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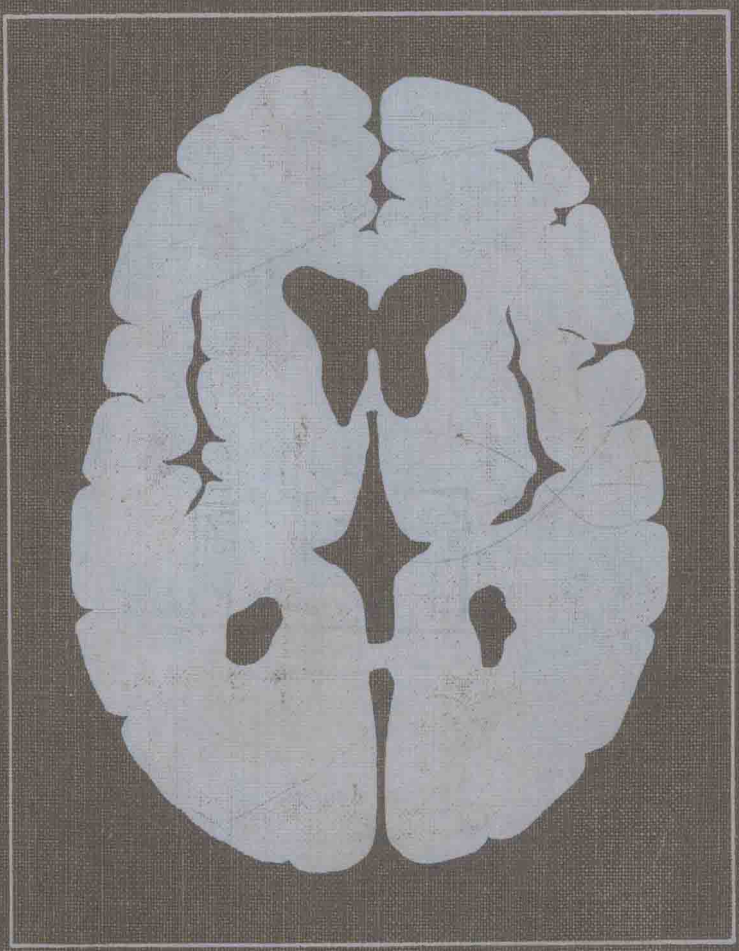
CORRELATIVE NEURORADIOLOGY

Second Edition



CORRELATIVE NEURORADIOLOGY

INTRACRANIAL RADIOGRAPHIC ANALYSIS WITH COMPUTED TOMOGRAPHY, ANGIOGRAPHY, AND MAGNETIC RESONANCE IMAGING

SECOND EDITION

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CORRELATIVE NEURORADIOLOGY

To Susan, Laura, and Scott
and
To Linda and Lauren

Preface

The overriding goal for radiologic imagers is tissue and structural discrimination. Thin-section computed tomography (CT) scanning, the use of intrathecal nonionic contrast agents, and gas cisternography are relatively new techniques that have gained rapid popularity since the first edition of *Correlative Neuroradiology* was published, and these are described in detail. Nuclear magnetic resonance scanning is introduced as an imaging method for normal topographic relationships. Since this text is not intended to be an atlas of pathology, cases used to illustrate topographic localizations were chosen carefully to encompass as many different types of neuropathology as possible. Two additional features were added to supplement this area: a tabular appendix that reviews the radiographic features of most lesions of the brain and its coverings, and very complete bibliographies for both the chapters (dealing with topographic localization) and the appendix (dealing with neuroradiologic features of intracranial pathology). A bibliography for magnetic resonance imaging (MRI, or magnetic CT as it is becoming popularly called) is included in Chapter 1 in order to supplement the information provided in this text. In spite of such extensive changes in this new edition, the basic theme of topographic localization of normal and abnormal intracranial anatomy is preserved. We believe that this emphasis is important in order to help the reader to provide accurate interpretations of neuroradiologic studies and to keep technological advances in perspective.

Magnetic resonance imaging is restructuring our neuroradiologic diagnostic arsenal. Although cerebral imaging has become the most precise and sophisticated of all regional imaging, magnetic CT takes this precision and sophistication even further. It is already clear that it will have an impact in several areas in which current methods fail to define the pathologic entity either because of artifacts or because of a lack of physical characteristics required by CT or angiography for differentiation of abnormal from normal brain. Most notable in the latter category are the changes of infectious processes, abnormalities of myelination, and cellular edema related to cerebral ischemia. The full impact of even the first-generation MRI scanners is not yet appreciated. Magnetic CT has the advantage of imaging in transaxial, coronal, or sagittal projections with ease. Furthermore, it does not suffer from the beam-hardening artifacts of conventional CT. These attributes make it very useful for demonstrating the topographic relationships among various intracranial structures. MR images of normal brain structures have been employed in the text to define the often complex intracranial topographic relationships that exist.

The second edition of *Correlative Neuroradiology* is directed to those readers who possess at least a rudimentary knowledge of neuroanatomy and in the course of their work must deal with neuroradiologic investigations for intracranial localization of either normal structures or neuropathology. It provides the foundation necessary to correctly recognize critical details of brain anatomy

and, more important, it provides a method of correlation among each of the imaging modalities. This edition is a composite of basic neuroanatomy and functional topographic relationships viewed from a radiographic perspective. It concentrates on the strengths of each radiographic imaging method and procedure. Each of the investigative parts contributes data to the final localization of a lesion, the differential diagnosis, and the most likely diagnostic consideration. In addition, the appendixes provide essential information about specific aspects of diagnosis of most neuropathologic states to assist the practitioner with differential diagnostic considerations. Thus, the second edition of *Correlative Neuroradiology* provides useful neuroradiologic information to persons at every level of expertise, while striving to serve those readers who need to develop both a foundation in neuroradiologic anatomy and a method for interpretation and analysis of radiologic studies.

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Acknowledgments

This text is due in part to the dedicated efforts of the radiologic technologists at the two hospitals at the University of Florida Medical Center, namely the J. Hillis Miller Health Center and the Gainesville Veterans Administration Medical Center. Their efforts in maintaining a high level of image quality on each examination greatly simplified the collection of case material used in the illustrations. The midsagittal inversion recovery image of the brain is courtesy of André Luiten of the Philips Corporation. Finally, we would like to acknowledge the support and understanding of our families during the many hours we devoted to manuscript preparation, and the help of Linda Lotz and Thomas Mareci, Ph.D., during the final stages of that preparation.

The majority of the magnetic CT images used as illustrations in this text were obtained on a Technicare NMR imaging system with a 0.15-Tesla resistive magnet. An inversion recovery, midsagittal image was obtained from a Philips 0.5-Tesla superconducting magnet. The majority of computed tomographic images were obtained from either a Philips Tomoscan 310 or a General Electric CT/T 8800 scanner. The angiographic images were generated from Philips angiographic systems with 0.6- and 0.3-millimeter focal spot sizes and Schoenander film changers. DuPont or Kodak subtraction films were used for subtracting the angiographic images. Other technical details, if relevant to the understanding of an image, are included in the legend.

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Contents

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Correlative Neuroradiology: An Overview of Technology and Terminology

The development of magnetic computed tomography (magnetic CT), also known as magnetic resonance imaging or MRI, opens a new chapter in the evaluation and imaging of normal and abnormal cerebral structures. Early reports have demonstrated its potential as a major diagnostic modality. However, even at the present state of technology magnetic CT can be of considerable diagnostic value. Along with computed tomography (CT) and cerebral angiography, it can play a significant role in imaging cerebral architecture. The strengths of each modality will become apparent in subsequent chapters. The full impact of tissue characterization by magnetic CT will not be realized without years of intensive investigational effort.

This text integrates the topographic features of the brain as they are imaged by CT, magnetic CT, and cerebral angiography. It is not intended as an atlas of intracranial pathology; however, cases have been selected to illustrate a broad range of abnormalities. These cases are cross-referenced with Appendix II, in which descriptions of a wide variety of intracranial pathologic entities can be found. Key references from the literature are included to allow expanded review beyond the scope of this text. Each chapter is divided into an initial consideration of the topographic features of normal regional anatomy and a subsequent discussion of the recognition and localization of pathology based on the principles learned. The text of each chapter reviews the pertinent radiotopography from an anatomic perspective, while the legends of the illustrations review radiotopography from the perspective of radiologic imaging. Therefore, the text and legends must be considered in concert.

This chapter deals with important technical considerations and terminology necessary for an understanding of the imaging capabilities of each diagnostic method. Magnetic CT has created a new vocabulary for those involved with neuroradiologic imaging. Each of the three principal imaging modalities, MRI, CT and angiography, evaluates some form of "tissue density." Unfortunately, the physical basis for this "density" differs markedly among these techniques, necessitating a separate discussion of each modality and its inherent method of image acquisition. Topographic features of brain anatomy are, of course, constant for a given patient regardless of the kind of images obtained. Therefore, radiotopographic analysis provides a reasonable framework within which

to integrate diagnostic data into a meaningful interpretation for the identification and localization of neuropathology. Since this book is restricted to the analysis of roentgenologic images, intracranial topography is referred to as either radiotopography or radioanatomy. A basic level of familiarity with cerebral topographic structures is assumed. For the reader who is less familiar with neuroanatomy, a general pictorial atlas of skull and brain anatomy will be a useful aid in understanding the concepts presented in Chapters 2 through 5.

CEREBRAL COMPUTED TOMOGRAPHY

CT Methodology: Image Planes

Computed tomography can be performed in coronal or transaxial planes and can be reconstructed in sagittal or oblique planes, depending mainly on the degree of spatial resolution and the capabilities of the computer software of the CT scanner. The topographic relationships among intracranial structures as described in this text can be applied to coronal and sagittal sections. However, the sections used are in the transaxial projection except where coronal views have particular usefulness, as in the suprasellar and incisural regions. Standard transaxial images are obtained with the plane of the x-ray beam parallel to either the infraorbitomeatal or supraorbitomeatal line. The former is used mainly for orbital evaluation and the latter for standard intracranial CT evaluation.

Transaxial CT Section Level

A complete CT examination of the brain includes serial sections that extend from the foramen magnum to the vertex of the skull. Sections should be contiguous or overlapping to avoid errors related to gaps between tomographic slices. Since the systems of numbering sections differ among CT machines, the sections illustrated in this book are designated as follows:

- *High-Convexity* CT sections image the skull and brain beginning at the vertex and extending inferiorly to the corpus callosum. These sections do not include the lateral ventricle.
- *MidConvexity* CT sections image the midportion of the cerebral mantle, the lateral ventricles (excluding the temporal horns), the cistern of the velum interpositum, the cistern of the vein of Galen, and the most superior part of the cerebellum.
- *Low-Convexity* CT sections include the third ventricle, the foramina of Monro, and the genu of the corpus callosum, but not the suprasellar cistern. The brain parenchyma imaged includes portions of the cerebral mantle as well as part of the cerebellar hemispheres and superior vermis.
- *Basilar* CT sections include the suprasellar cistern, the inferior surfaces of the temporal lobes (including the temporal horns), the gyri recti of the frontal lobes, and the remaining posterior fossa structures.

Usually several different CT sections are obtained within each of these regions, the exact number depending on the CT slice thickness, the size of the patient's head, and variations in the plane of the x-ray beam.

CT Tissue Density

To appreciate what the term *tissue density* implies in CT, one needs a cursory understanding of the physical basis of CT. Transmission CT is founded on the

principle that each kind of tissue has an inherent ability to absorb x-ray photons. Each will attenuate an incident x-ray beam to an extent proportionate to its atomic number. This physical ability, specific for each tissue, is represented by a quantity known as its linear attenuation coefficient. In cerebral CT an incident x-ray beam of known intensity is passed through an individual plane of the brain at a specified thickness. The intensity of the partially attenuated beam is registered by a system of scintillation detectors, the degree of x-ray attenuation having been determined by the attenuation coefficients of the tissues traversed by the detected photons. After the x-ray absorption by the target (the section of the brain) has been measured circumferentially, the digitalized data are collated and analyzed by a computer, which then reconstructs an image on a display matrix that reflects both spatial relationships and the relative attenuation of x-rays by the tissues being scanned. It is this differential attenuation of x-rays that provides what we refer to as "tissue density," which is usually measured in Hounsfield units. These CT attenuation units are absorption values that are computed based on the arbitrary assignment of values of 0 to water and -500 or -1000 (depending on the tomograph manufacturer) to air. They are similar to but not the same as linear attenuation coefficients. Furthermore, these units vary not only among tomograph manufacturers but also within any specific machine unless attention is paid to frequent standardization of the detector array.

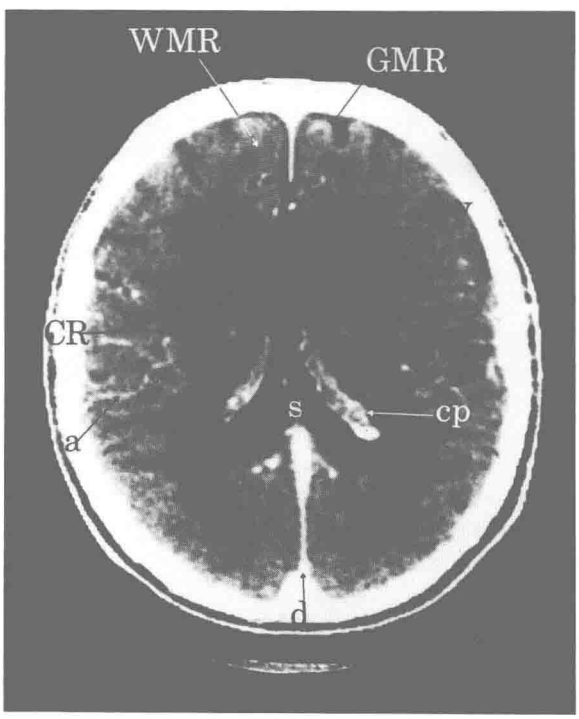
Rather than dealing with specific absorption values, we use qualitative terminology in this book to emphasize the CT tissue density of apparently normal brain parenchyma as it appears on the display unit. Normal brain parenchyma (or cerebral mantle) appears as a shade of gray that is arbitrarily designated as "isodensity." Structures that appear to be a darker shade of gray than isodensity are labeled as "less than isodense" or as having low CT density. These structures attenuate fewer x-ray photons than does normal brain parenchyma. Structures that are represented by a lighter shade of gray are said to be "greater than isodense" or of high CT density. Structures containing air, fat, or cerebrospinal fluid (CSF) appear less than isodense, whereas freshly clotted blood and calcified structures appear greater than isodense. The use of the terms high-, low-, and isodensity provides a convenient means of comparing and relating brain densities on a gray scale of attenuation values without citing the actual numerical values. However, this descriptive method is based on the perception of normal parenchymal density. When the brain mantle is diffusely abnormal or when focal pathology has a CT density similar to that of the normal brain, the abnormality cannot be distinguished on the basis of contrast density alone. The measurement of CT absorption values directly on the scanner console can be of particular value in individual cases. We do not intend to belittle the usefulness of numerical attenuation values, but to discuss them sufficiently for every type of pathology would be beyond the scope of this text, and such values are unnecessary in most clinical situations.

The actual CT image is dependent on both the CT tissue parameters, mainly the x-ray attenuation values, and the CT instrument parameters, mainly the x-ray kilovoltage and current (measured in milliamperes) and the duration of the exposure. The ultimate CT density of any material depends on its chemical composition and its concentration within the section. Image density when compared with water, as reflected by order on the gray scale, is predictable. Highly dense materials, such as those containing calcium, appear greater than isodense, and those containing lipid appear less than isodense. The gray scale order for CT is dependent on inherent tissue parameters and not on machine parameters for those radiographic techniques useful for CT imaging. The latter determine mainly the image quality. As will become evident later in this chapter, this relationship between image density and imaging parameters is vastly different with magnetic CT.

CT Enhancement with Iodinated Contrast Agents

Computed tomography can be performed with or without the administration of intravenous or intrathecal contrast material. The decision to use a contrast medium is dictated by several factors: the clinical indications for the study; any history of a previous adverse reaction to contrast medium; and, when an intrathecal, nonionic contrast medium is being considered, any history of seizures and the patient's recent and current medications. Metrizamide was the intrathecal agent employed in the cases illustrated in this text. Nonenhanced CT sections allow a baseline evaluation of CT parenchymal densities. This permits the identification of subtle regions of diminished or elevated density as occur with some recent infarctions or hematomas or with chronic calcium deposition. Intravenously enhanced CT sections demonstrate abnormalities of the blood–brain barrier and of regional perfusion. The former occur with inflammatory as well as with neoplastic processes. Thus, the intravenous administration of a contrast medium is a nearly routine part of the CT scanning procedure. The use of intrathecal contrast media, on the other hand, is reserved for situations in which subtle alterations in brain or cisternal topography are to be delineated, as is often the case in the regions of the sella and the foramen magnum. It can be useful also in determining whether a lesion is in communication with the CSF of the subarachnoid space, an issue that arises in cases of possible arachnoid cysts. The use of intravenous or intrathecal contrast agents must be tailored to the clinical situation in every instance.

FIGURE 1-1
NORMAL CT DENSITIES AND NORMAL INTRAVENOUS CONTRAST ENHANCEMENT



Midconvexity, Contrast-Enhanced CT Section. This scan through the midconvexity region of the cerebral hemispheres demonstrates the relative CT attenuation differences among the cerebral cortex, CSF within the lateral ventricles (LV), and the major white matter tracts of the corona radiata (CR) and the splenium (S) of the corpus callosum. The cerebral mantle includes the densities of the gray (GMR) and white matter (WMR). Their cumulative density is designated "isodensity," despite the subtle differences between them. Cerebrospinal fluid within the ventricular system is a considerably darker shade of gray, which is described as "less than isodensity" or "low density." Calcifications and bone have attenuation values "greater than isodensity" and are described in a qualitative sense as having high CT attenuation or high density. These qualitative terms reflect a range of absolute absorption values. When subtle differences in density are being compared, it may be necessary to use specific CT absorption numbers. This section also illustrates typical contrast enhancement of arteries (a), dural sinuses (d), and choroid plexus (cp) following the intravenous administration of contrast medium. Brain parenchyma also enhances, but uniformly and to a lesser extent, making it difficult for the observer to appreciate such differences. Focal contrast enhancement of other brain structures out of proportion to that of contiguous brain is considered abnormal and reflects either increased local blood flow or loss of blood–brain barrier integrity. Such abnormal enhancement is illustrated in Figure 1-4 and in greater detail in the remaining chapters.

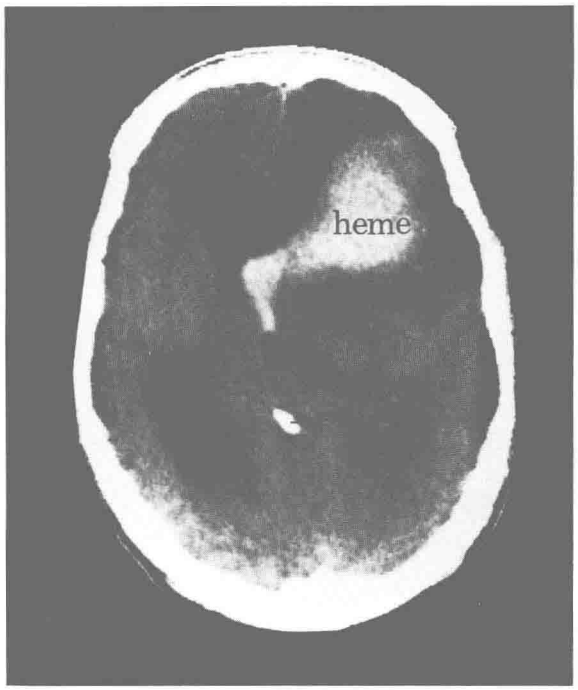


FIGURE 1-2
SPONTANEOUSLY ABNORMAL TISSUE DENSITY: GREATER-THAN-ISODENSE CT ATTENUATION

Midconvexity, Noncontrast CT Section. In this example a large hematoma (heme) is present in the left frontal region. This hemorrhage resulted from bleeding within a nodule of a metastatic melanoma. Spontaneously greater-than-isodense lesions contain either calcification or recently clotted blood. The difference in attenuation between calcification and thrombus on this CT section is evident if one compares the densities of the calcified pineal gland (P) and the intracerebral hematoma. Calcium can be present in various lesions or in brain tissue in varying concentrations. If the concentration is sufficiently low it will be undetectable. Alternatively, the calcium may be quite visible but its attenuation values may be within the range of those of a hematoma (variable from scanner to scanner, but usually up to 100 to 130 Hounsfield units). Clotted blood can be excluded as a diagnosis if the measured attenuation values exceed its established range for the scanner being used. For values within that range, no distinction between calcium and clotted blood can be made by means of measured attenuation values. The morphology of the density may suggest the diagnosis, but in some cases one must await the resorption of the clot to make the diagnosis on a follow-up scan.

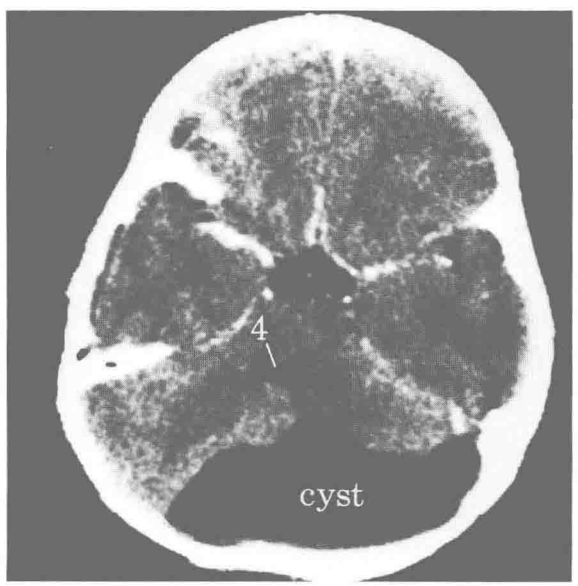
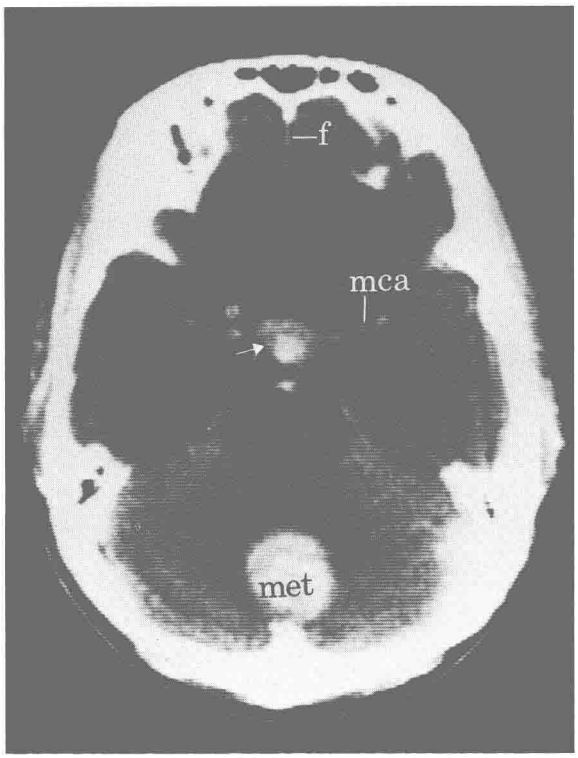


FIGURE 1-3
SPONTANEOUSLY ABNORMAL TISSUE DENSITY: LESS-THAN-ISODENSE CT ATTENUATION

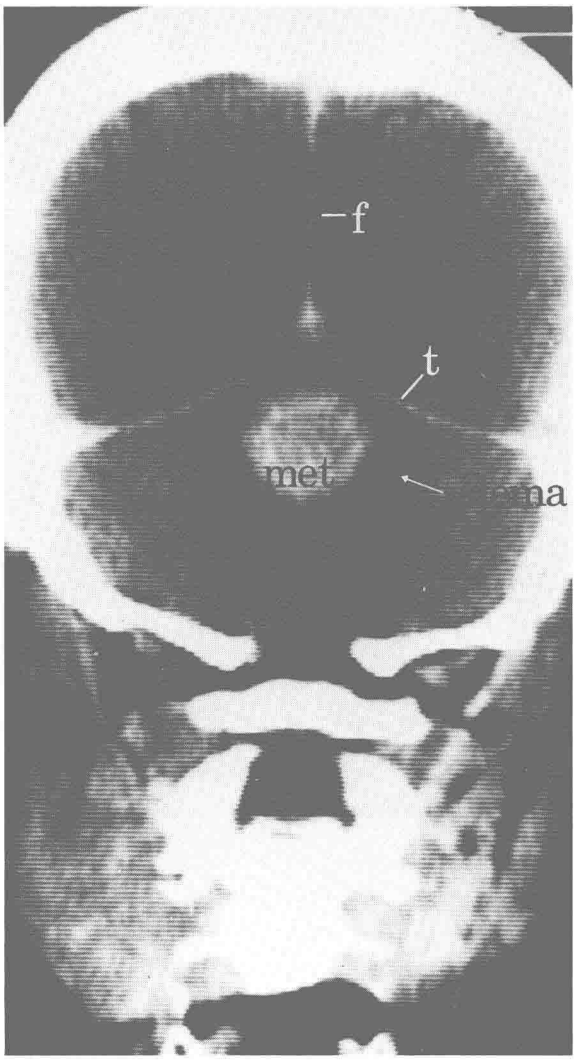
Basilar, Contrast-Enhanced CT Section. In this example normal parenchymal tissue density is evident in the frontal and temporal regions, while a large cystic lesion (cyst) of abnormally low attenuation is identified in the posterior fossa. This lesion exerts a local mass effect manifested as displacement of the fourth ventricle (4). Its smooth and sharply delineated margins, the absence of abnormal contrast enhancement, and its isodensity with CSF characterize it as an arachnoid cyst. Abnormalities with CT absorption values lower than that of brain generally fall into one of three categories: increased brain water (as seen in Figure 1-4, where brain edema surrounds a metastasis); density comparable to that of CSF; or density less than that of CSF, which usually indicates the presence of lipid material. The actual CT attenuation values corresponding to these three categories vary somewhat among scanners, so we do not list them here.

FIGURE 1-4
ABNORMAL CONTRAST ENHANCEMENT

(a) Basilar Transaxial and (b) Coronal Contrast-Enhanced CT Sections. These images illustrate normal contrast enhancement of the falx cerebri (f), the tentorium cerebelli (t), and the middle cerebral arteries (mca). In addition there is abnormal contrast enhancement of two lesions. The first is a small metastasis to the hypothalamus (arrow), and the second is a larger metastatic nodule within the cerebellar vermis (met). The vermic mass is surrounded by a zone of diminished CT attenuation (low density) representing cerebellar edema. A biopsy revealed metastatic carcinoid tumor from a primary pulmonary source. These sections illustrate abnormal contrast enhancement within the tumors, which in all likelihood is the result of a defective blood–brain barrier, and the abnormally low CT density of edema in the adjacent brain. The use of multiple projections clarifies the position of the mass within the cerebellum and its relationship to extrinsic structures, which may be of value for surgical localization.



(a)



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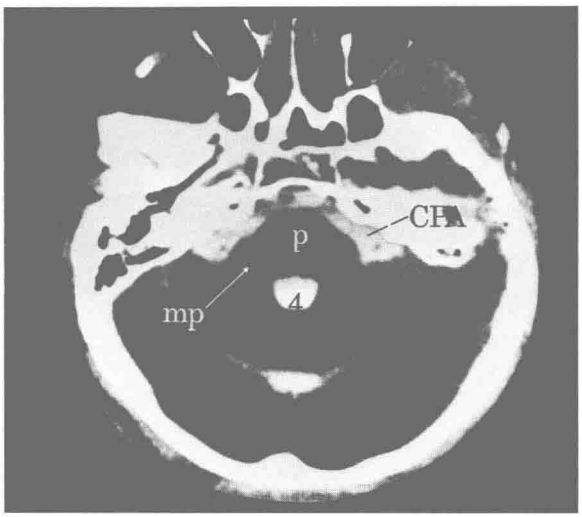


FIGURE 1-5
CT WITH INTRATHECAL CONTRAST ENHANCEMENT

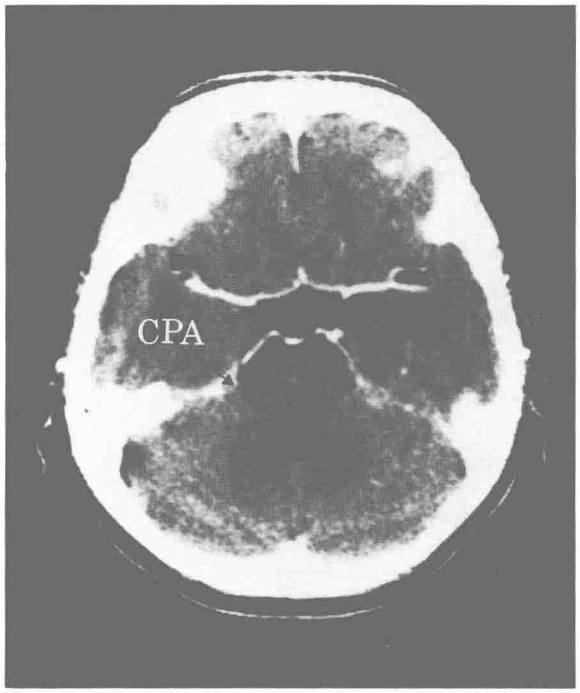
Basilar CT Cisternographic Section Following Intrathecal Administration of a Nonionic Contrast Medium (Metrizamide). This CT section images the brainstem and its adjacent cisterns with far greater clarity than is obtainable by routine CT with or without intravenous contrast enhancement. Identification of pontine surfaces without metrizamide is limited by the minimal amount of lower-density CSF within the adjacent cerebellopontine-angle (CPA) and prepontine cisterns. Usually the addition of metrizamide to the subarachnoid space markedly improves visualization of topographic details of the pons (p), the fourth ventricle (4), the middle cerebellar peduncles (mp), and the ventral surface of the cerebellum. Such intrathecal contrast agents are used when crowding of relatively small structures prevents their visual separation, which occurs most frequently in the posterior fossa and suprasellar regions. Intrathecal contrast is also useful for determining whether communication exists between a cystic lesion and either the subarachnoid space or the ventricular lumen.

CT With Intrathecal Gas ("Air CT")

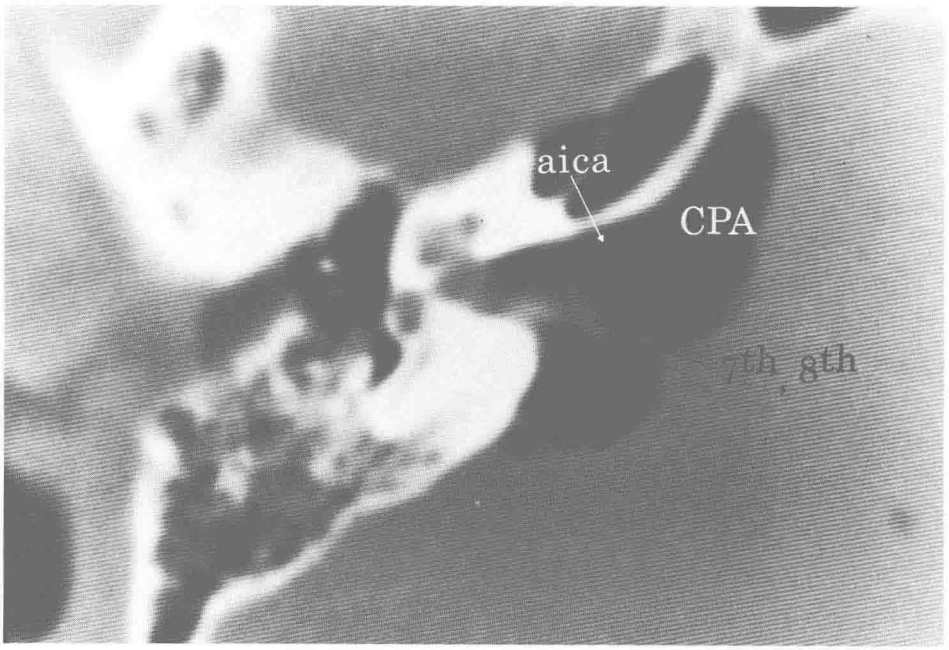
The evaluation of the cerebellopontine angle (CP angle) and the internal auditory canal is a common clinical indication for CT. Numerous radiographic methods have been employed in this regard. Currently, small lesions in the CP angle and/or internal auditory canal are most easily delineated by using intrathecal gas in conjunction with x-ray CT. The gases used most often include filtered room air, oxygen, and carbon dioxide. Most of the gas CT sections shown in this book were obtained with oxygen as the contrast agent. The role of magnetic CT in this area is to be determined, but limited early reports are encouraging.

FIGURE 1-6
CT WITH INTRATHECAL GAS

(a) Basilar, Intravenously Contrast-Enhanced CT Section and (b) Cerebellopontine-Angle Gas-CT Cisternographic Section. Figure *(a)* is a normal CT section that includes the cerebellopontine-angle cistern region (CPA). Details of this region are not evident because the minimal amount of CSF present provides a density insufficiently different from that of the many isodense structures crowded within the cistern. However, after introduction of gas (oxygen, filtered room air, or carbon dioxide) into the subarachnoid space and positioning it within the cerebellopontine-angle cistern, thin CT sections are capable of precisely imaging the anatomy in this region. In Figure *(b)* a loop of the anterior inferior cerebellar artery (aica) and the nerve bundle including the seventh and eighth cranial nerves (7^{th}, 8^{th}) are imaged clearly. Gas cisternography has limited usefulness except in the region of the internal auditory canal, where it has proved to be effective in imaging intracanalicular acoustic neurinomas.



(a)



(b)