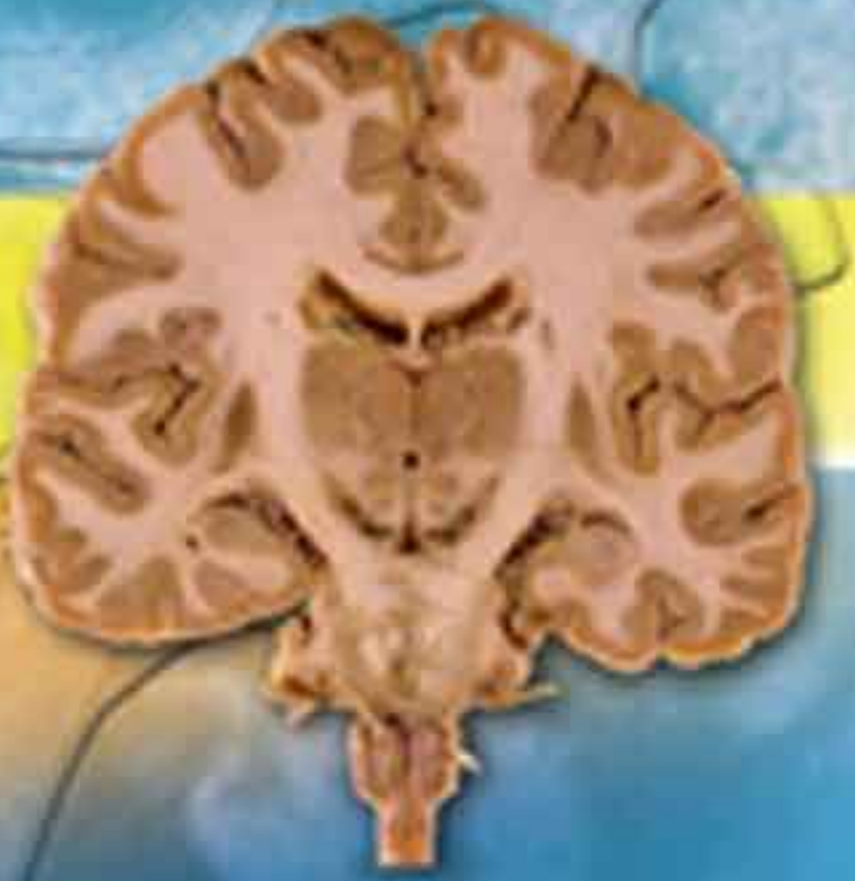
9th Edition

Duane E. Haines

NEUROANATOMY IN CLINICAL CONTEXT

An Atlas of Structures, Sections, Systems, and Syndromes



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NEUROANATOMY IN CLINICAL CONTEXT

An Atlas of Structures, Sections, Systems, and Syndromes

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Preface to the Ninth Edition

The first edition of this book contained several unique features, one of which was a particular emphasis on clinical correlations. This approach was one of several guiding principles that were followed through subsequent editions. By the seventh and eighth editions, many figure descriptions contained over 50% clinical information.

The Ninth Edition continues and improves the approach of emphasizing clinical relevance. Clinical content has been revised and increased throughout all chapters, and an all-new chapter on herniation syndromes has been added, all while maintaining an appropriate level of relevant neuroanatomical detail. Recognizing this continuing, and expanded, emphasis on clinically relevant neurobiology, the title has been modified to ***Neuroanatomy in Clinical Con*text** to more accurately reflect these important long-term features of this Atlas. The subtitle, ***An Atlas of Structures, Sections, Systems, and Syndromes***, has also been slightly modified to reflect the past and continuing emphasis on syndromes as well as the addition of new syndromes describing brain herniations and disc extrusions.

This new edition of ***Neuroanatomy in Clinical Context*** continues to: (1) provide a sound anatomical base for integrating neurobiological and clinical concepts; (2) introduce new text, MRI, CT, and artwork that emphasize information and concepts that are encountered in the clinical setting; (3) utilize contemporary clinical and basic science terminology; and (4) emphasize neuroscience information, concepts, and images that collectively constitute a comprehensive overview of systems neurobiology. In addition, the revision of existing pages, the addition of new pages in some chapters, and the inclusion of a new chapter on herniations, have resulted in an increase in the number of MRI, CT, CTA, and angiograms from about 260 to over 380. Understanding systems neurobiology is an absolutely essential element in the successful diagnosis and treatment of the neurologically compromised patient.

Many comments, suggestions, insights, and ideas from my colleagues, medical students, residents, and graduate students have been factored into the modifications in this new edition; their candor is greatly appreciated. While minor corrections, or changes, have been made on almost every page, the major improvements and new information introduced in the Ninth Edition of ***Neuroanatomy in Clinical Context*** are as follows:

First, all clinical information throughout the Atlas appears in a light blue screen. This: (1) makes it very easy to identify any and all clinical comments, or examples, on every page; (2) does not reduce clinical concepts by trying to compress them into small summary boxes; (3) keeps all clinical correlations and information in their proper neuroanatomical context; and (4) emphasizes the overall amount—and relevance—of the clinical information presented in this Atlas. This approach allows the user to proceed from a basic point to a clinical point or from a clinical point to a basic point, without a break in the flow of information, or the need to go to a different page. This greatly expedites the learning process.

Second, all gross spinal cord and brain images in Chapters 2 and 3 now appear in color. In some cases, original specimens were rephotographed; in other situations, new specimens were used that clearly reflected the orientation and view of the original black/white image. Also, a couple of new images are introduced. A special effort was made to present color images of the best quality as reasonably possible. Generally speaking, these color images follow the same sequence, are of the same views, and correlate with the same vascular illustrations as in the previous edition.

Third, brain herniation is ubiquitous in cases of trauma to the head that results in an increase in intracranial pressure. Sulci and cisterns may be obliterated, and the brain may be extruded from one compartment into another. Herniation may be silent or, more likely, may result in deficits reflecting the particular brain region damaged. Herniation syndromes have elegant anatomical correlates; in most of these cases, there is a close correlation between the brain structures injured and the deficits experienced by the patient. Recognizing the intimate relationship between function and structure, a new and succinct chapter on "Herniation Syndromes" (Chapter 9) is introduced. It is placed at this location since a mastery of systems neurobiology (from Chapter 8) will greatly expedite an understanding of the clinical implications of a herniation be it of the brain or of an intervertebral disc.

Fourth, the existing color coronal forebrain images in Chapter 6 and the axial and sagittal brain images in Chapter 7 were replaced with new high-quality versions of the same pictures. This was accomplished by making high-resolution scans of the original glass slides and processing them to emphasize clarity and detail.

Fifth, the color images of the spinal cord and the brainstem in Chapter 6, although previously scanned from original glass slides, have been carefully revised and reprocessed for further detail and clarity. In addition, a new cross section has been added to illustrate the fact that the trochlear nucleus, decussation of the superior cerebellar peduncle, substantia nigra, and the crus cerebri are characteristic features in a cross section of the brainstem at the level of the inferior colliculus.

Sixth, the two line drawings that illustrate the functional components of spinal cord and brainstem nuclei that previously appeared at the beginning of Chapter 8 have been revised, recolorized, and now appear as the introductory two pages for Chapter 6. The revised color scheme emphasizes the concept of four functional components (although information on the traditional seven functional components is still included), an approach that is more in line with contemporary developmental studies. The content of these two pages relates directly to spinal cord and brainstem nuclei that are shown on subsequent pages in Chapter 6 beginning with Figures 6-3A and B. A version of the longitudinal overview (Figure 6-2) also appears next to each stained section (e.g., Figure 6-3B) with only the nuclei at that specific level indicated and labeled. The spinal and brainstem nuclei in the line drawings at each level in Chapter 6 (e.g., Figure 6-3A) have been revised to match the color plate of the repositioned overview. This allows the user to easily identify the nuclei at that level, their functional component, and their continuity with other related nuclei of comparable function above and below that particular level.

Seventh, many other minor adjustments have been made throughout; these include, labeling changes and/or corrections, adding and/or relocating CT and MRI (both normal and abnormal) for a better correlation, clarifying clinical and neuroanatomical information, stressing a better correlation between structure and function, **bolding** key terms while retaining *italics* for emphasis of important points, and integrating tidbits of information that are encountered in the initial educational experience and that certainly energize the learning opportunity.

Two further issues figured prominently in this new edition. *First*, the question of whether, or not, to use eponyms in their possessive form. To paraphrase one of my clinical colleagues, "Parkinson did not die of his disease (so-called 'Parkinson' disease); he died of a stroke. It was never his own personal disease." There are rare exceptions, such as Lou Gehrig disease, but the point is well taken. McKusick (1998a,b) also has made compelling arguments in support of using the nonpossessive form of eponyms. However, it is acknowledged that views differ on this question—much like debating how many angels can dance on the head of a pin. Consultation with my neurology and neurosurgery colleagues, the style adopted by *Dorland's Illustrated Medical Dictionary* (2012) and *Stedman's Medical Dictionary* (2006), a review of some of the more comprehensive neurology texts (e.g., Rowland and Pedley, 2010; Ropper and Samuels, 2009), the standards established in the *Council of Biology Editors Manual for Authors, Editors, and Publishers* (1994), and the *American Medical Association's Manual of Style* (2007) clearly indicate an overwhelming preference for the nonpossessive form. Recognizing that many users of this book will enter clinical training, it was deemed appropriate to encourage a contemporary approach. Consequently, the nonpossessive form of the eponym is used.

The *second* issue concerns use of the most up-to-date anatomical terminology. With the publication of *Terminologia Anatomica* (Thieme, New York, 1998), a new official international list of anatomical terms for neuroanatomy is available. This new publication, having been adopted by the International Federation of Associations of Anatomists, supersedes *all* previous terminology lists. Every effort has been made to incorporate any applicable new or modified terms into this book. In addition, the well-reasoned modification in the Edinger-Westphal terminology that reflects its functional characteristics is also adapted for this Atlas (Kozicz et al., 2011). The Edinger-Westphal complex consists of an Edinger-Westphal preganglionic nucleus (EWpg) that projects specially to the ciliary ganglion and a Edinger-Westphal centrally projecting nucleus (EWcp) that projects to a variety of targets including the spinal cord, spinal trigeminal, cuneate, gracile, facial, inferior olivary, and parabrachial nuclei, and to the reticular formation, but does not project to the ciliary ganglion.

Lastly, the pagination of the Ninth Edition has been slightly modified to accommodate changes which have increased integration, introduced significant new clinical correlates and images, repositioned a few images to enhance learning opportunities and the overall flow of information, and to accommodate new pages and a new chapter on herniation syndromes. A sampling of Q&As are included in this print version with a much larger sample available online through thePoint. All the Q&As have been revised and updated to assist the user in practicing his or her level of understanding, comprehension, and competence.

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References

Council of Biology Editions Style Manual Committee. *Scientific Style and Format—The CBE Manual for Authors, Editors, and Publishers*. 6th ed. Cambridge: Cambridge University Press; 1994.

Dorland's Illustrated Medical Dictionary. 32nd ed. Philadelphia, PA: Saunders/Elsevier; 2012.

Federative Committee on Anatomical Terminology. *Terminologia Anatomica*. New York, NY: Thieme; 1998.

Iverson C, Christiansen S, Flanagin A, et al. *American Medical Association Manual of Style—A Guide for Authors and Editors*. 10th ed. New York, NY: Oxford University Press; 2007.

Kozicz T, Bittencourt JC, May PJ, et al. The Edinger-Westphal nucleus: A historical, structural, and functional perspective on a dichotomous terminology. *J Comp Neurol*. 2011;519(8):1413–1434.

McKusick VA. On the naming of clinical disorders, with particular reference to eponyms. *Medicine (Baltimore)*. 1998a;77(1):1–2.

McKusick VA. *Mendelian Inheritance in Man: A Catalog of Human Genes and Genetic Disorders*. 12th ed. Baltimore, MD: The Johns Hopkins University Press; 1998b.

Ropper AH, Samuels MA. *Adams and Victor's Principles of Neurology*. 9th ed. New York, NY: McGraw-Hill Companies, Inc.; 2009.

Rowland LP, Pedley TA. *Merritt's Neurology*. 12th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2010.

Stedman's Medical Dictionary. 28th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006.

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The modifications in this Ninth Edition focus on improving the integration of basic science concepts with the realities of their clinical applications, and offer several new innovations that make the learning of, and the transition between, basic science and clinical concepts easier, more fluid, and seamless. The color coding of all clinical information throughout the text, addition of new clinically relevant information and examples, and the upgrading of contemporary anatomical and clinical concepts and terms are but some examples.

A special thank you is due the following individuals: Drs. Bishnu Sapkota and David Sinclair (Neurology); Drs. Robert McGuire and William McCluskey (Orthopedics); Drs. Louis Harkey and Andy Parent (Neurosurgery); Dr. Alan Sinning, Mr. Ken Sullivan, and graduate student Mr. Martin O. Bohlen (Neurobiology and Anatomical Sciences); medical students Ms. Kelly Brister and Mr. Jarrett R. Morgan (for their help with a laminectomy); Dr. Tim McCowan (Radiology); Dr. Jonathan Wisco (UCLA, for a great idea that was used in modified format); Drs. Amy Jones and Bridgett Jones (Resident graduates); and Drs. Kim Simpson and Jim Lynch (Neurobiology and Anatomical Sciences). Their contributions included locating particular cases, extensively reviewing new and extant clinical text, unfettered access to radiological images, reviewing the previous edition for changes (the Joneses), assisting with new brain and spinal dissections, and for responding to numerous general inquiries. I have also greatly appreciated the high quality of my interaction with the Residents in Neurology and Neurosurgery. The cooperation with all of the above was a significant, and important aspect of getting this Ninth Edition done. There has been a long history of excellent cooperation and cross talk between all of these clinical departments and Neurology and Anatomical Sciences.

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Table of Contents

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Recipient of the 2008 Henry Gray/Elsevier Distinguished Educator Award from The American Association of Anatomists

Elected a Fellow of the American Association of Anatomists and a Fellow of the American Association for the Advancement of Science

Recipient of the 2010 Alpha Omega Alpha Robert J. Glaser Distinguished Teacher Award from AOA and The Association of American Medical Colleges

Neuroanatomy Consultant for Stedman's Medical Dictionary and for Dorland's Illustrated Medical Dictionary

Introduction and User's Guide

1

This new edition of ***Neuroanatomy in Clinical Context*** continues to emphasize brain anatomy in a clinically relevant format. This includes: (1) correlating the central nervous system (CNS) anatomy with magnetic resonance images (MRIs) and computed tomography (CT) throughout, and making these latter images available to teach basic neurobiology; (2) introducing numerous clinical terms, phrases, and examples in their proper context; (3) highlighting cerebrovascular anatomy and selected variations, all with clinical examples; (4) emphasizing regional brain anatomy, internal vascular territories throughout the CNS, and the myriad deficits resulting from vascular lesions as broadly defined; and (5) presenting an extensive treatment of systems neurobiology that integrates pathways, connections, blood supply, and deficits at all levels of the neural axis.

A major innovation in this new edition is the presentation of all clinical information in a light blue screen throughout the text. This: (1) makes it very easy to identify any and all clinical comments, or examples; (2) does not reduce clinical concepts to small summary boxes; (3) keeps all clinical correlations and information in their proper context; and (4) emphasizes the overall amount—and relevance—of the clinical information presented. This approach allows the user to proceed from a basic point to a clinical point or from a clinical point to a basic point, without a break in the flow of information, or the need to go to a different page.

The opportunity to view, study, and understand CNS anatomy in both **Anatomical** and **Clinical Orientations** continues to be provided, and emphasized. The style of presentation, sequence of topics (from external CNS anatomy, to internal details, to regions, to systems), and emphasis on clinical application expedite learning and understanding that will be eminently useful in the clinical years. This approach allows for learning concepts in a basic neurobiologic setting that can be seamlessly transferred to, and applied within, the clinical environment. A focused approach in this new edition is to continue the emphasis on integration of basic science with clinical application.

Recognizing that about 50% of intracranial events that result in neurological deficits are vascular in nature, as broadly defined, vascular anatomy, distribution territories, and vascular patterns and variations thereof are covered in appropriate detail. These related topics, and their clinical correlations are discussed and illustrated, to varying degrees, with computed tomography angiography (CTA), magnetic resonance angiography (MRA), and magnetic resonance venography (MRV) *in all chapters*. Recognizing vascular patterns, territories, variations, and the appearance of extravasated blood is central to a successful diagnosis.

A thorough knowledge and understanding of systems, reflexes, pathways, their blood supply, and the results of lesions thereof, are essential to diagnosis of the neurologically compromised patient. All of these topics are covered in this new edition. Put simply, the deficits seen in many patients who present with neurologic consequences are *a direct reflection of damage to functional systems* that convey information from the periphery to targets in the brainstem or forebrain, or centrally generated signals that convey information that influences motor activity. A thorough knowledge of systems neurobiology (sensory and motor pathways, spinal and brainstem reflexes) is absolutely essential. A concurrent understanding of the appearance and relationships of brain regions in MRI and CT is an integral part of the diagnostic effort. Systems traverse regions; it is not possible to become competent in one and not the other.

Frequent cross-references are included (figure and page number) to allow easy integration between chapters. In addition, the number of images (CT, CTA, MRI, MRA, MRV, angiograms, and venograms) has been increased from about 260 to more than 390 in this new edition. The use of these images in a contemporary educational setting is absolutely essential for preparing the student for the realities of the clinical experience. In the clinical years, the student will not be studying gross brain or stained slices, but will rely almost exclusively on CT, MRI, or variations on these modalities. The goal is to give students the knowledge base and skills needed to excel in the clinical environment.

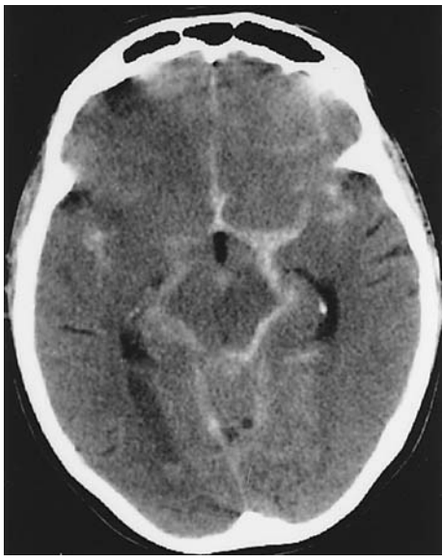
Imaging the Brain (CT and MRI)

Imaging the brain in vivo is now commonplace for the patient with neurological deficits. With this in mind, it is appropriate to make a few general comments on these imaging techniques and what is routinely seen, or best seen, in each. For details, consult sources such as Buxton,[1] Grossman,[2] Harnsberger et al.,[3] Lee et al.,[4] or Osborn et al.[5]

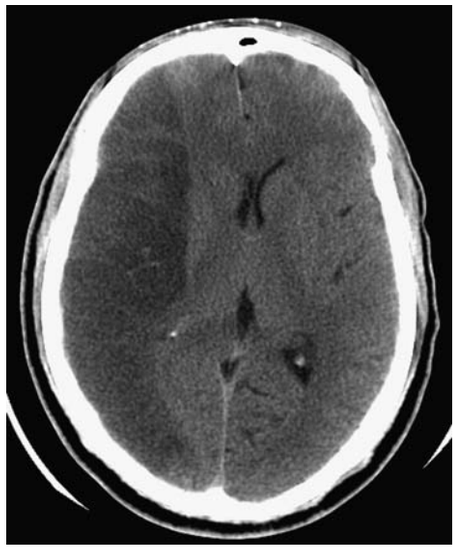
Computed Tomography (CT)

In CT, the patient is passed between a source of x-rays and a series of detectors. Tissue density is measured by the effects of x-rays on atoms within the tissue as x-rays pass through the tissue. Atoms of higher number have a greater ability to attenuate (stop) x-rays, whereas those with lower numbers are less able to attenuate x-rays. The various attenuation intensities are computerized into numbers (Hounsfield units or CT numbers). Bone is given the value of +1,000 and is white, whereas air is given a value of –1,000 and is black. In this respect, a lesion or defect in a CT that is **hyperdense** is shifted toward the appearance of bone; it is more white. For example, acute subarachnoid blood in CT is **hyperdense** to the surrounding brain; it is more white than the brain and is shifted more to the appearance of bone (Figure 1-1). A lesion in CT that is **hypodense** is shifted toward the appearance of air or cerebrospinal fluid; it is more black than the surrounding brain (Figure 1-2). In this example, the territory of the middle cerebral artery is *hypodense* (Figure 1-2). **Isodense** in CT refers to a condition in which the lesion and the surrounding brain have textures and/or shades of gray that are essentially the same. **Iso-** is Greek for equal: "equal density." Extravascular blood, an enhanced tumor, fat, the brain (gray and white matter), and cerebrospinal fluid form an intervening continuum from white to black. In general, Table 1-1 summarizes the white to black intensities seen for selected tissues in CT.

The advantages of CT are: (1) it is done rapidly, which is especially important in trauma; (2) it clearly shows acute and subacute hemorrhages into the meningeal spaces and brain; (3) it is especially useful for children in trauma cases; (4) it shows bone (and skull fractures) to advantage; and (5) it is less expensive than MRI. The disadvantages of CT are: (1) it does not clearly show acute or subacute infarcts or ischemia, or brain edema;



1-1 CT in the axial plane of a patient with subarachnoid hemorrhage. Bone is white, acute blood (white) outlines the subarachnoid space, brain is gray, and cerebrospinal fluid in the third and lateral ventricles is black.



1-2 Axial CT showing a hypodense area within the territory of the middle cerebellar artery on the right side of the patient. This is indicative of a lesion in this region which would result in substantive deficits.

(2) it does not clearly differentiate white from gray matter within the brain nearly as well as MRI; and (3) it exposes the patient to ionizing radiation.

Magnetic Resonance Imaging (MRI)

The tissues of the body contain proportionately large amounts of protons (hydrogen). Protons have a positive nucleus, a shell of negative electrons, and a north and south pole; they function like tiny spinning bar magnets. Normally, these atoms are arranged randomly in relation to each other because of the constantly changing magnetic field produced by the electrons. MRI uses this characteristic of protons to generate images of the brain and body.

When radio waves are sent in short bursts into the magnet containing the patient, they are called a radiofrequency pulse (RP). This pulse may vary in strength. When the frequency of the RP matches the frequency of the spinning proton, the proton will absorb energy from the radio wave (resonance). The effect is twofold. First, the magnetic effects of some protons are canceled out; second, the magnetic effects and energy levels in others are increased. When the RP is turned off, the relaxed protons release energy (an "echo") that is received by a coil and computed into an image of that part of the body.

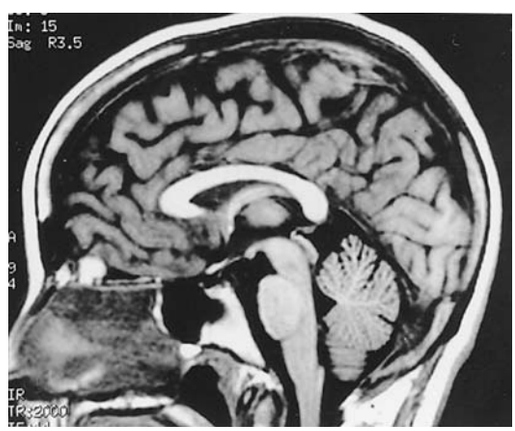
The two major types of MRI images (MRI/T1 and MRI/T2) are related to the effect of RP on protons and the reactions of these protons (relaxation) when the RP is turned off. In general, those canceled-out protons return slowly to their original magnetic strength. The image constructed from this time constant is called T1 (Figure 1-3). On the other hand, those protons that achieved a higher-energy level (were not canceled out) lose their energy more rapidly as they return to their original state; the image constructed from this time constant is T2 (Figure 1-4). The creation of a T1-weighted image versus a T2-weighted image is based on a variation in the times used to receive the "echo" from the relaxed protons.

The terms **hyperintense, hypointense,** and **isointense** apply to T1- and T2-weighted MRI. **Hyperintense** in T1 is a shift toward the appearance of fat, which is white in the normal patient; a hyperintense lesion in T1 is more white than the surrounding brain (Figure 1-5A; Table 1-2). A meningioma, and the surrounding edematous areas, are **hyperintense:** more white than the surrounding brain (Figure 1-5A). In T2, **hyperintense** is a shift toward the appearance of cerebrospinal fluid, which is also white in the normal individual (Figure 1-4); a hyperintense condition in T2 is also more white than the surrounding brain (Table 1-2). **Hypointense** in both T1 and T2 is a shift toward the appearance of air or bone in the normal patient; this is a shift to more black than the surrounding brain. In this example, there are **hypointense** areas (**arrows**) adjacent to the lateral ventricles in the frontal and occipital areas (Figure 1-5B). **Isointense** refers to a situation in which a lesion and the surrounding brain have shades of gray and/or textures that are basically the same. In this example of a pituitary tumor in a T1 MRI, the color and texture of the tumor is essentially the same as the surrounding brain; it is **isointense** (Figure 1-5C). **Iso-** is Greek for equal: "equal intensity."

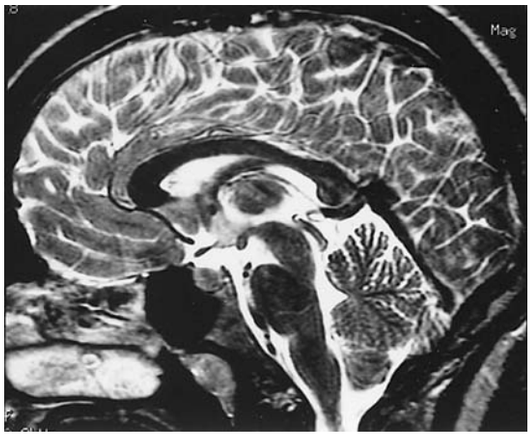
Table 1-2 summarizes the white to black intensities seen in MRI images that are T1-weighted versus T2-weighted. It should be emphasized that a

Table 1-1 The Brain and Related Structures in CT

Structure/Fluid/Space	Gray Scale
Bone, acute blood	Very white
Enhanced tumor	Very white
Subacute blood	Light gray
Muscle	Light gray
Gray matter	Light gray
White matter	Medium gray
Cerebrospinal fluid	Medium gray to black
Air, fat	Very black



1-3 A sagittal T1-weighted MRI. Brain is gray, and cerebrospinal fluid is black.



1-4 A sagittal T2-weighted MRI. Brain is gray, blood vessels frequently appear black, and cerebrospinal fluid is white.

number of variations on these two general MRI themes are routinely seen in the clinical environment.

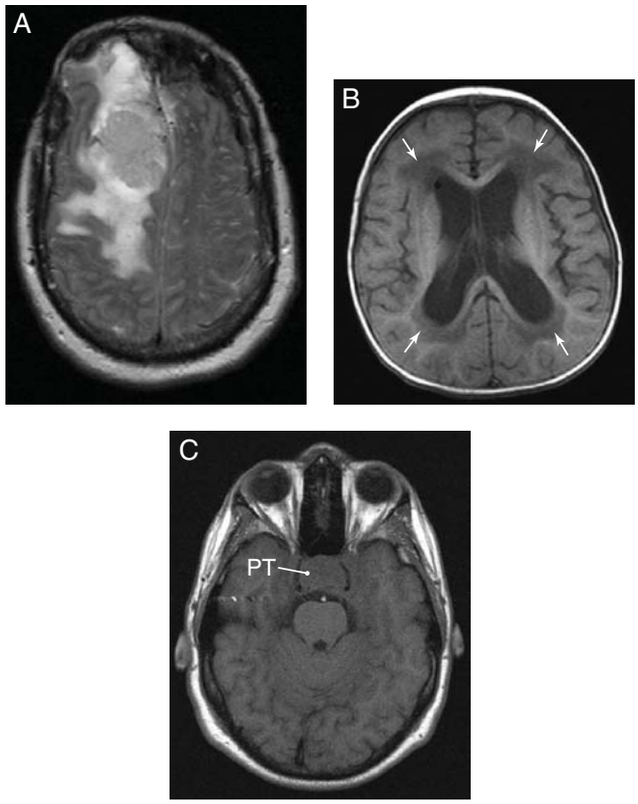
The advantages of MRI are: (1) it can be manipulated to visualize a wide variety of abnormalities or abnormal states within the brain; and (2) it can show great detail of the brain in normal and abnormal states. The disadvantages of MRI are: (1) it does not show acute or subacute subarachnoid hemorrhage or hemorrhage into the substance of the brain in any detail; (2) it takes much longer to do and, therefore, is not useful in acute situations or in some types of trauma; (3) it is comparatively more expensive than CT; and (4) the scan is extremely loud and may require sedation in children. The ensuing discussion briefly outlines the salient features of individual chapters.

Chapter 2

This chapter presents: (1) the gross anatomy of the spinal cord and its principal arteries; and (2) the external morphology of the brain from all views, including the insular cortex, accompanied by MRIs and drawings of the vasculature patterns from the same perspectives. In this new edition, all gross brain images appear in color, two new images have been included but none eliminated, and clinical terminology such as that used for segments of the cerebral vessels (A_1–A_5, M_1–M_4, and P_1–P_4), continues to be emphasized. In addition, new line drawings and accompanying CT that focus on vascular variations that have clinical implications are featured in this chapter.

Table 1-2 The Brain and Related Structures in MRI

NORMAL	T1	T2
Bone	Very black	Very black
Air	Very black	Very black
Muscle	Dark gray	Dark gray
White matter	Light gray	Dark gray
Gray matter	Dark gray	Light gray
Fat	White	Gray
Cerebrospinal fluid	Very black	Very white
ABNORMAL	T1	T2
Edema	Dark gray	Light gray to white
Tumor	Variable	Variable
Enhanced tumor	White	(Rarely done)
Acute infarct	Dark gray	Light gray to white
Subacute infarct	Dark gray	Light gray to white
Acute ischemia	Dark gray	Light gray to white
Subacute ischemia	Dark gray	Light gray to white



1-5 Axial MRIs showing a hyperintense lesion, meningioma, and edema (**A**), hypointense areas in the white matter of the hemisphere (**B, arrows**), and a pituitary tumor (PT) that is isointense (**C**).

Chapter 3

This chapter focuses on: (1) the relationships of cranial nerves; (2) their exits from the brainstem; (3) their appearance in representative MRI; and (4) examples of cranial nerve deficits seen in cases with lesions of the brainstem. All of the gross brain images showing the positions of cranial nerves now appear in color and minor corrections have been made in Table 3-1. The detailed cross-reference to other sections or pages in the Atlas where additional cranial nerve information is found was also revised. The figure descriptions were updated to increase their clinical value and relevance.

Chapter 4

The structure of the meninges, and their appearance in MRI or CT, is affected by a wide variety of events such as infections (meningitis), trauma, vascular incidents (epidural, subdural, subarachnoid hemorrhage), and tumor (meningioma) all of which are featured in this chapter. In addition, they are a central element in cases of increased intracranial pressure and consequent herniation. The size, shape, and relations of the ventricular system are clearly correlated with the distribution of intraventricular blood, and tumors of the choroid plexus; all of which are illustrated and described in this chapter. New clinical correlations have been added and all figure descriptions updated.

Chapter 5

The general morphology of the forebrain and brainstem is continued into the two sections of Chapter 5. A major improvement in this chapter is the replacement of all black/white photographs with comparable color images in the same coronal and axial planes and at the same general levels in each plane. A second change was to colorize the orientation drawings (upper left on each page) and to orient the axial drawing so as to increase its informational value.

The MRIs have been reorganized, and in several cases new ones inserted, so as to maintain the remarkably close correlation between structures identified in the brain slice and the same structures seen in the corresponding MRIs. The MRI and the brain slice appear on the same page so the correlation can be instantly made. Since brain sections at autopsy or in clinic–pathologic conferences are viewed as unstained specimens, the preference here is to present this material in a format that will most closely parallel what is seen in these clinical settings.

Chapter 6

The improvements made to this chapter are far-reaching, significant, and greatly improve its educational value and clinical emphasis, while retaining the innovations, overall organization, and sequence of earlier editions. Although many minor modifications were made, only the more encompassing are mentioned here.

First, the drawings and text explaining the functional components of the spinal cord and brainstem sensory and motor nuclei have always appeared at the beginning of Chapter 8 as Figures 8-1 and 8-2. Unfortunately, in this location, the succeeding images in Chapter 8 were concerned with neural systems and *not* particularly with the spinal cord or brainstem nuclei.

To redress this matter, these two images were moved to the beginning of Chapter 6, where they now appear as Figures 6-1 and 6-2. In this new location, their content, sensory and motor nuclei of the spinal cord and brainstem, *relate directly to, and correlate with,* the structures shown on the succeeding 25 or so pages regarding *all levels of the spinal cord and brainstem.* This new location recognizes the functional and structural relatedness to the information on the immediately following pages of this chapter.

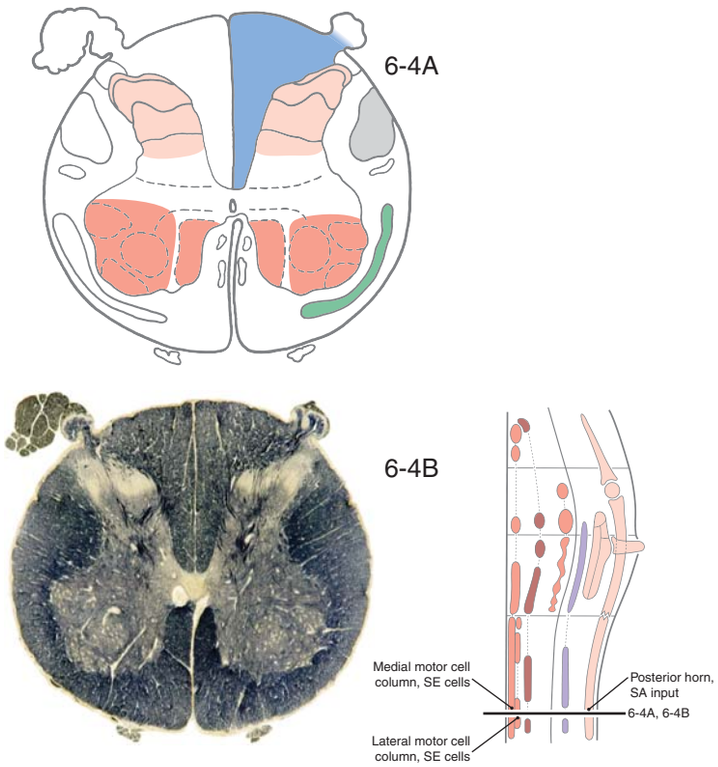
Second, concurrent with relocating these images to Figures 6-1 and 6-2, both drawings were recolored based on newer thinking in developmental biology. The traditional view of *seven* functional components has been supplemented with a more contemporary view that these seven may be condensed into *four* functional components. To this end, the color coding has been simplified to four colors that correspond with the four functional components. However, the text and figure labels explaining the *traditional* and *contemporary versions* are both presented so that the user may adopt/adapt whichever view works best in a given educational setting. Both the traditional and contemporary views are correct, to a large extent interchangeable, and useful.

Third, relocating the functional component images to Chapter 6 allowed for one of these images to be used, in a slightly modified format, on all spinal cord and brainstem images in this chapter. A version of Figure 6-2 was placed next to the stained image on the right-hand page (e.g., 6-4B), a line placed thereon representing the level of that specific cross section, and only those nuclei were labeled (in this case, spinal cord) that appear at this particular level (Figure 1-6). This approach was used on all spinal cord and brainstem levels in Chapter 6 and allows the user to easily visualize the relationships and continuity of functionally related cell columns at any level.

Fourth, the revised color palate was also used on the line drawings of the spinal cord and brainstem for all sensory and motor nuclei. For example, the line drawing in Figure 6-4A (facing 6-4B) now matches the overall color scheme (Figure 1-6). Consequently, the color of the spinal cord and brainstem sensory and motor nuclei on all left-hand pages is consistent throughout. All color coding matches in all drawings and at all levels of detail from Figure 6-3A to 6-28B throughout Chapter 6.

Fifth, the following structures are characteristically found at the level of a cross section through the inferior colliculus: the nuclei of the inferior colliculus, the trochlear nucleus, the decussation of the superior cerebellar peduncle, and caudal parts of the substantia nigra. A set of pages (line drawing and stained section) was added that illustrates these relationships.

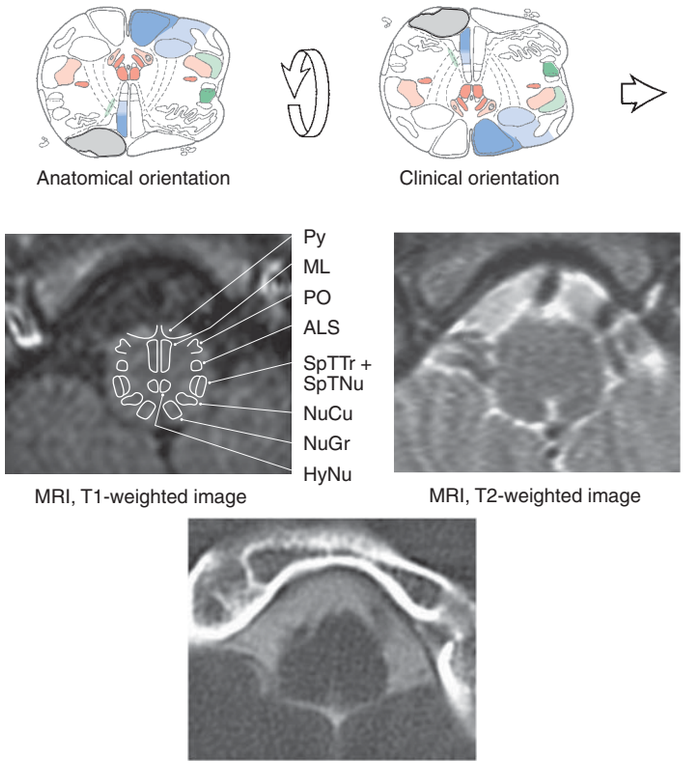
Sixth, the color images of the spinal cord and brainstem in Chapter 6 had previously been scanned from the original glass slide; for this new edition these images were reprocessed to improve clarity and detail. The color images of the coronal sections of the forebrain in Chapter 6 were replaced with high-resolution color scans of original glass slides and then processed to bring out the best detail and clarity possible.



1-6 A stained section of the lumbar spinal cord (lower) and the overview on spinal cord and brainstem cell columns showing the level of this section and of the line drawing on the facing page. For convenience only, these examples from 6-4A and 6-4B are reduced here to fit in a single column.

Innovations that were introduced in recent editions that integrated clinical with anatomical information, that provided options for viewing images in a format consistent with that seen in the clinical environment, and that stressed the clinical relevance and applicability of basic neurobiology are further emphasized in this new edition. First, the ability to flip an image from an **Anatomical Orientation** to a **Clinical Orientation** places everything in the image (line drawing or stained section) into a clinical format: (1) the images match exactly the corresponding MRI or CT, (2) the image has right and left sides, and (3) the topography of all tracts and nuclei in flipped images matches that as seen in CT or MRI. All images in Chapter 6 that can be flipped to a **Clinical Orientation** are identified by this symbol in the lower left of the image.

Understanding the brain and its internal structures in Clinical Orientation is absolutely essential to successful diagnosis. Second, the inherent value of viewing brain anatomy and line drawings in a Clinical Orientation is stressed throughout this chapter, particularly in relation to somatotopy, vascular supply and territories, clinical examples, and the MRI or CT, most of which are featured on the same page as the line drawing or stained section. Third, the color keys have been revised to reflect the modified color palate for the sensory and motor nuclei of the spinal cord and brainstem. Fourth, continuity from **Anatomical Orientation** to **Clinical Orientation** is again illustrated in a series of line drawings and MRI and CT on odd numbered pages showing spinal cord and brainstem levels (Figure 1-7). This new edition continues to utilize CT cisternograms as an integral part of the learning experience (Figure 1-8).



1-7 An example of the brainstem showing anatomical and clinical orientations at about the caudal one-third of the medulla and the corresponding T1-weighted MRI (with especially important structures labeled), T2-MRI, and CT cisternogram. The abbreviations are keyed to the full label on the facing page in Chapter 6. For additional examples and details of brainstem and spinal cord, see Chapter 6.

Chapter 7

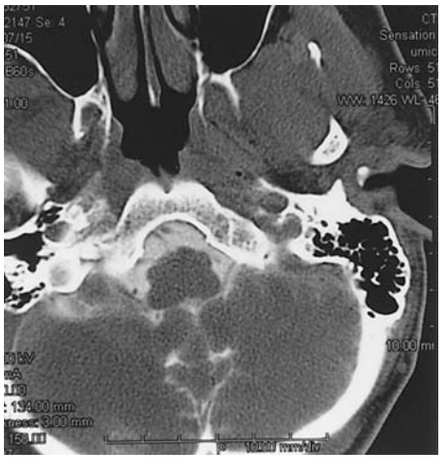
The arrangement of pages in this chapter remains the same as in previous editions: axial brain images in color and the corresponding axial MRI are on left-hand pages and sagittal brain images in color and the corresponding sagittal MRI are on right-hand pages. The heavy red line on the axial images (odd numbered Figures 7-1 to 7-9) indicates the plane of section of the sagittal image on the facing page; similarly, the heavy red line on the sagittal images (even numbered Figures 7-2 to 7-10) indicates the plane of section of the axial image on the facing page. Correlations between stained slices and between structures in MRI can be easily made.

A significant new improvement in this chapter is that high-resolution scans of the original stained sections mounted on glass slides were made and carefully processed for clarity and detail. This resulted in images of high quality in which internal detail is enhanced and anatomical relationships of all structures are more apparent.

The ability to compare different planes of section (stained section and MRI) on facing pages allows the user to build a three-dimensional view of a variety of internal structures in images that are commonly available in the clinical environment. However, these images can also be viewed as an axial series (all left-hand pages) or a sagittal series (all right-hand pages). Educational flexibility is inherent within these arrangements.

Chapter 8

This chapter illustrates a wide variety of clinically relevant CNS tracts/pathways in both **Anatomical and Clinical Orientations**, includes 15 illustrations of pathways of spinal and brainstem reflexes that may be tested during a comprehensive neurological examination, and contains



1-8 CT of a patient following injection of a radiopaque contrast media into the lumbar cistern. In this example, at the medullary level (a cisternogram), neural structures appear gray and the subarachnoid space appears light.

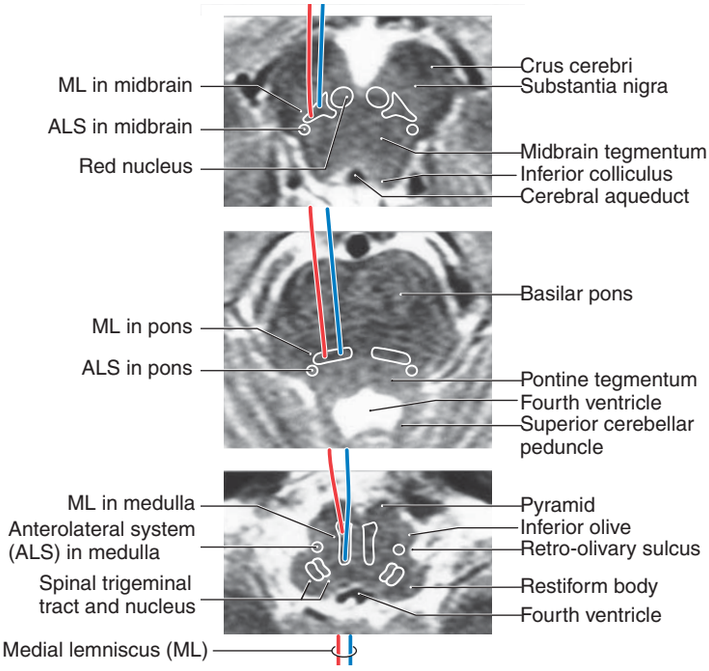
literally dozens of clinical correlations or examples. The following features enhance the user's comprehension of information and concepts that are directly relevant to diagnosing the impaired patient. *First,* inclusion of comprehensive pathways in an atlas format allows for the learning of clinically relevant concepts in a variety of settings: lecture, laboratory, self-study, small group, and during clinical rotations. *Second,* pathways that are most important to developing diagnostic skills are presented in **Anatomical** and **Clinical Orientations** which show: (1) its origin, extent, course, and termination; (2) **laterality**, an enormously important clinical concept; (3) position throughout the neural axis and its decussation, if applicable; (4) somatotopy within tracts; and (5) the blood supply at all levels. *Third,* a brief summary of the principal neuroactive substances associated with many pathways, whether they result in excitation (+) or inhibition (–) at their receptor sites, and deficits that may correlate with the loss of particular neurotransmitters is included. *Fourth,* clinical correlations accompany each pathway drawing; these describe deficits, lesions, clinical terminology, and laterality of deficits at different levels of the pathway. In toto, the drawings in Chapter 8 provide a maximal amount of clinically relevant information; each in a single easy-to-follow illustration.

Interspersed within this chapter are 13 sets (26 pages) of illustrations presented in **Clinical Orientation** that immediately follow, and complement, the corresponding pathway presented in **Anatomical Orientation** (Figures 1-9 and 1-10). These clinical illustrations overlay MRIs, focus on cranial nerves and long tracts that are especially important to the diagnosis of the impaired patient. This approach recognizes that in some educational settings pathways are taught anatomically, while in others the emphasis is on a Clinical Orientation; both approaches are accommodated in this atlas. It is, however, important to emphasize that when viewing MRI or CT of a patient compromised by neurologic lesion or disease, *all of the internal brain anatomy and all tracts, including their somatotopy, are seen in a* **Clinical Orientation**. It is absolutely essential that the user *recognize and understand this fact of clinical reality.*

Since *all* possible pathways that may be taught in a given neurobiology course cannot be anticipated, flexibility is designed into this chapter. The last figure in each section is a blank master drawing that follows the same format as the preceding figures. These may be used for learning, review, practicing pathways, in an instructional setting, and as a substrate for examination questions.

Chapter 9

This new chapter on **Herniation Syndromes: Brain and Spinal Discs** illustrates, in more than 60 new line drawings, MRIs, and CT scans, the



1-9 The medulla, pons, and midbrain portions of the posterior column-medial lemniscus pathway (see Figure 8-3A for the entire pathway) superimposed on MRI and shown in a *Clinical Orientation*. For convenience only, this example from Figure 8-3A is reduced here to fit in a single column.

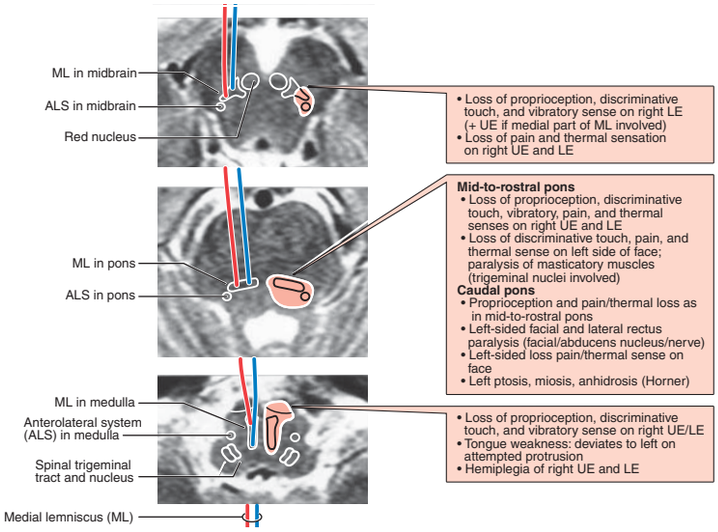
close correlation between structures damaged resultant to a herniation and the predictable deficits. There are elegant, and in many situations, remarkably precise correlations between the deficits experienced by the patient and the structures damaged in herniation syndromes; in some cases the deficits accurately predict the type and location of the herniation. Recognizing that brain herniations share general features in common with intervertebral disc extrusions, selected spinal cord syndromes are included to offer a more complete picture of this general phenomenon.

There is a finite amount of space in the cranial cavity; small space-taking events may temporarily be accommodated, while large and especially rapidly occurring events are not tolerated. Anything that compromises this finite amount of space, such as a tumor, hemorrhagic event, brain edema, or any of a number of other causes, may result in increased intracranial pressure (ICP) and a cascade of events that leads to herniation of the brain from one location/compartment to another; these are commonly called *herniation syndromes*. A herniation may be silent with deficits to follow later, or may result in sudden and potentially catastrophic deficits; in some cases, and if untreated, death may follow within minutes.

Increased ICP may be signaled by effacement of sulci or cisterns or a shift in brain structures that may be subtle, particularly in an isodense CT, or obvious as in an edematous tumor. Once evidence of ICP has been determined, a course of treatment is put in motion to guard against further deterioration.

Chapter 10

This chapter contains a series of angiograms (arterial and venous phases), MRA images, and MRV images. The angiograms are shown in lateral and anterior–posterior projections—some as standard views with corresponding digital subtraction images. MRA and MRV technology are noninvasive methods that allow for the visualization of arteries (MRA) and veins and venous sinuses (MRV). However, there are many situations when both arteries and veins are seen with either method. Use of MRA and MRV is commonplace, and this technology is an important diagnostic tool.



1-10 The medulla, pons, and midbrain portions of the posterior column-medial lemniscus pathway (see Figure 8-3B for the entire pathway) superimposed on MRI in a *Clinical Orientation*, with lesions and corresponding deficits at representative levels. For convenience only, this example from Figure 8-3B is reduced here to fit in a single column.

Chapter 11

The questions and corresponding answers of Chapter 11 recognize that examinations are an essential part of the educational process and that these elements should prepare, as much as reasonably possible, the user for future needs and expectations. Many are prepared as a patient vignette and in the USMLE Step-1 style (single best answer) which emphasize: (1) anatomical and clinical correlations; (2) application of basic neurobiology concepts to clinical practice; (3) integration of regional neurobiology, systems neurobiology, neurovascular patterns, and disease processes; and (4) the topographical maps within motor and sensory systems as related to lesions of tracts, nuclei, and the cerebral cortex.

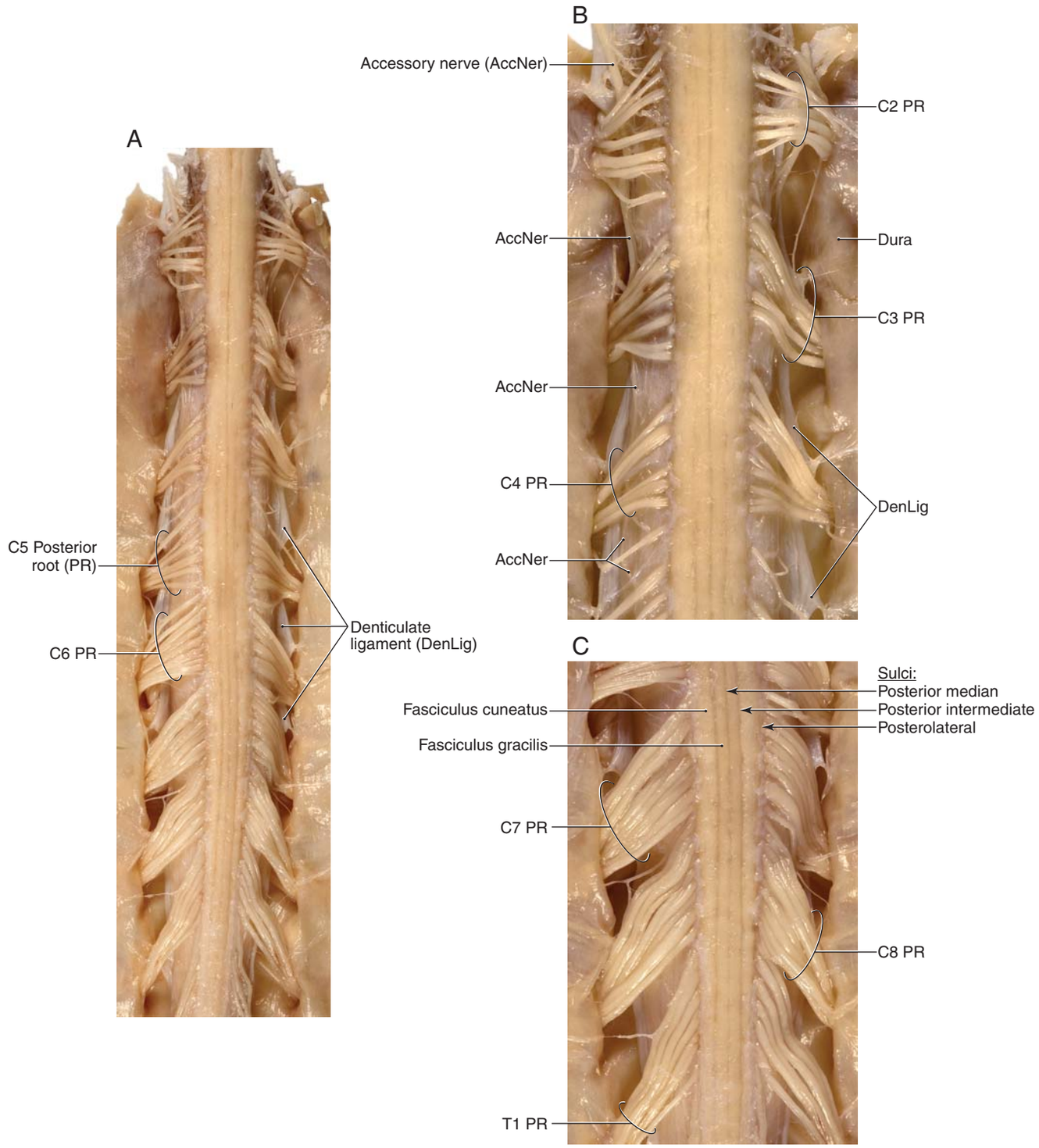
While generally grouped by chapter, questions may draw on information from more than one chapter thus reflecting the reality of many major examinations. Correct answers are given, incorrect answers are explained, and page references are given for more detail. A sampling of questions and answers is provided in this chapter with a total of over 300 provided online. While not exhaustive, these questions represent a broad range of clinically relevant topics.

References

1. Buxton RB. *Introduction to Functional Magnetic Resonance Imaging, Principles and Techniques*. Cambridge, UK: Cambridge University Press; 2002.
2. Grossman CB. *Magnetic Resonance Imaging and Computed Tomography of the Head and Spine*. 2nd ed. Baltimore, MD: Williams & Wilkins; 1996.
3. Harnsberger HR, Osborn AG, Macdonald AJ, et al. *Diagnostic and Surgical Imaging Anatomy: Brain, Head & Neck, Spine*. Salt Lake City, UT: Amirsys Publishing Inc; 2011.
4. Lee SH, Rao KCVG, Zimmerman RA. *Cranial MRI and CT*. 4th ed. New York, NY: McGraw-Hill Health Professions Division; 1999.
5. Osborn AG, Salzman KL, Barkovich AJ, et al. *Diagnostic Imaging: Brain*, 2nd ed. Salt Lake City, UT: Amirsys Publishing Inc.; 2010.

Q&A for this chapter is available online on thePoint

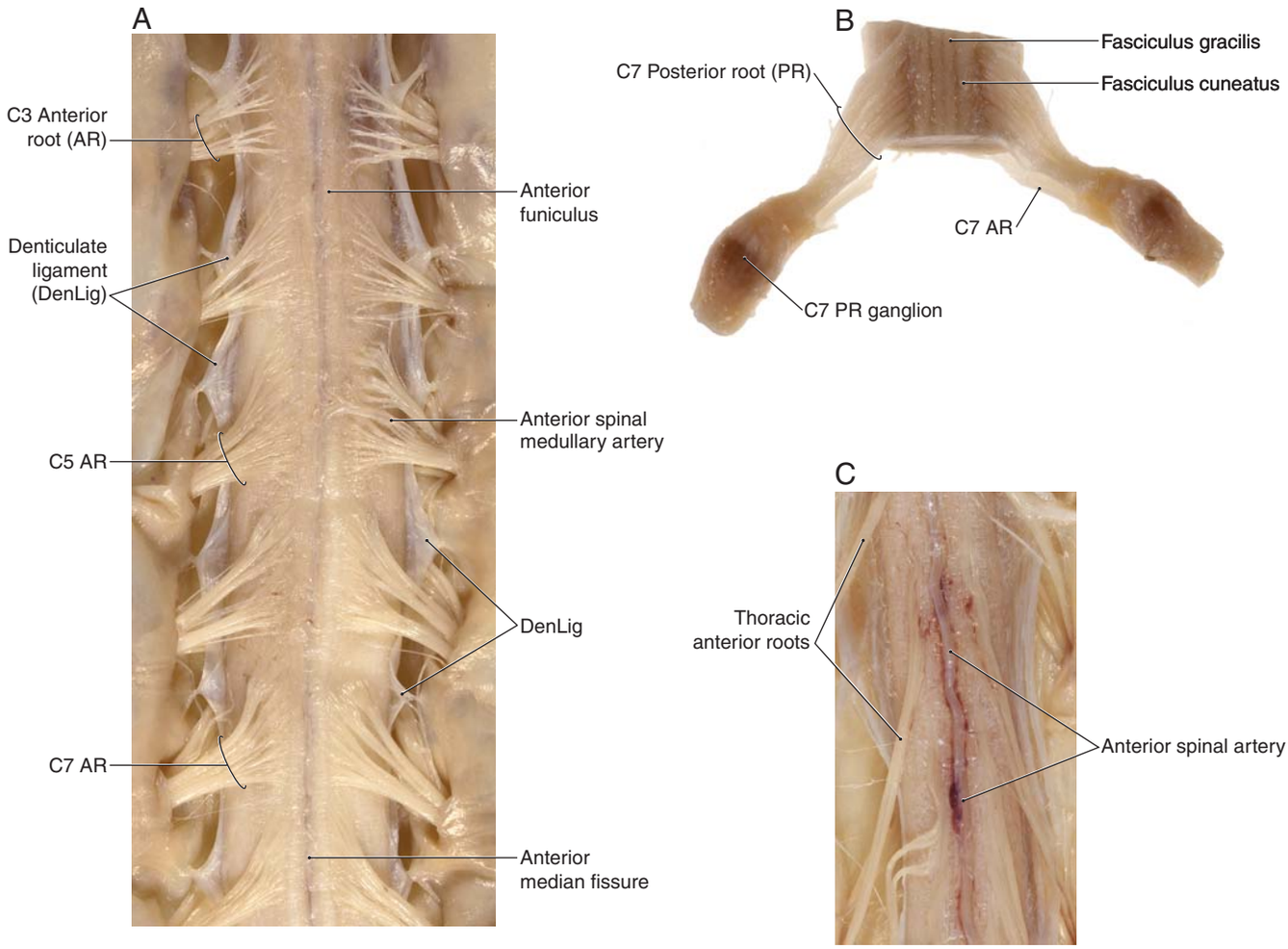
External Morphology of the Central Nervous System 2



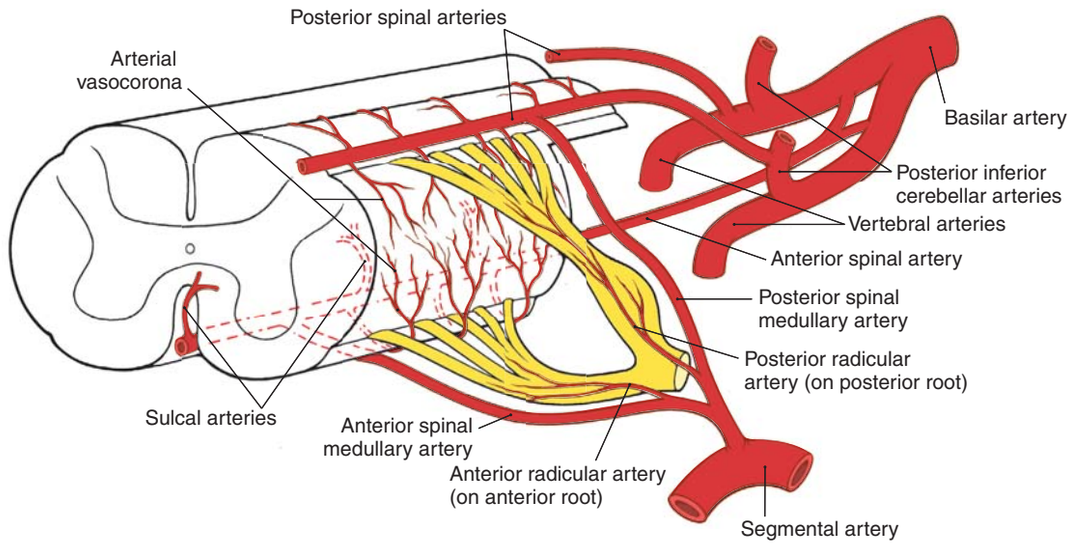
2-1 Overview of a posterior aspect of the spinal cord from C2–T1 (**A**) and details from the same specimen showing the C2–C4 and C7–T1 levels (**B, C**). The **denticulate ligaments** anchor the spinal cord within the dural sac; they are pial tissue sheets that extend laterally to attach to the arachnoid on the inner surface of the dura. The **accessory nerve** courses between the anterior and posterior roots (**B**) and the posterior surface of the cord clearly shows structures and sulci characteristic of the posterior column system (**C**).

Posterior and **anterior spinal medullary arteries** accompany their respective roots (Figure 2-3 on facing page) and the radicular arteries supply their respective roots. The posterior spinal artery is located medial to the posterior root entry zone and the anterior spinal artery is in the anterior median sulcus (Figure 2-3 on facing page).

Radiculopathy results from spinal nerve root damage. The most common causes are **intervertebral disc disease/protrusion** or **spondylolysis**, and the main symptoms are *pain radiating in a root or dermatomal distribution, weakness,* and **hyporeflexia** of the muscles served by the affected root. The discs most commonly involved at cervical (C) and lumbar (L) levels are C6–C7 (65%–70%), C5–C6 (16%–20%), L4–L5 (40%–45%), and L5–S1 (40%–45%). Thoracic disc problems are rare, well under 1% of all disc protrusions. For additional information on spinal disc extrusions, see Chapter 9.



2-2 Anterior aspect of the spinal cord from C3–C7 (**A**), the C7 segment showing the **posterior** and **anterior roots** and the **posterior root ganglion** (**B**), and a view of the anterior surface at thoracic levels showing the **anterior spinal artery** and the comparatively diminutive size of the thoracic roots (**C**).



2-3 Semi-diagrammatic representation showing the origin and general location of principal arteries supplying the spinal cord. The **anterior and posterior radicular arteries** arise at every spinal level and serve their respective roots and ganglia. The **anterior and posterior spinal medullary arteries** (also called **medullary feeder arteries** or **segmental medullary arteries**) arise at intermittent levels and serve to augment the blood supply to the spinal cord. The **artery of Adamkiewicz** is an unusually large spinal medullary artery arising usually on the left in low thoracic or upper lumbar levels (T9–L1). The arterial vasocorona is a diffuse anastomotic plexus covering the cord surface.