

Stanley Jacobson · Elliott M. Marcus

Neuroanatomy for the Neuroscientist

Second Edition

Neuroanatomy for the Neuroscientist

Second Edition

Stanley Jacobson • Elliott M. Marcus

Neuroanatomy for the Neuroscientist

Second Edition

 Springer

Stanley Jacobson, PhD
Professor of Anatomy and Cellular
Biology Fulbright Scholar
Tufts University Health Sciences School
Boston, MA, USA
stan.jacobson@tufts.edu

Elliott M. Marcus, MD
Professor of Neurology
University of Massachusetts
School of Medicine
Worcester, MA, USA

ISBN 978-1-4419-9652-7 e-ISBN 978-1-4419-9653-4
DOI 10.1007/978-1-4419-9653-4
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2011932536

© Springer Science+Business Media, LLC 2011

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher (Springer Science+Business Media, LLC, 233 Spring Street, New York, NY 10013, USA), except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden.

The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

*To our wives: Avis Jacobson and Nuran Turksay.
To our children: Arthur Jacobson, Robin Seidman,
Erin Marcus, and Robert Letson, and
to our grandchildren: Ross Jacobson, Zachary Letson,
and Amelia Letson.
To our teachers, students, and colleagues.*

About the Author



Dr. Elliott Marcus, Professor of Neurology at University of Massachusetts (Emeritus). At 78, Dr. Marcus – a neurologist and educator for five decades at Tufts Medical Center, Tufts University School of Medicine, and the University of Massachusetts Medical School at Saint Vincent Hospital – died on July 25, 2011 in Massachusetts General Hospital in Boston.

Even as the end drew near, Dr. Elliott Marcus pressed on with his life’s work: sharing the knowledge he had gleaned through a lifetime of dedicated study and teaching neuroscience. He received his undergraduate education at Yale University and earned an MD from Tufts University School of Medicine. He was trained in neurology at Tufts Medical Center and also served with distinction for two years in the US Army. He taught at Tufts University School of Medicine from 1964 to 1976 where he was the “father” of neuroscience teaching to medical students. He then moved to St. Vincent’s Hospital in Worcester Massachusetts in 1976 where he was Chief of Neurology. He also was a Professor of Neurology at the University of Massachusetts and an active member of that department. He was a clinical neurologist and he published many papers on diagnosis and treatment of seizure disorders. He retired in 1998 and continued active teaching of neurology residents and medical students at UMass until just before his death.

Even as non-Hodgkin’s lymphoma took its toll on Dr. Marcus, he pushed himself, discussing his contributions to a forthcoming book that he and Dr. Stanley Jacobson, a Professor of Anatomy and Cellular Biology at Tufts Medical School and a friend and colleague for over 40 years, were collaborating on and telling friends to make sure the work continued beyond the span of his limited days. He wanted to live and be there to teach and to be there for his grandchildren.

Friends and colleagues said he was dedicated to his work, loved his family, and inspired generations of doctors. Dr. Thomas Sabin, a Professor of Neurology at Tufts Medical School described Dr. Marcus as a superb neurologist and someone with a brilliant intellect. Dr. David

Chad, a Professor of Neurology and Pathology at UMass Medical School, said Dr. Marcus's passion for neurology and teaching was always evident. Dr. Marcus often traveled from Florida more than a decade after his official retirement in 1998 to work with neurology students. He would talk with them, letting them learn through conversations, rather than just giving the answers, Chad said.

"He had a Socratic method of teaching; he let students sort of find the truth," Chad said. "He would open the subject up. He would bring out the key issues to be discussed. He wouldn't stand up and give the answers. He'd ask questions and give feedback. He was an excellent communicator. He loved sharing what he knew. He brought scholarship to his teaching."

Dr. Cynthia Brown, who first met Dr. Marcus in 1980 as a resident neurologist at UMass Medical School and Saint Vincent's Hospital, described neurology as a "very intellectual specialty." "To have someone as bright and inspiring as Dr. Marcus helps to validate one's choice to be a neurologist," she said. "He's really a doctor's doctor, and it is very sad to think that the upcoming classes of medical students will not be able to have his tutorials."

Boston Globe
Boston, MA

Melvin Mason
Stanley Jacobson

Preface

Neuroanatomy for the Neuroscientist

The purpose of this textbook is to enable a Neuroscientist to discuss the structure and function 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 two authors have a long experience in teaching neuroscience courses at the first or second year level to medical and dental students in which clinical information and clinical problem-solving are integral to the course. In addition, the first author has taught for many years 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 help engage the students. The second author has developed a case history of problem-solving sessions in the book "Integrated Neurosciences" by E.M. Marcus and S. Jacobson, Kluwer 2003 and he also conducted a problem-solving seminar in which all medical students at the University of Massachusetts participated during their clinical neurology clerkship rotation. This provides the students an opportunity to refresh their problem-solving skills and to review that basic science material is essential for clinical neurology. At both levels, we have observed that this inclusion of case history materials reinforces the subject matter learned by markedly increasing the interest of the students in both basic and clinical science material. This text is a modified version of "Integrated Neurosciences" published by Kluwer in 2003. This book is also an updated version of an earlier integrated textbook originally developed by the authors along with Dr. Brian Curtis and published by W.B. Saunders in 1972 as "An Introduction to the Neurosciences." The text provides an updated approach to lesion localization in neurology, utilizing the techniques of computerized axial tomography (CT scanning), magnetic resonance imaging (MRI), and magnetic resonance angiography (MRA). Multiple illustrations demonstrating the value of these techniques in clinical neurology and Neuroanatomical localization have been provided. The clinical cases illustrations have been utilized in the body of the text.

In this, the second edition, decisions had to be made so that the size of the textbook remained within limits that could be managed in most of today's neuroscience courses and we could respond to some of the very worthwhile suggestions from our colleagues. The printed book contains the core topics concerned with the central nervous system. We have divided this book into four sections: I: Introduction to the Central Nervous System (Chaps. 1–10), II: The Systems (Chaps. 11–17), and III: The Non-Nervous Elements (Chaps. 18–21). We have added a chapter with case histories, Chap. 20, and following suggestions from our colleagues have been added as an Atlas (Chap. 22). We have updated "Movies on the Brain", Chap. 21, and we have used several of these movies as an adjunct to the course ("Young Dr. Frankenstein" directed by Mel

Brooks has a wonderful scene introducing the CNS, and “Little Shop of Horrors” directed by Frank Oz features Steve Martin as a dentist. Making 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 with its many episodes and its Medical Manual are at the top of our list!

We have added Chap. 20 with representative cases of disease within the CNS to add in the students, ‘understanding of the disease process within the CNS. We have also included a discussion on the eighth nerve in the cranial nerve chapter and a discussion on the olfactory system in the limbic system chapter. In addition, we have added material in the form of an Atlas at the end of the spinal cord chapter, the brain stem, and thalamic chapters and finally we have included a separate chapter, Chap. 21 as an Atlas with labeled gross sections and myelin stained sections of the brain to aid in identifying the regions within the brain. A number of other topics including cell biology, cell physiology, embryology, nerve, and muscle are usually covered in other courses and the students should examine these topics in those courses. The anatomy of the peripheral nervous system and autonomic nervous system 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 Dr. Marcus. For a number of the cases, our associates at the New England Medical Center, St. Vincent Hospital, Fallon Clinic, and the University of Massachusetts School of Medicine either requested our opinion or brought the 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 the 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 Segaraa 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 MD, MPH while still a medical student at Tufts Medical School developed the illustrated drawings that have been used throughout the second edition of this book to illustrate the retina, pathways, levels of the spinal cord, levels of the brain stem, and levels of the thalamus. Dr. Mary Gauthier Delaplane while a medical student at Boston University School of Medicine provided the anatomical drawings illustrating the cranial nerves, and the Neuroembryology chapter. Anne Que, Paul Ning, Tiffany Mellott, Elizabeth Haskins, and Tal Delman aided Dr. Delaplane. Dr. Marc Bard provided drawings for the earlier version of this text while a student at Tufts University School of Medicine. 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 editors Ann Avouris and Joseph Burns for all their help. Any faults or errors are those of the authors and we would therefore appreciate any suggestions or comments from our colleagues.

Boston, MA
Worcester, MA

Stanley Jacobson
Elliott M. Marcus

Contents

Part I Essential Organization of the Central Nervous System

1 Introduction to the Nervous System	3
The Neuron	3
The Nervous System	6
Peripheral Nervous System	6
Central Nervous System.....	6
Central Nervous System Pathways	13
Case History 1.1	14
Glands Associated with the Brain.....	15
References.....	15
2 Neurocytology	17
The Neuron	17
Dendrites	17
Soma.....	17
Golgi Type I and II Neurons	17
Dendritic Spines	18
Cytoplasm Organelles	20
Nucleus.....	20
Rough Endoplasmic Reticulum or Nissl Body	20
Mitochondria.....	21
Neurosecretory Granules.....	22
Neuronal Cytoskeleton.....	22
Microtubules and Axoplasmic Flow	23
Neurofibrillar Tangles	23
Axon and Axon Origin (Axon hillock).....	24
Myelin Sheath: The Insulator in an Aqueous Media	24
Myelination: Schwann Cell in PNS and Oligodendrocyte in CNS.....	25
Central Nervous System Pathways	25
Synapse	26
Synaptic Structure	26
Synaptic Types	27
Synaptic Transmission	27
Neurotransmitters.....	27
Modulators of Neurotransmission.....	27
Synaptic Vesicles.....	27
Synaptic Types	28
Effectors and Receptors	28

Supporting Cells of the Central Nervous System	28
Astrocytes.....	30
Oligodendrocytes	30
Endothelial Cells.....	31
Mononuclear Cells: Monocytes and Microglia.....	31
Ependymal Cells	33
Response of Nervous System to Injury.....	34
Degeneration	34
Regeneration	34
Blood-Brain Barrier	37
Blood-Brain Barrier	37
Extracellular Space.....	38
References.....	38
3 Neuroembryology and Congenital Malformations	43
Introduction.....	43
Formation of the Central Nervous System.....	43
Neural Crest Cells	43
Histogenesis	44
Repair of Damaged Nervous System	45
Principles of Differentiation Within the CNS	45
Growth Cone Guidance.....	45
Programmed Cell Death.....	45
Neuronal Death	46
Development of Blood Vessels in the Brain.....	46
Development of Ventricular System	46
Formation of Peripheral Nervous System.....	47
Spinal Cord Differentiation: Origin of the Spinal Cord.....	47
Brain Differentiation.....	48
Rhombencephalon (Hind Brain)	48
Mesencephalon.....	49
Prosencephalon	50
Diencephalon.....	50
Cranial Nerves.....	50
Prenatal Development of Cerebral Cortex	53
Neuronal Migration.....	55
Changes in Cortical Architecture as a Function of Postnatal Age.....	55
Neuronal Maturation	56
Abnormal Development.....	57
Malformations Resulting from Abnormalities in Growth and Migration with Incomplete Development of the Brain	58
Genetically Linked Migration Disorders	58
Bibliography	62
4 Spinal Cord with Atlas of Spinal Cord	63
Gross Anatomy	63
Spinal Cord: Structure and Function.....	63
Nerve Roots.....	64
Gray Matter	65
Laminar Organization of Central Gray (Fig. 4.6)	66
Interneurons	67
Segmental Function	68
Motor/Ventral Horn Cells.....	68
Sensory Receptors.....	69

Stretch Receptors	70
Nociception and Pain	71
Modulation of Pain Transmission	72
White Matter Tracts	73
Descending Tracts in the Spinal Cord.....	73
Ascending Tracts in the Spinal Cord.....	74
The Anterolateral Pathway.....	74
III. Upper and Lower Motor Neurons Lesions	76
A. Upper Motor Neuron Lesion (UMN).....	76
B. Lower Motor Neuron Lesion.....	78
IV. Spinal Cord Case Histories	78
Case History 4.1	78
Case History 4.2.....	79
Atlas Spinal Cord	79
References.....	82
5 Brain Stem Gross Anatomy	85
Introduction.....	85
Gross Anatomical Divisions	85
Sites of Transition	85
Relationship of Regions in the Brain to the Ventricular System	86
Gross Anatomy of Brain Stem and Diencephalon.....	86
Anterior Surface of Gross Brain Stem	86
Posterior Surface of Brain Stem and Diencephalon.....	88
Arterial Blood Supply to the Brain Stem and Diencephalon.....	91
Medulla	91
Pons.....	91
Midbrain.....	92
Diencephalon.....	92
References.....	92
6 Brain Stem Functional Localization with Atlas of the Brain Stem	93
Tegmentum.....	93
Differences Between the Spinal Cord and Brain Stem.....	93
Functional Localization in Brain Stem Coronal Sections and an Atlas of the Brainstem.....	93
Medulla	94
Pons.....	98
Midbrain.....	103
Functional Centers in the Brain Stem.....	107
Reticular Formation	107
Respiration Centers	108
Cardiovascular Centers	109
Deglutition.....	109
Vomiting.....	109
Emetic Center.....	110
Coughing.....	110
Taste	110
Localization Dysfunction in the Cranial Nerves.....	111
Localization of Disease Processes in the Brain Stem	112
Guidelines for Localizing Disease in the Brain Stem	112
Neuroanatomical Localization Exercise Chapter 6: Identify the Tracts and Nuclei in the Brain Stem	112
Suggested Readings.....	114

7 The Cranial Nerves	115
How the Cranial Nerves Got Their Numbers.....	115
Functional Organization of Cranial Nerves	115
Other Useful Facts on the Cranial Nerves.....	115
Origins of Cranial Nerves and Associated Muscles.....	118
The Individual Cranial Nerves	118
Cranial Nerve I, Olfactory, Special Sensory/Special Visceral Afferent	118
Cranial Nerve II, Optic, Special Somatic Sensory	118
Cranial Nerve III, Oculomotor, Pure Motor (Somatic and Parasympathetic, Only III).....	120
Cranial Nerve IV Trochlear, Pure Motor	120
Cranial Nerve VI, Abducens, Pure Motor.....	121
Cranial Nerve V, Trigeminal, Mixed Nerve (Sensory and Motor But No Parasympathetic)	121
Cranial Nerve, VII Facial, Mixed Nerve (Sensory, Motor, Parasympathetic)	122
Cranial Nerve VIII, Vestibulo-Cochlear.....	124
Cranial Nerve IX, Glossopharyngeal, Mixed (Sensory, Motor, Parasympathetic): Nerve to Third Pharyngeal Arch	128
Cranial Nerve X Vagus.....	129
Cranial Nerve XI Spinal Accessory, Pure Motor-Somatic and Visceral.....	130
Cranial Nerve XII Hypoglossal.....	130
Cranial Nerve Dysfunction	131
Motor Cranial Nerve Lesion	131
Cranial Nerve Dysfunction	131
Motor Cranial Nerve Lesions.....	131
Sensory Cranial Nerve Lesion	132
Cranial Nerve Case Histories.....	132
Cranial Nerve Case 7.1	132
Cranial Nerve Case 7.2	133
Cranial Nerve Case 7.3	133
Cranial Nerve Case 7.4	133
Suggested Readings	134
8 Diencephalon with Atlas of the Thalamus	135
Overview.....	135
The Thalamus Has Several Major Roles.....	135
Thalamus from a Phylogenetic Perspective	135
Functional Divisions of Thalamic Nuclei	135
Nuclei of the Thalamus	136
Functional Organization of Thalamic Nuclei.....	136
Sensory and Motor Relay Nuclei: The Ventrobasal Complex and Lateral Nucleus.....	136
Limbic Nuclei: The Anterior, Medial, Lateral Dorsal, Midline, and Intralaminar Nuclei.....	139
Specific Associational-Polymodal/Somatic Nuclei-The Pulvinar Nuclei	139
Special Somatic Sensory Nuclei-Vision And Audition, The Lateral Geniculate And Medial Geniculate Nuclei of the Metathalamus.....	140
Nonspecific Associational.....	141