5). The white matter of the spinal cord is divided into three columns: anterior, posterior, and lateral. The pathways interconnecting the spinal cord and brain are found in these columns.

The spinal cord has a tubular shape and has two regions of enlargement, the lower cervical that controls the upper extremity and the lumbosacral enlargement that controls the lower extremity.

1.2.2.2 Brain

Brain Stem (Chaps. 5–7) (Fig. 1.6)

The columnar organization seen in the gray and white matter of the spinal cord is modified in the brain stem by the development of the ventricular system and the presence of the cranial nerves.

The brain stem (Figs. 1.6 and 1.7) consists of three regions from inferior to superior: *medulla*, *pons*, and *midbrain*. The brain stem is often the most difficult region of the central nervous system for the student to learn, because of the presence of the cranial nerves and associated nuclei. You may initially feel overwhelmed by its