BRS
BOARD REVIEW SERIES

Neuroanatomy

FIFTH EDITION

Douglas J. Gould

- Outline format highlights the most tested topics for USMLE Step 1
- More than 575 board-style questions help test your memorization and mastery
- Online access—offers greater study flexibility

Wolters Kluwer Health | Lippincott Williams & Wilkins

BRS
BOARD REVIEW SERIES

Neuroanatomy

FIFTH EDITION

BRS
BOARD REVIEW SERIES

Neuroanatomy

FIFTH EDITION

Douglas J. Gould, Ph.D.
Professor
Department of Biomedical Sciences
Oakland University William Beaumont School of Medicine
Rochester, Michigan

*Author of **1st–4th** Editions:*
James D. Fix, PhD
(1931–2010)

Wolters Kluwer | Lippincott Williams & Wilkins
Health
Philadelphia • Baltimore • New York • London
Buenos Aires • Hong Kong • Sydney • Tokyo

Acquisitions Editor: Crystal Taylor
Product Manager: Catherine Noonan
Marketing Manager: Joy Fisher-Williams
Designer: Holly Reid McLaughlin
Compositor: S4Carlisle Publishing Services

Fifth Edition

351 West Camden Street
Baltimore, MD 21201

Two Commerce Square
2001 Market Street
Philadelphia, PA 19103

Printed in China

Library of Congress Cataloging-in-Publication Data

Gould, Douglas J., author.
Neuroanatomy / Douglas J. Gould.—5th edition.
p. ; cm. — (Board review series)
Revised edition of: Neuroanatomy / James D. Fix. 4th ed. c2008.
Includes bibliographical references and index.
ISBN-13: 978-1-4511-7609-4
ISBN-10: 1-4511-7609-0
I. Fix, James D. Neuroanatomy. Revision of (work): II. Title. III. Series: Board review series.
[DNLM: 1. Neuroanatomy—Examination Questions. 2. Neuroanatomy—Outlines. WL 18.2]
QM451
611'.8076—dc23

2013005723

DISCLAIMER

Care has been taken to confirm the accuracy of the information present and to describe generally accepted practices. However, the authors, editors, and publisher are not responsible for errors or omissions or for any consequences from application of the information in this book and make no warranty, expressed or implied, with respect to the currency, completeness, or accuracy of the contents of the publication. Application of this information in a particular situation remains the professional responsibility of the practitioner; the clinical treatments described and recommended may not be considered absolute and universal recommendations.

The authors, editors, and publisher have exerted every effort to ensure that drug selection and dosage set forth in this text are in accordance with the current recommendations and practice at the time of publication. However, in view of ongoing research, changes in government regulations, and the constant flow of information relating to drug therapy and drug reactions, the reader is urged to check the package insert for each drug for any change in indications and dosage and for added warnings and precautions. This is particularly important when the recommended agent is a new or infrequently employed drug.

Some drugs and medical devices presented in this publication have Food and Drug Administration (FDA) clearance for limited use in restricted research settings. It is the responsibility of the health care provider to ascertain the FDA status of each drug or device planned for use in their clinical practice.

To purchase additional copies of this book, call our customer service department at **(800) 638-3030** or fax orders to **(301) 223-2320**. International customers should call **(301) 223-2300**.

Visit Lippincott Williams & Wilkins on the Internet: http://www.lww.com. Lippincott Williams & Wilkins customer service representatives are available from 8:30 am to 6:00 pm, EST.

9 8 7 6 5 4 3 2 1

To Marie for her love, patience, wisdom, and understanding.
To Maggie and Lulu for all the joy they bring.

Reviewers

Marc Braunstein
Merrian Brooks
Christos Constantinidis, PhD
James L. Culberson, PhD
David Crawley
Ana C.G. Felix, MD
Karan Gulaya
Douglas James
Shonda Janke
Amelia Keaton
Kathleen M. Klueber, PhD
Albert Lamperti, PhD
Stephanie Markle
Fiore Mastroianni
Sidney L. Palmer, PhD
Sheree Perron
Nicholas Potvin
Libby Rhee
Amy Shah
Ricci Sylla
Penny Toliopoulos
Anne Williams

Preface

BRS Neuroanatomy, fifth edition, is a concise review of human neuroanatomy intended for heatlh professions students including medical and dental students preparing for the United States Medical Licensing Examination (USMLE) Step 1 and other examinations. It presents the essentials of human neuroanatomy in a concise, tightly-outlined, well-illustrated format. There are more than 600 board-type questions with complete answers and explanations, some included at the end of each chapter and some in a comprehensive examination at the end of the book.

NEW TO THIS EDITION

- Color used throughout to enhance neuroanatomic pathways
- Color used to block in tables and highlight clinical correlations
- Localization of sensory disorders
- Updated color artwork throughout
- Updated terminology to conform with Terminologica Anatomica

To the Student

To make the most of this book, carefully study the illustrations, computed tomography scans, magnetic resonance images, angiograms as well as the figure legends; much of the board question information lies within the images and legends. The answers to at least 30 common USMLE questions are outlined below; refer to these tips as you review the chapters.

Acknowledgments

Special thanks to and in respectful memory of **Dr. James Fix**, for creating the first four editions of BRS *Neuroanatomy*—the foundation upon which this fifth edition is based. I thank my students and colleagues for their valuable input as the fifth edition was developed. I also thank the Lippincott Williams & Wilkins staff and their associates for their contributions to this edition—Crystal Taylor, Acquisitions Editor; Catherine Noonan, Managing Editor; and the student and faculty reviewers, who were invited by the publisher to provide valuable feedback and suggestions.

Contents

Reviewers *vi*
Preface *vii*
Acknowledgments *viii*

1. GROSS ANATOMY OF THE BRAIN 1

Objectives 1
- I. Introduction 1
- II. Divisions of the Brain 1
- III. Atlas of the Brain and Brainstem 10

Review Test 22

2. MENINGES AND CEREBROSPINAL FLUID 24

Objectives 24
- I. Meninges 24
- II. Ventricles 28
- III. Cerebrospinal Fluid 30
- IV. Hydrocephalus 30
- V. Meningitis 31
- VI. Herniation 32
- VII. Circumventricular Organs 34

Review Test 36

3. BLOOD SUPPLY OF THE CENTRAL NERVOUS SYSTEM 39

Objectives 39
- I. Arteries of the Spinal Cord 39
- II. Venous Drainage of the Spinal Cord 40
- III. Arteries of the Brain 41
- IV. Cerebral Arterial Circle (of Willis) 45
- V. Meningeal Arteries 45
- VI. Veins of the Brain 45
- VII. Venous Dural Sinuses 46
- VIII. Angiography 48
- IX. Intracranial Hemorrhage 52

Review Test 54

4. DEVELOPMENT OF THE NERVOUS SYSTEM 58

Objectives 58

I. Overview 58
II. Development of the Neural Tube 58
III. Neural Crest 59
IV. Placodes 61
V. Stages of Neural Tube Development 61
VI. Spinal Cord (Medulla Spinalis) 63
VII. Medulla oblongata (Myelencephalon) 64
VIII. Metencephalon 66
IX. Mesencephalon (Midbrain) 67
X. Development of the Diencephalon, Optic Structures, and Hypophysis 68
XI. Development of the Telencephalon 70
XII. Congenital Malformations of the Central Nervous System 71

Review Test 77

5. NEUROHISTOLOGY 79

Objectives 79

I. Overview 79
II. Neurons 79
III. Neuroglia 82
IV. Nerve Cell Degeneration and Regeneration 86
V. Axonal Transport 87
VI. Capillaries of the Central Nervous System 87
VII. Sensory Receptors 89

Review Test 91

6. SPINAL CORD 93

Objectives 93

I. Introduction 93
II. External Morphology 93
III. Internal Morphology 98
IV. Myotatic Reflex 101

Review Test 102

7. TRACTS OF THE SPINAL CORD 104

Objectives 104

I. Ascending Tracts 104
II. Descending Tracts 109
III. Integrative Pathways 111
IV. Clinical Correlations 112

Review Test 114

8. LESIONS OF THE SPINAL CORD 117

Objectives 117

I. Lower Motor Neuron Lesions 117
II. Upper Motor Neuron Lesions (UMNs) 119
III. Sensory Pathway Lesions 119
IV. Peripheral Nervous System Lesions 120
V. Combined Upper and Lower Motor Neuron Lesions 120
VI. Combined Motor and Sensory Lesions 121
VII. Intervertebral Disk Herniation 124

Review Test 125

9. BRAINSTEM 129

Objectives 129

I. Introduction 129
II. Medulla Oblongata (Myelencephalon) 129
III. Pons 134
IV. Mesencephalon (Midbrain) 138
V. Corticobulbar (Corticonuclear) Fibers 142

Review Test 143

10. CRANIAL NERVES 145

Objectives 145

I. Introduction 145
II. Nervus Terminalis (NT; Cranial Nerve 0) 145
III. Olfactory Nerve (CN I) 145
IV. Optic Nerve (CN II) 146
V. Oculomotor Nerve (CN III) 148
VI. Trochlear Nerve (CN IV) 149
VII. Trigeminal Nerve (CN V) 150
VIII. Abducent Nerve (CN VI) 151
IX. Facial Nerve (CN VII) 151
X. Vestibulocochlear Nerve (CN VIII) 154
XI. Glossopharyngeal Nerve (CN IX) 154
XII. Vagal Nerve (CN X) 155
XIII. Accessory Nerve (CN XI) 156
XIV. Hypoglossal Nerve (CN XII) 157

Review Test 159

11. TRIGEMINAL SYSTEM 162

Objectives 162

I. Trigeminal Nerve (CN V) 162
II. Ascending Trigeminothalamic Tracts 163

III. Trigeminal Sensory Nuclei 165
IV. Trigeminocerebellar Fibers 166
V. Trigeminal Reflexes 167
VI. Clinical Correlations 168
Review Test 170

12. LESIONS OF THE BRAINSTEM 172

Objectives 172
I. Introduction 172
II. Vascular Lesions of the Medulla 172
III. Vascular Lesions of the Pons 173
IV. Lesions of the Midbrain 175
V. Acoustic Neuroma (Schwannoma) 176
VI. Internuclear Ophthalmoplegia 177
VII. Jugular Foramen (Vernet) Syndrome 177
VIII. Subclavian Steal Syndrome 178
Review Test 179

13. DIENCEPHALON: THALAMUS AND HYPOTHALAMUS 183

Objectives 183
I. Introduction: The Thalamus 183
II. Boundaries of the Thalamus 183
III. Primary Thalamic Nuclei and their Major Connections 184
IV. Blood Supply of the Thalamus 187
V. Internal Capsule 187
VI. Blood Supply of the Internal Capsule 188
VII. Clinical Correlations 188
VIII. Overview: The Hypothalamus 189
IX. Surface Anatomy of the Hypothalamus 189
X. Hypothalamic Regions and Nuclei 189
XI. Major Hypothalamic Connections 192
XII. Major Fiber Systems 194
XIII. Functional Considerations 195
XIV. Clinical Correlations 196
Review Test 197

14. AUDITORY SYSTEM 202

Objectives 202
I. Introduction 202
II. Outer, Middle, and Inner Ear 202
III. Auditory Pathway 204
IV. Efferent Cochlear (Olivocochlear) Bundle 206
V. Hearing Defects 206

VI. Tuning Fork Tests 207
VII. Brainstem Auditory Evoked Response (Baer) 207
Review Test 209

15. VESTIBULAR SYSTEM 211

Objectives 211
I. Introduction 211
II. Labyrinth 211
III. Vestibular Pathways 213
IV. Efferent Vestibular Connections 214
V. Medial Longitudinal Fasciculus 214
VI. Vestibulo-Ocular Reflexes 215
VII. Decerebrate and Decorticate Rigidity 216
VIII. Clinical Correlations 216
Review Test 218

16. VISUAL SYSTEM 220

Objectives 220
I. Introduction 220
II. The Retina 220
III. Visual Pathway 224
IV. Pupillary Light Reflexes and Pathway 225
V. Pupillary Dilation Pathway 227
VI. The Convergence–Accommodation Reaction 227
VII. Centers for Ocular Motility 228
VIII. Clinical Correlations 229
Review Test 232

17. OLFACTORY, GUSTATORY, AND LIMBIC SYSTEMS 236

Objectives 236
I. Olfactory System 236
II. Gustatory System 237
III. Limbic System 239
Review Test 245

18. BASAL NUCLEI AND THE EXTRAPYRAMIDAL MOTOR SYSTEM 249

Objectives 249
I. Basal Nuclei 249
II. Extrapyramidal Motor System 249
Review Test 256

19. CEREBELLUM 258

Objectives 258

I. Overview 258
II. Major Divisions of the Cerebellum 258
III. Cerebellar Cortex 260
IV. Major Cerebellar Pathways 262
V. Cerebellar Dysfunction 264
VI. Cerebellar Lesions 264

Review Test 266

20. AUTONOMOUS NERVOUS SYSTEM 268

Objectives 268

I. Overview 268
II. Divisions of the Autonomic Nervous System 268
III. Visceral Afferent Fibers and Pain 272
IV. Autonomic Innervation of Selected Organs 273
V. Clinical Correlations 275

Review Test 276

21. NEUROTRANSMITTERS AND PATHWAYS 278

Objectives 278

I. Introduction 278
II. Acetylcholine 279
III. Dopamine 280
IV. Norepinephrine (Noradrenalin) 281
V. Serotonin (5-Hydroxytryptamine [5-HT]) 282
VI. Opioid Peptides 283
VII. Nonopioid Neuropeptides 284
VIII. Amino Acids 284
IX. Nitric Oxide 287
X. Functional and Clinical Correlations 287

Review Test 289

22. CEREBRAL CORTEX 293

Objectives 293

I. Overview 293
II. Neocortex 293
III. Functional Areas of the Cerebral Cortex 294
IV. Cerebral Dominance 299
V. Split-Brain Syndrome 301
VI. Blood Supply to the Major Functional Cortical Areas 302

VII. Apraxia 303
VIII. Aphasia 304
IX. Dysprosodies 305
Review Test 306

Comprehensive Examination 311

Appendix: Table of Cranial Nerves 339

Glossary 342

Index 353

chapter 1

Gross Anatomy of the Brain

Objectives

- Identify the major structures of the brain from typical brain sections and diagrams—use the Atlas of the Brain and Brainstem on p. 10.
- Describe the telencephalon, including the lobes of the cerebral hemispheres and the major gyri of each.
- Differentiate the structures of the limbic and olfactory senses from other parts of the brain.
- List the different parts of the diencephalon, brainstem, and cerebellum.

I. INTRODUCTION

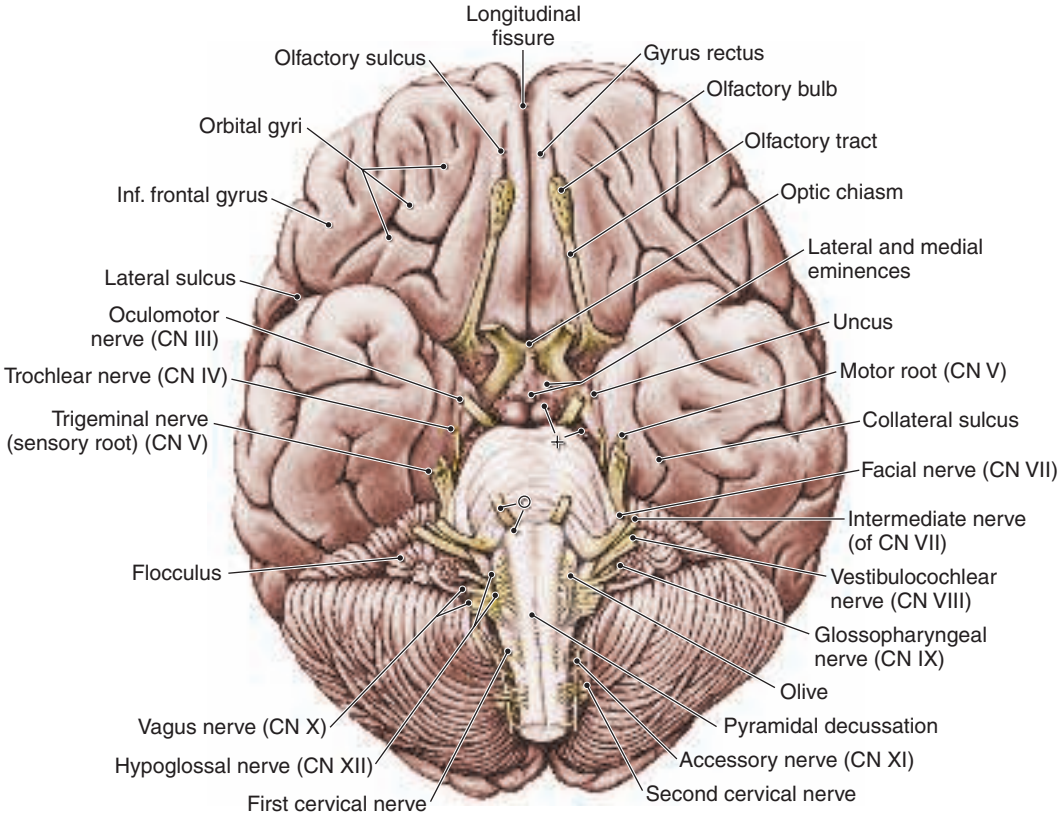
- part of the central nervous system (CNS) that lies within the cranial vault—the **encephalon.** Its surface is convoluted and exhibits **gyri** and **sulci.**
- consists of the **cerebrum** (cerebral hemispheres and diencephalon), the **brainstem** (midbrain, pons, and medulla), and the **cerebellum**
- weighs 350 g in the newborn and 1400 g in the adult.
- covered by three connective tissue membranes, the **meninges.**
- surrounded by **cerebrospinal fluid (CSF)** that supports it and protects it from trauma

II. DIVISIONS OF THE BRAIN

The brain is classified into six postembryonic divisions: **telencephalon, diencephalon, mesencephalon, pons, medulla oblongata,** and **cerebellum.**

A. Telencephalon

- consists of the **cerebral hemispheres** and the **basal nuclei.** The cerebral hemispheres contain the **lateral ventricles.**
  1. **Cerebral hemispheres** (figures 1.1 through 1.5)
     - separated by the longitudinal cerebral fissure and the falx cerebri.
     - interconnected by commissural fiber bundles (i.e., corpus callosum).
     - consists of six lobes and the olfactory structures:
       a. **Frontal lobe** (see figures 1.3 and 1.4)
          - extends from the central sulcus to the frontal pole.
          - lies superior to the lateral sulcus and anterior to the central sulcus.
          - made up of the following gyri:
            (1) **Precentral gyrus**
                - consists of the primary motor area (area 4).



+ = Mamillary body; cerebral peduncle
o = Abducens nerve; pyramid of medulla

FIGURE 1.1. Base of the brain. (Modified from Truex RC, Kellner CE. *Detailed Atlas of the Head and Neck.* New York, NY: Oxford University Press; 1958:34.)

(2) Superior frontal gyrus
- contains supplementary motor cortex on the medial surface (area 6).

(3) Middle frontal gyrus
- contains the frontal eye field (area 8).

(4) Inferior frontal gyrus
- contains the Broca speech area in the dominant hemisphere (areas 44 and 45).

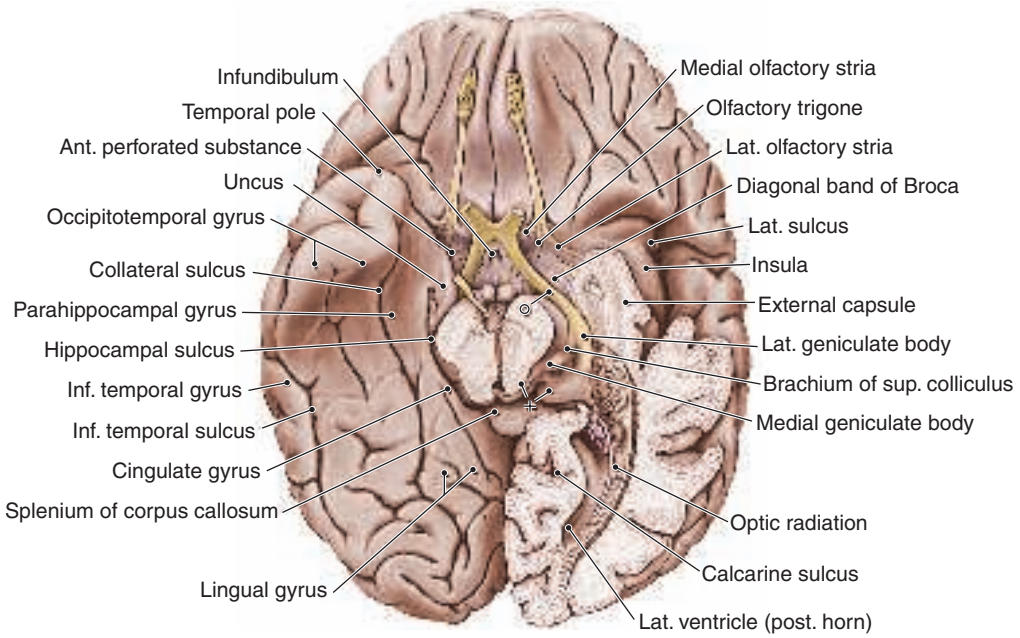
(5) Gyrus rectus and orbital gyri
- separated by the olfactory sulcus.

(6) Anterior paracentral lobule
- found on the medial surface between the superior frontal gyrus (paracentral sulcus) and the central sulcus.
- represents a continuation of the precentral gyrus on the medial surface.

b. Parietal lobe (see Figures 1.3 through 1.5)
- extends from the central sulcus to the occipital lobe and lies superior to the temporal lobe.
- contains the following lobules and gyri:

(1) Postcentral gyrus
- the primary somatosensory area of the cerebral cortex (areas 3, 1, and 2).

(2) Superior parietal lobule
- comprises association areas involved in somatosensory functions (areas 5 and 7).



o = Optic tract
+ = Brachium of inf. colliculus

FIGURE 1.2. Inferior surface of the brain showing the principal gyri and sulci. The left hemisphere has been dissected to show the visual pathways and relation of the optic radiation to the lateral ventricle. (Modified from Truex RC, Kellner CE. *Detailed Atlas of the Head and Neck.* New York, NY: Oxford University Press; 1958:46.)

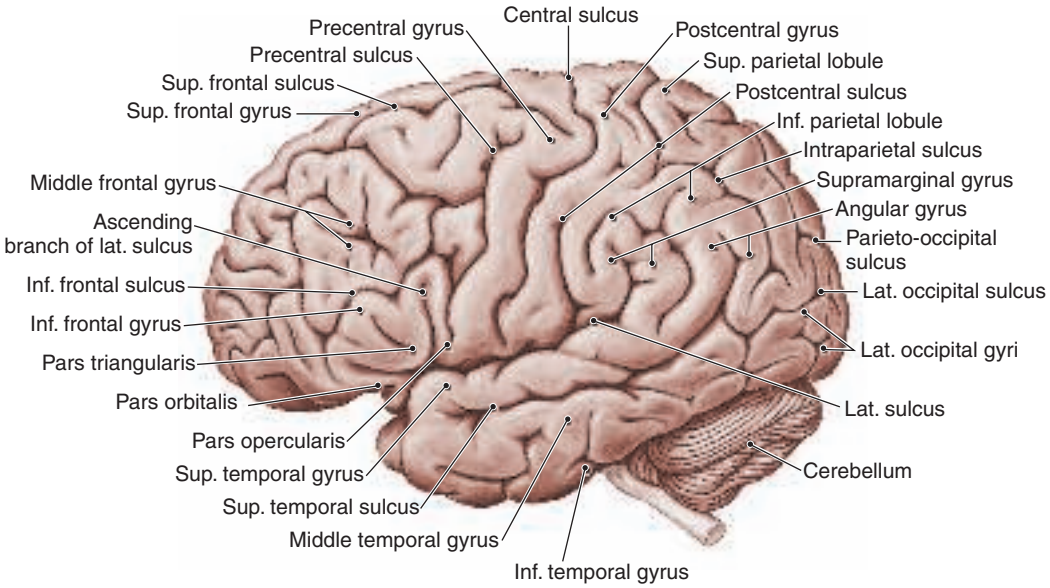
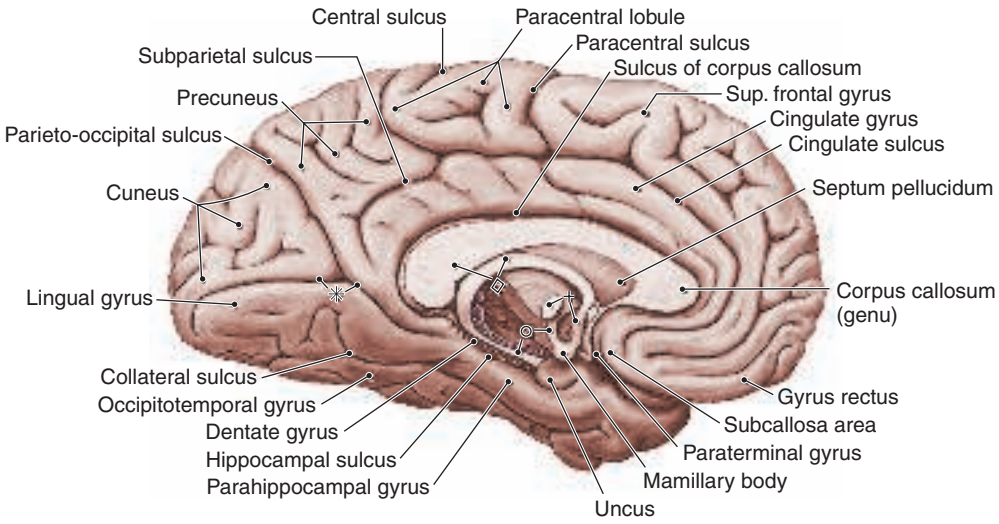


FIGURE 1.3. Lateral surface of the brain showing the principal gyri and sulci. (Modified from Truex RC, Kellner CE. *Detailed Atlas of the Head and Neck.* New York, NY: Oxford University Press; 1958:47.)



✳ = Calcarine fissure
◊ = Splenium of corpus callosum; body of fornix
+ = Interthalamic adhesion: ant. column of fornix
o = Fimbria of fornix; mamillothalamic tract

FIGURE 1.4. Medial surface of the brain showing the principal gyri and sulci. Parts of the thalamus and hypothalamus have been removed to show the fimbria and anterior column of the fornix and the mamillothalamic tract. (Modified from Truex RC, Kellner CE. *Detailed Atlas of the Head and Neck*. New York, NY: Oxford University Press; 1958:49.)

(3) Inferior parietal lobule

- **Supramarginal gyrus**
  - **(a)** interrelates somatosensory, auditory, and visual inputs (area 40).
- **Angular gyrus** (area 39)
  - **(a)** receives impulses from primary visual cortex.

(4) Precuneus

- located between the paracentral lobule and the cuneus.

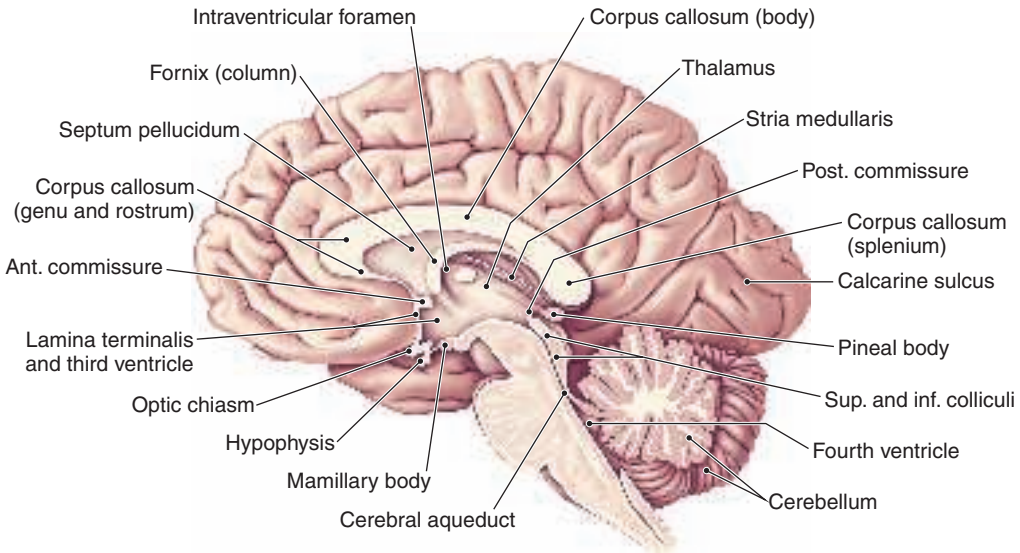


FIGURE 1.5. Midsagittal section of the brain and brainstem showing the structures surrounding the third and fourth ventricles. (Modified from Bear MF, Connors BW, Paradiso MA: *Neuroscience: Exploring the Brain.* 3rd ed. Baltimore, MD: Lippincott Williams & Wilkins; 2007:207.)

(5) Posterior paracentral lobule
- located on the medial surface between the central sulcus and the precuneus.
- represents a continuation of the postcentral gyrus on the medial surface.

c. Temporal lobe (see Figures 1.2 through 1.4)
- extends from the temporal pole to the occipital lobe, lying inferior to the lateral sulcus.
- extends from the lateral sulcus to the collateral sulcus.
- contains the following gyri:

(1) Transverse temporal gyri of Heschl
- found within the lateral sulcus.
- extends from the superior temporal gyrus toward the medial geniculate body (Figure 1.6).
- the primary auditory areas of the cerebral cortex (areas 41 and 42).

(2) Superior temporal gyrus
- associated with auditory functions.
- contains the **Wernicke speech area** in the dominant hemisphere (area 22).
- contains the planum temporale on its superior (hidden) surface.

(3) Middle temporal gyrus

(4) Inferior temporal gyrus

(5) Lateral occipitotemporal gyrus (fusiform gyrus)
- lies between the inferior temporal sulcus and the collateral sulcus.

d. Occipital lobe (see Figures 1.3 through 1.5)
- lies posterior to a line connecting the parieto-occipital sulcus and the preoccipital notch.

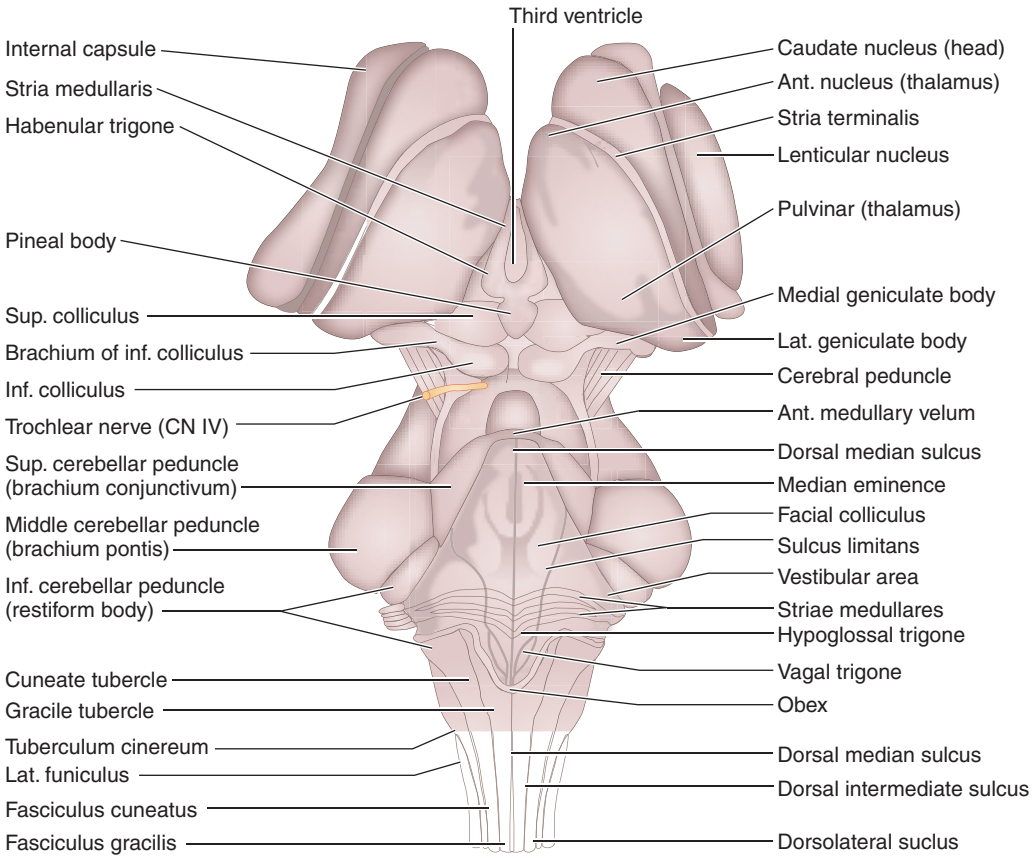


FIGURE 1.6. Posterior surface anatomy of the brainstem. The cerebellum has been removed to show the three cerebellar peduncles and the floor of the fourth ventricle (rhomboid fossa). (Modified from Truex RC, Carpenter MB. *Human Neuroanatomy.* Baltimore, MD: Williams & Wilkins; 1969:31.)

- contains two structures:
  - **(1) Cuneus**
    - situated between the parieto-occipital sulcus and the calcarine sulcus.
    - contains the visual cortex (areas 17, 18, and 19).
  - **(2) Lingual gyrus**
    - lies inferior to the calcarine sulcus.
    - contains the visual cortex (areas 17, 18, and 19).

e. Insular lobe (insula) (see Figure 1.2)
- lies within the lateral sulcus.
- has short and long gyri.

f. Limbic lobe (see Figures 1.4 and 22.1B)
- a C-shaped collection of structures found on the medial hemispheric surface that encircles the corpus callosum and the lateral aspect of the midbrain.
- includes the following structures:
  - **(1) Paraterminal gyrus and subcallosal area** (see Figure 1.4)
    - located anterior to the lamina terminalis and inferior to the rostrum of the corpus callosum.
  - **(2) Cingulate gyrus**
    - parallel and superior to the corpus callosum.
    - merges with the parahippocampal gyrus.
  - **(3) Parahippocampal gyrus**[1]
    - lies between the hippocampal and collateral sulci and terminates in the **uncus**.
  - **(4) Hippocampal formation** (see Figures 1.2 and 1.4)
    - lies between the choroidal and hippocampal fissures.
    - connected to the hypothalamus and septal area via the **fornix**.
    - includes three structures:
      - **(a) Dentate gyrus** (see Figure 1.4)
      - **(b) Hippocampus** and
      - **(c) Subiculum** (see Figure 17.5)

g. Olfactory structures (see Figure 1.2)
- found on the orbital surface of the brain and include the following:
  - **(1) Olfactory bulb and tract**
    - an outpouching of the telencephalon.
  - **(2) Olfactory bulb**
    - receives the olfactory nerve (CN I).
  - **(3) Olfactory trigone and striae**
  - **(4) Anterior perforated substance**
    - created by penetrating striate arteries.
  - **(5) Diagonal band of Broca** (see Figure 1.2)
    - interconnects the amygdaloid nucleus and the septal area.

2. Basal nuclei (ganglia) (Figure 1.7; see Figures 1.6 and 18.1)
- constitute the subcortical nuclei of the telencephalon.
- include the following structures:

a. Caudate nucleus
- part of the striatum, together with the putamen.

b. Putamen
- part of the striatum, together with the caudate nucleus.
- part of the lentiform nucleus along with the globus pallidus.

c. Globus pallidus
- part of the lentiform nucleus, together with the putamen.

d. Subthalamic nucleus
- part of the diencephalon that functions with the basal nuclei.

3. Lateral ventricles (see Figure 2.4)
- ependyma-lined cavities of the cerebral hemispheres.
- contain **CSF** and **choroid plexus**.

[1]Some authorities include the parahippocampal gyrus as a temporal lobe structure.