the dependent portion of the abdominal or pelvic cavity with patient movement. Alternatively, it can be complex, an exudate, in which case it is denser than simple fluid, is accompanied by solid tissue (eg, tumor deposits in peritoneal metastases) or layered material (eg, blood from trauma or inflammatory cellular debris in peritonitis), and often is loculated, or unable to move freely throughout the intraperitoneal cavity (eg, abscess).

Pancreatic injury is uncommon, but potentially serious. Mortality from pancreatic injuries is nearly 20%. Being crushed against the spine probably accounts for the frequency of injury to the body of the pancreas. Pancreatic trauma may or may not be associated with increased amylase. Usually caused by blunt trauma, pancreatic trauma is often associated with injuries to other organs, such as liver and bowel. These injuries produce intraperitoneal blood and fluid and interstitial mesenteric edema, which can be confusing. As with hepatic trauma, CT with intravenous contrast is usually the modality of choice to evaluate pancreatic trauma, but even on CT, the diagnosis can be difficult. On CT, the pancreas may be ill defined, enlarged, or even disrupted, that is, fractured.

Bowel and mesenteric injuries are found in approximately 5% of all patients undergoing laparotomy after motor vehicle accidents. Injuries of the bowel and mesentery frequently accompany injury to the liver or pancreas. These injuries can result in massive intraperitoneal bleeding from disruption of mesenteric vessels, or peritonitis from bowel perforation. As elsewhere, CT is the modality of choice to evaluate patients for possible bowel or mesenteric injuries, but these injuries, like those to the pancreas, can be difficult to detect. On CT, injuries of the bowel and mesentery include free air with the intraperitoneal or retroperitoneal spaces, free intra-abdominal fluid, circumferential or eccentric bowel wall thickening, enhancement of the bowel wall, streaky soft-tissue infiltration of the mesenteric fat, free mesenteric hematoma (Figure 11-44), and especially sentinel clot. Angiography may demonstrate free extravasation of contrast material in injuries of the mesenteric vessels, and percutaneous embolization may stop bleeding when surgery is not possible.

**EXERCISE 11-4. BILIARY INFLAMMATION**

11-11. What is the most likely diagnosis in Case 11-11 (Figure 11-45)?
A. Acute cholecystitis  
B. Uncomplicated cholelithiasis  
C. Chronic cholecystitis  
D. Porcelain gallbladder

11-12. What is the most likely diagnosis in Case 11-12 (Figure 11-46)?
A. Oriental cholangiohepatitis  
B. Acquired immunodeficiency syndrome (AIDS)-associated cholangiopathy  
C. Choledocholithiasis  
D. Porcelain gallbladder

▲Figure 11-44. CT of mesenteric injury demonstrates fluid and hematoma (•) in the jejunal mesentery with active extravasation of contrast material (arrow) into the mesentery.

▲Figure 11-45. Case 11-11. A 53-year-old male with acute right upper quadrant pain, fever, pain on palpation over the gallbladder, and elevated liver function tests.
11-13. What is the most likely diagnosis in Case 11-13 (Figure 11-47)?
A. Acute cholecystitis
B. Emphysematous cholecystitis
C. Porcelain gallbladder
D. Hydrops of gallbladder

11-14. What is the most likely diagnosis in Case 11-14 (Figure 11-48)?
A. Choledocholithiasis
B. Ascending cholangitis
C. Acute cholecystitis
D. Emphysematous cholecystitis

Radiographic Findings

11-11. In this case, the gallbladder is distended and the wall is thickened, measuring more than 5 mm, and has multiple lamina, indicating gallbladder wall inflammation from acute cholecystitis (A is the correct answer to Question 11-11).

11-12. In this case, the gallbladder wall is markedly thickened, measuring over 1 cm, with multiple lamina, but is not tender to palpation, findings often seen with AIDS cholangiopathy (B is the correct answer to Question 11-12).

11-13. In this case, gas within the gallbladder wall and lumen is the primary abnormality, indicating emphysematous cholecystitis (B is the correct answer to Question 11-13).

11-14. In this case, CT demonstrates dilatation of the biliary ducts with enhancement and thickening of the wall (arrows). In the clinical setting of fever and jaundice, this most strongly suggests cholangitis (B is the correct answer to Question 11-14).

Discussion

Calculi are a common problem in the gallbladder and biliary ducts. Cholelithiasis is one of the most common abdominal
Gallstones develop when the composition of bile, which includes bile salts, lecithin, and cholesterol, varies from normal and creates supersaturation of cholesterol, which then precipitates. Historically, patients thought to be harboring gallstones on the basis of clinical criteria were examined by oral cholecystography, which shows filling defects in the gallbladder lumen opacified by orally ingested iodinated contrast material. However, this examination has been largely replaced by sonography, occasionally supported by other imaging information. On US, gallstones usually appear as mobile, intraluminal, echogenic foci that cast a well-defined acoustic shadow (Figure 11-49). Two other possible appearances are echogenic foci in the gallbladder fossa without visible surrounding bile when the gallbladder is contracted, and small, mobile, echogenic foci that do not cast a shadow. On CT, gallstones appear as dense, well-defined, intraluminal structures (Figure 11-50), but their density can vary from fat density to near bone density, depending on the relative concentration of calcium and cholesterol. Because of their varying density, they can sometimes be difficult to see on CT. MR imaging of the biliary system, especially MRCP, has become more important in biliary imaging, including the detection of calculi of the gallbladder and biliary tree. Although US remains the primary and initial means of identifying biliary calculi, MRCP can be used as a supplementary technique, especially in ductal calculi, because imaging of the biliary tree
by US may be suboptimal when obscured by bowel gas. MRCP can depict the biliary system, filling defects within the biliary tree (Figure 11-51), and congenital variants of the biliary ducts and is about as accurate as ERCP in displaying a biliary "road map." It can also be used to evaluate the biliary ducts when ERCP is impossible to perform, such as when the patient has undergone a Billroth procedure, interrupting the continuity of the upper gastrointestinal tract. NM and angiography have no major role at this time in assessment of gallstones.

Choledocholithiasis occurs when calculi pass from the gallbladder into the biliary ducts or when calculi develop originally within the ductal system. Regardless of origin, they may obstruct the biliary ducts, cause biliary colic, and lead to cholangitis. Common duct stones can be evaluated with US, CT, and MRI, or by direct visualization with ERCP. On US, choledocholithiasis appears as echogenic foci within the lumen of the biliary duct. Sonographically, common duct stones are detected less readily than gallbladder stones, and meticulous technique is required. The entire course of the common bile duct may be technically difficult or impossible to follow. Choledocholithiasis can cause acoustic shadows, but for technical reasons these stones are detected less frequently than cholelithiasis (Figure 11-52). On CT, choledocholithiasis appears as intraluminal biliary ductal foci, which, like gallbladder stones, may vary in density from hypodense to isodense to hyperdense to bile, depending on their composition (Figure 11-53). On MRCP, choledocholithiasis is seen as a filling defect in the duct.

Cholecystitis is inflammation of the gallbladder that is almost always caused by obstruction of the cystic duct, usually by an impacted calculus. The inflammation may be acute or chronic, uncomplicated or complicated, calculous or acalculous. As the gallbladder continues to accumulate bile, intraluminal pressure increases and vascular insufficiency of the wall occurs, causing ischemia, necrosis, and often supervening inflammation. The gallbladder distends, the gallbladder wall thickens from edema, and the patient is tender to palpation over the gallbladder (positive Murphy’s sign).

Both ultrasound and hepatobiliary NM studies are the modalities of choice to evaluate possible cholecystitis. Sonographic signs of acute cholecystitis include cholelithiasis, gallbladder wall thickening (greater than 3 mm), irregular or...
linear hypoechoic structures within the gallbladder wall, a positive sonographic Murphy’s sign, and marked gallbladder distention (Figure 11-54). A combination of these signs is a good positive predictor of acute cholecystitis. In marked chronic cholecystitis, US shows persistent gallbladder wall thickening or sludge, stones, and contraction of the gallbladder. However, in the presence of cholelithiasis, the gallbladder almost always shows signs of chronic inflammation histologically, even without symptoms or sonographic findings.

Hepatobiliary NM HIDA scans depict acute cholecystitis as an absence of filling of the gallbladder with the radionuclide once it is excreted by the liver into the biliary ducts; this absence of filling is due to the obstruction of the cystic duct lumen by inflammatory edema of the cystic duct wall (Figure 11-55). Sufficient time must be given to fill the gallbladder. This time interval depends upon whether or not morphine is administered. Morphine increases the tone of the sphincter of Oddi and increases intraluminal common bile duct pressure to overcome the resistance to bile flow into the gallbladder in chronic cholecystitis, but not in acute cholecystitis when a stone obstructs the duct. Acute cholecystitis is diagnosed when absence of activity is noted either 45 minutes after morphine augmentation or after 4 hours without morphine.

Figure 11-54. Longitudinal US in acute cholecystitis showing a thickened GB wall with linear, hypoechoic fluid/edema in the wall (arrowheads). Note the numerous rounded echogenic foci with shadowing in the neck of the GB representing gallstones (arrow). These findings, in conjunction with tenderness to palpation by the transducer over the GB (sonographic Murphy’s sign), strongly suggest acute cholecystitis.

Figure 11-55. NM hepatobiliary scan in acute cholecystitis showing the absence of gallbladder activity in the gallbladder fossa (arrowhead), 60 minutes following administration of the agent and even after administration of morphine.
augmentation. Delayed gallbladder visualization after 1 hour usually reflects chronic cholecystitis. On CT, the morphologic findings in patients with acute cholecystitis are similar to the US findings, including gallstones and thickened and inhomogeneous gallbladder wall. However, CT is not as sensitive as US or NM either to the presence of gallstones or to acute cholecystitis. MR imaging can depict the presence of gallbladder wall inflammation in the absence of wall thickening by demonstrating wall enhancement following Gd infusion (Figure 11-56). The exact role of MR imaging in cholecystitis has not yet been completely evaluated. Angiography has no role in the diagnosis of cholecystitis.

Many potential complications and conditions are associated with cholecystitis. These include hydrops, porcelain gallbladder, milk-of-calcium bile, and emphysematous cholecystitis.

Hydrops refers to the marked distention of the gallbladder by clear, sterile mucus, usually under conditions of chronic, complete cystic duct obstruction. On imaging studies, the primary finding is enlargement of the gallbladder (Figure 11-57).

**Figure 11-56.** (A) Preinfused T1-weighted MR imaging scan showing cholelithiasis and a low signal intensity gallbladder wall (arrow). (B) Postinfused T1-weighted MR imaging scan demonstrating gallbladder wall enhancement (arrow), reflecting the hyperemia of inflammation, signifying acute cholecystitis.

**Figure 11-57.** Longitudinal US in hydrops showing a massively enlarged gallbladder due to complete obstruction of the cystic duct and accumulation of clear mucus.
Porcelain gallbladder refers to calcification of the gallbladder wall, as a result of chronic inflammation causing dystrophic calcification and often associated with recurrent acute cholecystitis. Gallbladder stones are usually present, and there is a higher incidence (approximately 10% to 20%) of gallbladder carcinoma. On imaging studies, complete or incomplete circular wall calcification is present and is seen as a curvilinear, highly echogenic wall on US or as a curvilinear, high-attenuation wall on CT (Figure 11-58).

Milk-of-calcium bile refers to a precipitation of calcified material within the lumen of the gallbladder, usually associated with chronic cholecystitis. US shows echogenic sludge-like material, possibly with gallstones. CT demonstrates the distinctive appearance of a horizontal bile-calcium level.

Emphysematous cholecystitis is a distinctive condition and should be treated as a medical/surgical emergency. Like acute cholecystitis, it is marked by intense gallbladder wall inflammation, but unlike acute cholecystitis, it is not necessarily associated with gallstones. It may be related to ischemia of the gallbladder wall from small-vessel disease, and it affects an older age group than does acute cholecystitis. The most common group affected is older diabetic men. Gas is released by bacterial invasion and accumulates in the gallbladder wall, lumen, or both. On US, gas is seen as an echogenic focus producing poorly defined or “dirty” shadowing behind it. The wall is thickened, perhaps focally, with gas. On CT, air-density gas is seen within the lumen or wall (Figure 11-47). MR imaging and angiography have no current role in evaluation of these complications.

Like inflammation of the gallbladder, inflammation of the biliary ducts, or cholangitis, is an important clinical condition. It is less common than cholecystitis. AIDS-associated cholangiopathy, ascending cholangitis, and oriental cholangiohepatitis are three important forms of cholangitis.

AIDS-associated cholangiopathy is marked by the frequent isolation of opportunistic organisms, including Cryptosporidium and cytomegalovirus from the bile, and by considerable inflammation of the bile duct wall. On US or CT, the gallbladder or biliary duct walls may be markedly thickened (greater than 4 mm) (Figure 11-46) and may contain irregular lamina. Inflammation is present, but stones may or may not be present. Cholangiography shows irregular strictures, papillary stenosis, or both.

Ascending cholangitis is a bacterial inflammation of both walls and lumina of the biliary system, including the gallbladder. It is almost always due to obstruction of the biliary tract, especially when caused by choledocholithiasis and distal bile-duct stenosis. The presence of grossly purulent material within the duct indicates supplicative cholangitis. Cross-sectional imaging studies are used to define the level and cause of obstruction. Cholangiography can show the abnormal biliary ducts directly. The purulent material of supplicative cholangitis may be seen as echogenic material on US, high-density material on CT, or filling defects on cholangiography.

Oriental cholangiohepatitis is a common illness in endemic areas of Asia and can be seen in Asian immigrants in this country. It may be caused by bile duct wall injury from the parasitic infestation. Ductal stones commonly form, and the ducts are dilated. A characteristic finding is the presence of intraductal (especially intrahepatic ductal) calculi. These findings are readily demonstrated with US, CT, and cholangiography.

**EXERCISE 11.5. PANCREATIC INFLAMMATION**

11-15. What is the most likely diagnosis in Case 11-15 (Figure 11-59)?
A. Acute edematous pancreatitis
B. Pancreatic abscess
C. Pancreatic phlegmon
D. Hemorrhagic pancreatitis

11-16. What is the most likely diagnosis in Case 11-16 (Figure 11-60)?
A. Acute edematous pancreatitis
B. Hemorrhagic pancreatitis
C. Gastrointestinal artery pseudoaneurysm
D. Pancreatic abscess
11-17. What is the most likely diagnosis in Case 11-17 (Figure 11-61)?
A. Acute edematous pancreatitis
B. Chronic pancreatitis
C. Pancreatic phlegmon
D. Hemorrhagic pancreatitis

Radiographic Findings

11-15. In this case, the overall size of the pancreas (P) is enlarged, and the tissue around the pancreas is edematous with associated fluid (arrow). All are findings of acute edematous pancreatitis (A is the correct answer to Question 11-15).

11-16. In this case, peripancreatic inflammatory changes and a high-density collection are seen adjacent to the pancreatic head, representing a collection of blood created by hemorrhagic pancreatitis (B is the correct answer to Question 11-16).

11-17. In this case, multiple calcifications are distributed throughout the pancreas (arrows) and there is enlargement of the pancreatic duct (arrowhead) with atrophy of the parenchyma. All are findings of chronic calcific pancreatitis (B is the correct answer to Question 11-17).

Discussion

Pancreatitis, an inflammatory condition of the pancreas, has a number of causes including alcohol abuse, trauma, cholelithiasis, peptic ulcer, hyperlipoproteinemia, hypercalcemia, and infection. Pancreatic inflammation may be acute or chronic. Acute pancreatitis and chronic pancreatitis may not represent different stages of the same disease.

Acute pancreatitis can occur once or repetitively and usually has the potential for healing. It can be associated with mild to severe inflammatory edema (edematous or interstitial pancreatitis) or with hemorrhage (hemorrhagic or necrotizing pancreatitis). These two forms of acute pancreatitis may be distinguishable only by the severity and time course of the disease. Edematous pancreatitis resolves within 2 to 3 days with appropriate therapy, whereas hemorrhagic pancreatitis requires much longer to resolve. The
The diagnosis of simple pancreatitis is usually based on medical history, physical examination, and laboratory results. With this information, imaging studies are usually unnecessary, and scans show the pancreas to be normal or only slightly enlarged. The surrounding fat is edematous. The pancreas appears hypoechoic on US (Figure 11-62). On CT the surrounding fat appears as areas of streaky interstitial soft-tissue density in the transverse mesocolon around the pancreas (Figure 11-63).

Clinical criteria to predict the severity or likelihood of complications of pancreatitis correlate well with the presence and extent of extrapancreatic abnormalities on imaging studies. Imaging is useful in acute pancreatitis when assessing potential complications. These complications include hemorrhagic pancreatitis, vascular complications, phlegmon, and abscess.

Hemorrhagic pancreatitis is usually due to erosion of small vessels, is often a serious problem, and indicates an acutely and critically ill patient. It appears as a collection of echogenic material on US. On CT, it appears as a collection of high-density material and can be extremely extensive as it is an aggressive process (Figure 11-64). This material represents the blood.

Large vessels are at risk for developing pseudoaneurysms when the histolytic enzymes released by the inflamed pancreas erode their walls, leading to a focal, highly vascular structure within the region of the pancreas. The splenic, gastroduodenal, and hepatic arteries are particularly vulnerable. On US and CT, flow within an enlarged rounded vessel can be seen. Angiography establishes the diagnosis by showing a focally enlarged vessel, sometimes with extravasation. However, CTA is also effective for detecting pseudoaneurysms related to pancreatitis.

Phlegmon is an inflammatory, boggy, edematous, soft-tissue mass, distinct from fluid, arising from the pancreas and diffusely spreading away from it. Phlegmon appears as a diffuse soft-tissue echogenicity or density process surrounding the pancreas and contains neither the blood of hemorrhagic pancreatitis nor the fluid of an abscess (Figure 11-65).

Abscesses are a potentially life-threatening complication of pancreatitis. Infection associated with pancreatitis can be
thought of as representing infected necrosis (diffuse infection without pus collection) or pancreatic abscess (collection of pus surrounded by a capsule). Infected necrosis is harder to identify on imaging studies than is pancreatic abscess, because it is less distinct and blends into the surrounding edema. On US, abscess appears as a poorly defined anechoic or hypoechoic lesion. It enhances sound posteriorly and may contain debris. Gas appears as a poorly defined echogenic focus within the nondependent aspect of the lesion and casts a “dirty” shadow. On CT, the lesion is poorly defined and may contain gas collections. After contrast material infusion, the border enhances. If gas is absent, abscess cannot be differentiated from phlegmon or pseudocyst (Figure 11-66). In general, NM and angiography do not have a major role in evaluation of acute pancreatitis.

Unlike acute pancreatitis, chronic pancreatitis is considered to indicate permanent pancreatic damage. Chronic pancreatitis may or may not be preceded by prior attacks of acute pancreatitis. The pancreas will develop calcifications within the ductal system (Figure 11-61). Masslike enlargement of the pancreas can periodically occur, but often the gland eventually atrophies. The pancreatic duct may dilate. These findings are visible on both US and CT. NM and angiography do not have a current major role in evaluation of chronic pancreatitis.

**EXERCISE 11-6. PANCREATIC NEOPLASM**

11-18. What is the most likely diagnosis in Case 11-18 (Figure 11-67)?
   - A. Pancreatic cyst
   - B. Ductal pancreatic carcinoma
   - C. Pancreatic metastasis
   - D. Peripancreatic lymphadenopathy

11-19. What is the most likely diagnosis in Case 11-19 (Figure 11-68)?
   - A. Cholangiocarcinoma
   - B. Cystic pancreatic neoplasm
   - C. Ductal pancreatic carcinoma
   - D. Pancreatic cyst
11-19. In this case, CT demonstrates a fluid density lesion (arrow) in the tail of the pancreas (P). There is enhancement along the rim (arrowhead) that is not associated with surrounding inflammatory change in the peripancreatic fat. Findings are compatible with a cystic neoplasm of the pancreas (B is the correct answer to Question 11-19).

11-20. In this case, CT demonstrates a unilocular fluid attenuation mass (arrow) in the tail of the pancreas (P) without enhancement or nodularity. This is difficult to distinguish from a cystic neoplasm; however, at surgery this was a lymphoepithelial cyst (C is the correct answer to Question 11-20).

Discussion

Pancreatic masses include tumors, tumor-like masses such as cysts and developmental anomalies, and inflammatory lesions. These can overlap in appearance, as when an inflammatory mass simulates a neoplastic mass on imaging studies. They can be causally related, as when a neoplastic mass secondarily causes an inflammatory mass. Therefore, differentiation among them is not entirely possible, either clinically or radiographically. However, the prognostic and management implications of the lesions that create pancreatic masses differ considerably and therefore require extensive and often invasive investigation. Although contrast studies of the gastrointestinal tract can be used to infer the presence of a mass, usually cross-sectional imaging studies are employed to establish the diagnosis.

Tumors of the pancreas are important clinical entities; some have an extremely poor prognosis and some produce serious clinical symptoms. They can be classified according to origin as epithelial tumors, endocrine tumors, and miscellaneous lesions. Epithelial tumors can be solid or cystic. Solid ductal adenocarcinoma is the most common overall and carries the worst prognosis (mean survival 4 months). Cystic tumors can be divided into cystic lesions arising from the pancreatic parenchymal cells, such as cystadenoma or cystadenocarcinoma, and those arising from the pancreatic ductal cells, such as intraductal papillary mucinous tumors. Compared to adenocarcinoma, these tumors have a less serious prognosis. Endocrine, or islet cell, tumors elaborate hormonal substances and can create clinically significant symptoms. The two most common of these are insulinoma, which releases insulin and produces hypoglycemia, and gastrinoma, which releases gastrin and produces Zollinger-Ellison syndrome. There are many other important kinds of hormonally active pancreatic endocrine tumors, and each is designated by the hormone it
secretes (e.g., glucagonoma, somatostatinoma). Miscellaneous lesions arise from pancreatic parenchymal tissue (e.g., metastases, especially from melanoma, and lung or breast cancer) or from tissue other than pancreas (e.g., intrapancreatic cholangiocarcinoma or peripancreatic lymph node). These miscellaneous lesions are important because they sometimes strongly simulate true pancreatic neoplasms on imaging studies.

Ductal adenocarcinoma has a variety of appearances on imaging studies. On US, it usually is seen as a focal, hypoechoic, irregular, solid mass. Rarely, it is isoechoic or involves the entire gland. In some pancreatic head masses, the only finding may be that the uncinate process is rounded. The pancreatic or biliary duct may be dilated by the obstructing tumor. Pseudocysts, cystic collections in or around the pancreas, may form because of pancreatic duct dilatation and perforation. On CT, the tumor presents as a solid, low-density, irregular mass, perhaps with ductal dilatation, pseudocyst formation, or both (Figure 11-67). It usually enhances to a lesser extent than the surrounding pancreas (Figure 11-70). Occasionally, the tumors will enhance brightly. The pancreas distal to a ductal adenocarcinoma is often atrophic. Angiography may be used to demonstrate the vascular anatomy and establish definitively whether certain key vessels (e.g., the superior mesenteric artery or vein) are encased. If so, the lesion is unresectable. NM currently has no established role in evaluation of pancreatic tumors. Associated metastases in the liver establish the fact that a pancreatic mass cannot be simply inflammatory (Figure 11-71). General pertinent negatives on cross-sectional imaging may help to differentiate adenocarcinoma from other nontumorous masses. Calcification is rarely, if ever, seen in ductal adenocarcinoma, and it is almost never hypervascular.

Ductal adenocarcinoma is simulated by a number of other entities. These include peripancreatic lymphadenopathy, intrapancreatic cholangiocarcinoma, and pancreatic metastases.

Peripancreatic lymphadenopathy from lymphoma, leukemia, or any other primary malignancy can closely resemble a pancreatic mass. On imaging studies it may appear as solid soft tissue in the pancreatic region (Figure 11-72). Keys to
differentiating lymphadenopathy from a primary solid mass include smooth lobulation and pseudoseptations caused by incomplete coalescence of the lymph nodes. Also, peripancreatic lymphadenopathy is much less likely to obstruct the pancreatic duct, although suprapancreatic lymph nodes obstruct the biliary duct as it passes through the porta hepatis.

Two uncommon neoplastic processes that occur in the pancreas are cholangiocarcinoma and metastases. Cholangiocarcinoma usually does not occur within the pancreas, but when it does, it can exactly mimic a pancreatic head mass to the extent of producing both the pancreatic and common bile duct dilatation. Metastases appear as solid intrapancreatic lesions, but with necrosis, they appear as fluid masses. Because they may be completely indistinguishable from primary tumors, the diagnosis may be inferred only from the clinical history. Pancreatic metastases are quite uncommon, usually arise from melanoma or lung primary lesions, and mimic a focal mass lesion of any neoplastic origin (Figure 11-73).

Pancreatic endocrine tumors may also simulate ductal adenocarcinoma, and in fact, no specific features consistently distinguish the two. Occasionally, however, certain imaging features can be helpful, especially when combined with the history. Many islet cell tumors appear simply as solid masses within the pancreas. However, some (especially in insulinoma) may appear hypervascular when studied with fast bolus or dynamic CT, and they may appear as extremely dense lesions immediately after enhancement with intravenous contrast material. Calcifications, which sometimes are very dense, are more commonly seen with islet-cell tumors. MR imaging may have a role in the evaluation of islet-cell tumors, because these tumors have a characteristic appearance on MR studies.

Islet-cell tumors and their metastases have extremely high signal intensity on T2-weighted MR imaging, which can be used to characterize the origin of the lesion.

Primary cystic pancreatic malignancies and pancreatic cysts are not readily confused with typical ductal adenocarcinoma. Currently, cystic pancreatic masses are classified according to whether they arise from parenchymal cells or ductal cells. Cystic malignancies arising from pancreatic parenchyma...
are classified as either serous or mucinous cystic neoplasms. This classification is helpful, because the two lesions are distinguishable from each other and from solid lesions on imaging studies. Serous cystadenomas are usually composed of innumerable very small cysts (1 mm to 2 cm). Sometimes they contain highly vascularized fibrous septa and a central stellate fibrotic scar, which may calcify. They are generally benign. Mucinous cystic neoplasms are composed of unilocular or multilocular cysts larger than 5 cm and may have large papillary excrescences. They are considered malignant or premalignant lesions. Both serous cystadenomas and mucinous cystic neoplasms are cystic, but differences in the typical sizes of the cysts can be recognized on US or CT. Cystic malignancies arising from pancreatic ductal epithelial cells are called intraductal papillary mucinous tumors. These tumors contain considerable mucus and therefore exhibit complex appearances on MR imaging. MRCP can be helpful to demonstrate communication with the pancreatic duct. Pancreatic cysts can occur as isolated congenital cysts or as part of a more generalized multiorgan process that includes adult polycystic disease or von Hippel-Lindau disease (Figure 11-74). Regardless, their appearance is similar to that of a cyst in any other organ (Figure 11-69). US and CT depict a uniloculated or multiloculated cyst. A pancreatic cyst can be very difficult to differentiate from a mucinous cystic neoplasm. Management is controversial, and they are often followed even when small.

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SUGGESTED READING

Technological advances in radiology during the past 30 years have vastly improved our ability to diagnose neurologic diseases. Prior to the introduction of computed tomography (CT) in 1974, neuroradiologic examinations of the brain consisted primarily of plain films of the skull, cerebral arteriography, pneumoencephalography, and conventional nuclear medicine studies. Unfortunately, these techniques, for the most part, provided only indirect information about suspected intracranial processes, were insensitive in detecting subtle or early brain lesions, or were potentially harmful to the patient. Computed tomography revolutionized the radiologic workup of central nervous system (CNS) abnormalities because for the first time normal and abnormal structures could be directly visualized with minimal risk to the patient.

In the late 1980s, it became apparent that magnetic resonance (MR) imaging would become the procedure of choice for evaluating many neurologic disorders, as well as for demonstrating vascular flow phenomena. Since then, there have been many technological advances associated with this modality. These include improvements in magnet and coil design, decrease in imaging time, and the development of new pulse sequences. In addition to advances in conventional anatomic imaging, there has also been substantial growth of “physiologic” MR imaging including MR spectroscopy (MRS), diffusion-weighted (DW) and perfusion-weighted (PW) MR imaging, and functional MR imaging (fMRI), among others. These imaging modalities provide functional information about the brain and have the potential to greatly extend our understanding of neuropathology beyond structure alone.

Revolutionary breakthroughs in CT scanning technology during the 1990s facilitated the development of advanced CT...
applications, namely, dynamic contrast-enhanced CT angiography (CTA) and CT perfusion (CTP). These techniques, which allow high spatial resolution imaging of the cervical and intracranial vasculature, are currently being used in the evaluation of the acute stroke patient in many medical centers. Furthermore, recent technologic advances in CT imaging have markedly decreased scan times and have allowed evaluation of very tiny anatomic structures because of improvement in spatial resolution.

Recent advances in nuclear medicine functional imaging techniques, including single photon emission computed tomography (SPECT) and positron emission tomography (PET), improvements in conventional angiographic methods, and expansion of catheter-based therapeutic procedures have provided the neuroradiologist today with an even greater variety of strategies for diagnosing and treating neurologic abnormalities.

The main purpose of this chapter is to acquaint the reader with the major radiologic techniques used currently to evaluate the brain and its coverings. The strengths and weaknesses of these techniques are discussed. Imaging anatomy of the brain and its coverings is briefly reviewed. Basic guidelines pertaining to technique selection for evaluating common neurologic conditions are provided. Finally, examples of common brain abnormalities are presented. It is assumed that readers have a basic understanding of neuroanatomy and neuropathology.

Although this chapter may give some insight into neuroradiologic study interpretation, that is not its primary goal. Rather, readers should expect to become reasonably familiar with the various techniques employed to examine the brain and should gain some idea about the appropriate ordering of examinations in specific clinical situations.

TECHNIQUES

Radiologic modalities useful in evaluating the brain and its coverings can be divided into two major groups: anatomic modalities and functional modalities. Anatomic modalities, which provide information mostly of a structural nature, include plain films of the skull, CT, MR imaging, cerebral arteriography (CA), and ultrasonography (US). On the other hand, SPECT and PET imaging, CT perfusion, DW and PW MR imaging, fMRI, and MRS are primarily functional modalities, which give information about brain perfusion or metabolism. Some techniques provide both anatomic and functional information. For example, cerebral arteriography depicts blood vessels supplying the brain but also allows us to estimate brain circulation time. Ultrasound of the carotid bifurcation is another modality that provides both anatomic and functional information. A routine sonogram of the carotid bifurcation gives anatomic data that, when combined with Doppler data, readily provides information about blood flow.

The following discussion of current neuroradiologic techniques emphasizes relative examination cost and patient risk, along with the advantages and disadvantages of each technique. The normal imaging appearance of the brain and its coverings is also illustrated.

Plain Radiographs

Plain radiographs of the skull are obtained by placing a patient’s head between an x-ray source and a recording device (ie, x-ray film). Whereas bones of the skull attenuate a large number of x-rays to create an image, soft tissues such as scalp or brain are poorly visualized, if at all. Another difficulty in plain film interpretation results from the spherical shape of the skull, leading to multiple superimposed structures. The resultant skull radiograph primarily gives information about the bones of the skull, but no direct information about the intracranial contents. Indirect information about intracranial abnormalities can sometimes be obtained from the skull plain radiograph, although this information can be quite subtle, even in the setting of advanced disease. Skull plain radiographs have been largely replaced today by more sensitive techniques such as CT or MR imaging. Even in the setting of suspected skull fracture, plain radiographs are rarely indicated, because CT scans also show the fracture, as well as any intracranial abnormality that might require treatment. Currently, plain radiographs of the skull serve a very limited role in routine neuroimaging and are only briefly discussed.

Computed Tomography

CT scans consist of computer-generated cross-sectional images obtained from a rotating x-ray beam and detector system. Advances in scanning technology now permit simultaneous acquisition of multiple images during a single rotation of the x-ray tube (eg, currently up to 256 slices) during a breath-hold. The resultant images, unlike plain films, exquisitely depict and differentiate between soft tissues, thus allowing direct visualization of intracranial contents and abnormalities associated with neurologic diseases. The contrast or brightness (“window” or “level,” respectively) of these images can be adjusted to highlight particular tissues.

Typically, a head CT consists of images adjusted to emphasize soft-tissue detail (soft-tissue windows) as well as images adjusted to visualize bony detail (bone windows) (Figure 12-1). As stated earlier, CT image generation is dependent on variable attenuation of the x-ray beam based on the density of structures it passes through (eg, bones of the skull base are very dense and attenuate a large percentage of the x-ray beam). Therefore, cortical bone appears white (has a high attenuation value or Hounsfield unit), whereas air within the paranasal sinuses appears black (has a low attenuation value).
Cerebral white matter has a slightly lower Hounsfield number than does cerebral gray matter and consequently appears slightly darker than gray matter on a head CT scan (Figure 12-1A). Intracranial pathologic conditions can be either dark (low attenuation) or bright (high attenuation), depending on the particular abnormality. For example, acute intracranial hemorrhage is typically very bright, whereas an acute cerebral infarction demonstrates low attenuation when compared to the surrounding normal brain because of the presence of edema.

The CT technologist can change the slice thickness and angulation, among other technical factors, to alter the way an image appears. Images are typically obtained axially in helical fashion, with acquisition of a volumetric data set. Current scanner technology allows the axial data set to be reformatted in coronal, sagittal, or oblique planes or as a 3-D image, with little, if any, loss of resolution. CT examinations may be performed after intravenous administration of an iodinated contrast agent, especially when MRI is contraindicated or unavailable. These agents “light up” or enhance normal blood vessels and dural sinuses, as well as intracranial structures that lack a blood-brain barrier (BBB), such as the pituitary gland, choroid plexus, or pineal gland. Pathologic conditions that interrupt the BBB (such as neoplasm, infection, or cerebral infarction) also demonstrate enhancement after contrast material administration. For this reason, lesions that may be invisible on a noncontrast study are often obvious on the contrast-enhanced scan.

The intravenous administration of a contrast bolus can be appropriately timed to maximize vascular opacification of the arterial or venous circulation (CTA or CTV, respectively). These high spatial resolution 3-D CTA images (Figure 12-2) of the cervical and intracranial vasculature are routinely employed to quantify vessel stenosis due to atherosclerotic disease, to assess for vascular injury related to trauma, or to detect cerebral aneurysm in the patient with subarachnoid hemorrhage.

In particular, CTA has become a standard component of evaluating the acute stroke patient. CTA accurately identifies the location and extent of large vessel occlusions and can be supplemented by a more detailed, quantitative evaluation of the cerebral microvascular hemodynamics (CT perfusion).
evaluate for dural venous sinus thrombosis, and distinguish partial sinus obstruction from venous occlusion in the setting of adjacent brain masses. CT venography can also differentiate slow flow from thrombosis, which may occasionally be difficult with MR techniques.

The major advantages of CT are that it is inexpensive, is widely available, can be used in patients with MR-incompatible hardware, and allows a relatively quick assessment of intracranial contents in the setting of a neurological deficit. The images obtained are very sensitive to the presence of acute hemorrhage and calcification, and images revealing exquisite bony detail of the skull and skull base can be acquired. Because of the configuration of the scanner, patients are reasonably accessible for monitoring during the examination.

CT scanners do have a number of disadvantages, however. Patients are exposed to ionizing radiation and iodine-based contrast agents (although lower doses of contrast are needed with newer multidetector scanners). Imaging artifacts can interfere with accurate interpretation. In particular, images of the brainstem and posterior fossa are often degraded by "streak artifacts" from dense bone (Figure 12-3).

during the early phase of bolus passage. Software analysis of this tailored CTA data produces maps of capillary-level cerebral perfusion, typically measured by mean transit time (MTT), cerebral blood flow (CBF), and cerebral blood volume (CBV). In the setting of cerebral infarction, these parameters can help interpret the infarct “core” (CBV) versus the ischemic “penumbra” (MTT and CBF). Evaluation of potential mismatch between the infarct core and surrounding penumbra serves as the rationale for instituting various reperfusion techniques.

Another recent application of CTA is in the screening evaluation of blunt cerebrovascular injury, including closed head injuries, seatbelt abrasion (or other soft-tissue injury) of the anterior neck, basilar skull fracture extending through the carotid canal, and cervical vertebral body fracture. It is an accurate technique for detecting internal carotid artery (ICA) dissections and for assessing stenoses, although evaluation is difficult in areas of surrounding dense bone as a result of associated “streak artifact.” However, this noninvasive, relatively short imaging procedure rivals conventional angiographic methods, as it requires no patient transfer and can sensitively identify vascular injury in relation to other associated brain insults, cervical spine injury, or facial or basilar skull fractures.

High-resolution data acquisition during the venous phase following intravenous contrast administration (CT venography) can be used to identify dural sinuses and cerebral veins,
Streak artifacts from metallic objects (e.g., fillings, braces, surgical clips) can also obscure abnormalities. Images can be severely degraded by patient motion. Fortunately, unlike MR scans, individual CT images degraded by motion can be rapidly reacquired.

**Magnetic Resonance Imaging**

One of the most exciting developments in radiology during the past 30 years has been the growth of magnetic resonance imaging (MRI), which is currently the mainstay of clinical neuroimaging. The concept of nuclear magnetic resonance (NMR), initially used for probing the physiochemical structure of molecules, was first described in the 1930s, but it took more than 40 years before the translation of NMR phenomena could be used for clinical imaging.

MR examinations, like CT scans, consist of computer-reconstructed cross-sectional images (Figure 12-4). In MR imaging, however, unlike CT scans or plain radiographs, the information collected is not x-ray beam attenuation. The MR image is a visual display of NMR data collected principally from nuclei within body tissues—especially hydrogen nuclei within water and fat molecules. Intrinsic tissue relaxation occurs by two major pathways, called longitudinal, or T1, and transverse, or T2, decay. MR imaging sequences that emphasize T1 decay are commonly referred to as T1-weighted; sequences that accentuate T2 relaxation properties are called T2-weighted (Figure 12-4). Most MR scans of the brain use both of these sequences, because certain abnormalities may only be obvious on one or the other. T2-weighted images are usually easy to identify because fluid (e.g., cerebrospinal, globe vitreous) is very bright; fluid on a T1-weighted scan is usually dark. Fat is bright on T1-weighted scans, but darker on T2-weighted images. On the other hand, both cortical bone and air are very dark on all imaging sequences. Brain tissue has intermediate intensity; vessels can have almost any signal, depending on the velocity of flowing blood.

The most commonly used clinically approved contrast agent for MR imaging is gadopentetate-dimeglumine or Gd-DTPA, which is very well tolerated and generally safe, although caution must be used in patients with renal impairment because of the associated risk of developing nephrogenic systemic sclerosis (refer to Chapter 1). Its major use in the CNS is to improve lesion detectability by “lighting up” pathologic conditions that either lack a BBB or have a disrupted BBB.

Conventional MR imaging depicts excellent soft-tissue contrast. Traditionally, long image acquisition times, image artifacts related to patient motion, and the increased cost of scanning due to limited patient throughput have hampered the clinical utility of MR imaging. Over the past 15 years, technical advances in gradient technology, coil design, image reconstruction algorithms, contrast administration protocols, and data acquisition strategies have accelerated the development and implementation of fast imaging methods. These techniques, including fast gradient echo imaging, fast spin echo imaging, FLAIR (fluid-attenuated inversion recovery), and echo planar imaging, have enabled substantial reductions in imaging time. Images may be acquired during a single breath-hold on a clinical scanner, eliminating respiratory and motion artifacts. Vessel conspicuity can be enhanced by application of fat-suppression sequences, which eliminate unwanted signal from background tissues. These improvements have led to a vast range of applications that were previously impractical, including high-resolution MRA, DW and PW MR imaging, MRS, fMRI, and real-time monitoring of interventional procedures.

Since its first clinical application nearly 15 years ago, MRA has proven to be a useful tool for evaluation of the cervical or intracranial carotid vasculature. MRA represents a class of techniques that utilize the MR scanner to noninvasively generate three-dimensional images of the carotid or vertebral-basilar circulations. Although a detailed discussion of these techniques is beyond the scope of this chapter, several comments are noteworthy. These methods permit distinction between blood flow and adjacent soft tissue, with or without administration of intravenous contrast. As noted earlier, revolutionary developments have permitted MRA images to be rapidly acquired with ever-improving temporal and spatial resolution.

Presently, MRA serves as one of the first-line studies for evaluation of arterial occlusive disease and for screening of intracranial aneurysms. These methods have largely replaced conventional arteriographic studies for evaluation of atherosclerotic disease, except in cases of critical stenosis (>70%). In these instances, the degree of luminal narrowing may be overestimated by MRA and may require verification with CTA, catheter-based study, or Doppler ultrasound. Moreover, aneurysms detected on an intracranial MRA typically require a catheter-based study for detailing aneurysm size and orientation, for establishing the location of adjacent vessels and collateral flow, and for confirming suspicious vascular dilatation, as well as for detecting the presence of vasospasm or additional aneurysms that may not be readily apparent on the MRA study. In an increasing number of cases, catheter-based studies will additionally be performed for coil embolization (obliteration) of detected aneurysms, rather than surgical clipping.

Molecular diffusion, the random translational movement of water and other small molecules in tissue, is thermally driven and is referred to as Brownian motion. Over a given time period, these random motions, expressed as molecular displacements, can be detected using specifically designed diffusion-sensitive MR sequences. A common application of diffusion imaging is the detection of early ischemic infarction, where the infarcted tissue “lights up”
Figure 12-4. Normal head MR images. Sagittal T1-weighted (A), axial T1-weighted (B), and axial T2-weighted (C) images. Note differences in signal between gray matter (large arrows), white matter (curved arrows), CSF (small arrowheads), fat (small arrows), and cortical bone (large arrowheads) on different pulse sequences. Normal structures include the genu (g) and splenium (s) of the corpus callosum (cc), fornix (f), optic chiasm (oc), pituitary gland (pit), midbrain (mb), pons (p), medulla (m), cerebellar vermis (Cb), straight sinus (SS), caudate head (c), putamen (pt), and thalamus (T).
because of a “restricted diffusion” state within the intracellular compartment. Other applications of diffusion-sensitive sequences include differentiating cysts from solid tumors, as well as evaluating inflammatory/infectious conditions (encephalitis, abscess) or white matter abnormalities (hypertensive encephalopathy).

Perfusion MR imaging measures cerebral blood flow at the capillary level of an organ or tissue region. Perfusion-weighted MR imaging has applications in the evaluation of a number of disease states, including cerebral ischemia and reperfusion, brain tumors (Figure 12-5), epilepsy, and blood flow deficits in Alzheimer’s disease. In addition, the close spatial coupling between brain activity and CBF permits the application of perfusion MR techniques to imaging brain function. MR perfusion imaging is technically complex and requires advanced scanner and postprocessing software for image generation. Various methods can be employed including contrast bolus technique (analogous to CT perfusion) or arterial spin labeling (ASL). ASL uses a radiofrequency pulse to “label” protons flowing in the cervical arteries and that signal is subsequently imaged as those protons flow into the cerebrum. One of the major advantages of ASL is that it requires no contrast administration, which is of great benefit in patients with renal impairment.

Functional MR imaging is an important brain mapping technique that uses fast imaging techniques to depict regional cortical blood flow changes in space and time during performance of a particular task (eg, flexion of the index finger). The utilization of this technique to localize brain activity is historically based on measurable increases in cerebral blood flow (and blood volume) with increased neural activity, referred to as neurovascular coupling. The hemodynamic response to a stimulus is not instantaneous, but on the order of a few seconds. Consequently, fMRI techniques are considered an indirect approach to imaging brain function, but provide excellent spatial resolution and can be precisely matched with anatomic structures. Changes in blood oxygenation and perfusion can be imaged using fMRI techniques, which has become the most widely used modality for depicting regional brain activation in response to sensorimotor or cognitive tasks.

An important clinical application of fMRI is presurgical mapping, whereby eloquent brain cortex can be defined in relation to mass lesions (Figure 12-6). This allows for the
judicious selection of an appropriate management strategy (surgical versus nonsurgical) according to the functional nature of the adjacent brain tissue. A second application involves determination of the cerebral hemisphere responsible for language and memory tasks in a patient with complex partial seizures, prior to undergoing temporal lobectomy. Additionally, several groups have reported successful functional activation studies for lateralizing language preoperatively utilizing fMRI.

MR spectroscopy (MRS) provides qualitative and quantitative information about brain metabolism and tissue composition. This functional analysis is based on detecting variations in the precession frequencies of spinning protons in a magnetic field. One factor influencing the precession or resonance frequency is the chemical environment of the individual proton. Protons in different cerebral metabolites can be sensitively discriminated on this basis, and the position of these metabolites can be displayed as a spectrum. The x-axis position of a given metabolite reflects the degree of “chemical shift” of the metabolite with respect to a designated reference metabolite and is expressed in units of parts per million (or ppm). The area under the peak is determined by the number of protons that contribute to the MR signal.

The major metabolites detected in the CNS are N-acetyl aspartate (NAA), a neuronal marker; choline, a marker for cellularity and cell membrane turnover; creatine, a marker for energy metabolism; and lactate, a marker for anaerobic metabolism. In addition to these metabolites, others have been assessed, including alanine, glutamine, myoinositol, and succinate, using various MR strategies. Presently, MRS is being used in clinical practice to provide functional information regarding many CNS abnormalities, and complements the conventional MR imaging study. A common application relates to the pre- and posttreatment evaluation of brain tumors, with MRS playing an important role in assessing for residual or recurrent tumor following surgical resection.

MR imaging offers a number of advantages over CT in the workup of patients with neurologic disease. Its soft-tissue contrast resolution is superior to that of CT, and lesions that may be subtle or invisible on CT are frequently obvious on MR imaging. MR imaging also allows acquisition of multiplanar views in the sagittal, axial, coronal, and oblique projections that may be impossible to obtain with CT. Furthermore, MR imaging gives information about blood flow without the need for a contrast agent, and bony streak artifacts that obscure lesions of the brainstem and cerebellum on CT scans are not present on MR images. Finally, MR imaging does not expose the patient to ionizing radiation.

**Cerebral Arteriography**

Cerebral arteriography involves the injection of water-soluble contrast material into a carotid or vertebral artery. Contrast material is injected into the desired vessel via a small catheter, which has been introduced into the body through the femoral or brachial artery. Information about the arterial, capillary, or venous circulation of the brain is recorded on serial plain films or, most commonly, digitized for viewing on a monitor or for storage within a computer (Figure 12-7).

Cerebral arteriograms are expensive (two to three times as much as MR examinations) and are relatively more risky procedures than other noninvasive neuroradiologic studies. The major risk of the procedure is stroke, which may occur in one of every 1,000 patients. Stroke during cerebral arteriography occurs either from an embolic event (eg, inadvertent injection of air, thrombus formation on the catheter tip, atherosclerotic plaque dislodged by catheter manipulation) or from catheter-related local vessel trauma (eg, dissections or occlusions).

Although CT angiography has largely replaced catheter angiography for most routine diagnostic evaluations, catheter angiography is invaluable in the workup of vascular
diseases affecting the CNS. Specifically, it remains the gold standard for assessing vasculitis and is indispensable in evaluating and treating cerebral aneurysms and certain intracranial vascular malformations or fistulas. It is a useful adjunct to cross-sectional imaging (CTA, MRA, or US) to assess vascular stenosis as well as carotid or vertebral artery integrity after trauma to the neck, especially in the setting of acute neurological deficit. Finally, it is unsurpassed for showing vascular anatomy of the brain and is, therefore, useful as a preoperative road map.

The field of interventional neuroradiology continues to grow and exert considerable impact on the diagnosis and treatment of certain CNS diseases. New catheter designs and materials, recently developed endovascular devices (extracranial/intracranial stents), and an increasing number of trained specialists performing endovascular procedures have led to novel therapeutic applications and approaches for managing previously untreatable conditions. Endovascular diagnostic and therapeutic procedures, based on fundamental cerebral arteriography principles, have gained widespread

**Figure 12-7.** Normal cerebral arteriogram. (A) Lateral view of the cervical carotid artery. Catheter is located within the common carotid artery, and contrast material fills internal (arrows) and external (arrowheads) carotid arteries. (B) Lateral view of the head after injection of the carotid artery (arrow). Note anterior cerebral (A), ophthalmic (O), posterior communicating (PC), and middle cerebral (M) branches.
acceptance and, in some cases, rival traditional neurosurgical approaches in terms of complication rates, clinical outcomes, and long-term survival benefit. Although a full discussion of these techniques is beyond the scope of this chapter, they include pharmacologic and mechanical thrombolysis of intracranial clot in the setting of acute infarction or dural sinus thrombosis; embolization (obliteration) of intracranial aneurysms using thrombosing material (ie, coils); carotid artery angioplasty and/or stent placement for critical stenotic narrowing or radiation-induced arterial stricture; preoperative or definitive devascularization of a hypervascular mass or arteriovenous malformation; embolization of small, bleeding external carotid artery branches in epistaxis; balloon occlusion tests of the carotid artery; and endovascular treatment of vasospasm. Embolization materials include particulate emboli, liquid adhesive glues, and various coils.

**Ultrasonography**

Ultrasonography is the diagnostic application of ultrasound to the human body. Major applications of ultrasonography in CNS disease include gray-scale imaging and Doppler evaluation of carotid artery patency and flow in the setting of atherosclerosis, assessment of vasospasm in the setting of subarachnoid hemorrhage using transcranial Doppler, screening evaluation of intracranial abnormalities in the newborn and young infant (Figure 12-8), and detection of intracranial hemorrhage in premature infants prior to extracorporeal membrane oxygenation therapy. Ultrasound has also been used intraoperatively to demonstrate the spinal cord and surrounding structures during spine surgery and to define tumor and cyst margins during craniotomies.

Transcranial Doppler is a recently developed tool in the evaluation of cerebrovascular disorders. It uses low-frequency sound waves to adequately penetrate the skull and produces spectral waveforms of the major intracranial vessels for evaluation of flow velocity, direction, amplitude, and pulsatility. Present clinical applications include diagnosis of cerebral vasospasm, evaluation of stroke and transient ischemic attack, detection of intracranial emboli, serial monitoring of vasculitis in children with sickle cell disease, and assessment of intracranial pressure and cerebral blood flow changes in patients with head injury or mass lesions.

Ultrasound examinations, although moderately expensive, are virtually risk-free to the patient, involve no ionizing radiation, and are portable (ie, can be performed at the bedside). However, examination quality and therefore diagnostic accuracy are operator-dependent. Also, the heavy reliance of ultrasonography on the presence of an adequate “acoustic window” through which an examination can be performed diminishes its usefulness in examining the

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**Figure 12-8.** Coronal (A) and sagittal (B) head ultrasound of a neonate. Normal structures include the corpus callosum (CC), lateral ventricle (LV), cavum septum pellucidum (CS), sylvian fissure (SF), third ventricle (3V), fourth ventricle (4V), temporal lobe (TL), frontal lobe (FR), occipital lobe (OCC), cerebellum (CER), and thalamus (TH).
brain after the fontanelles close in infancy. Finally, to the untrained eye, anatomic structures and pathologic processes as depicted by US are not as readily apparent as they are on CT or MR images.

**Single Photon Emission Computed Tomography**

SPECT uses a rotating gamma camera to reconstruct cross-sectional images of the distribution of a radioactive pharmaceutical that has been administered to a patient (usually intravenously). For brain imaging, radioactive iodine ($^{123I}$) or technetium ($^{99mTc}$) is combined with a compound that rapidly crosses the BBB and localizes within brain tissue in proportion to regional blood flow. The rotating gamma camera detects gamma rays emitted by the radiopharmaceutical and produces cross-sectional images of the brain that are really a map of brain perfusion (Figure 12-9). SPECT imaging also gives indirect information about brain metabolism, because perfusion is usually highest to parts of the brain with high metabolic activity and lowest to areas with low metabolic demand. Normal SPECT examinations demonstrate activity concentrated primarily in areas of high perfusion/metabolism, such as the cortical and deep gray matter (Figure 12-9).

SPECT studies are moderately expensive (as much as or more than brain MR imaging), and, as expected, they provide limited anatomic information. SPECT also exposes patients to ionizing radiation. Because patients rarely have allergic reactions to the radiopharmaceuticals used, the examination is of low risk. Although SPECT provides critical information regarding regional cerebral perfusion, particularly in the setting of stroke, this information can be more readily obtained during CTA/CT perfusion or MR perfusion acquisitions. SPECT has also been used with varying degrees of success in the workup of patients with epilepsy or dementia.

**Positron Emission Tomography**

PET scans consist of computer-generated cross-sectional images of the distribution and local concentration of a radiopharmaceutical. This technique is very similar to SPECT imaging; however, there are differences in the type of camera and radiopharmaceuticals used. PET studies use radiopharmaceuticals labeled with a cyclotron-produced positron emitter, which are very expensive to produce and have a very short half-life (on the order of seconds to minutes). The most widely used radiotracer is $^{18F}$-deoxyglucose. PET scanning with this agent gives a measurement of brain glucose metabolism. Areas of high metabolic activity (ie, cerebral cortex, deep gray nuclei) demonstrate greater radiopharmaceutical uptake than do areas of low metabolic activity, such as white matter or cerebrospinal fluid (Figure 12-10). The bones of the skull and scalp soft tissues are, for the most part, invisible. Other agents are useful in assessing regional cerebral blood flow, neuroreceptor function, and the like.

Since the previous edition, PET scans have become much more widely available, although they remain expensive. The expense, in large part, is related to the cost of imaging equipment and in the production or delivery of radiopharmaceuticals. Although patients undergoing PET examinations are exposed to ionizing radiation, the overall risk to the patient is low. Anatomic resolution, although not as good as with CT or MR imaging, is better than with SPECT imaging. The major advantage of PET imaging is that it is extremely versatile, providing in vivo information about brain perfusion, glucose metabolism, receptor density and, ultimately, brain function.

PET provides useful information in the setting of stroke, epilepsy, dementia, and tumors. At present, the two main indications are in the workup of patients with complex partial seizures and in identifying tumor recurrence in patients who have undergone surgery, radiation therapy, or both, for brain tumors.
TECHNIQUE SELECTION

The primary goal of a radiologic examination is to provide useful information for disease management. Radiologic studies can provide a diagnosis or can give information about disease extent or response to treatment. In the present medical climate, it has also become imperative that radiologic workups be performed efficiently and in a cost-effective manner. This requirement presents a problem for clinicians trying to decide which test to order in a given clinical situation.

The major strengths and weaknesses of neuroradiologic examinations have been discussed earlier in this chapter. The following brief discussion concerns the appropriate ordering of examinations in clinical situations. Several points should be emphasized. First, although a recommended modality may clearly be superior to another in evaluating a particular neurologic condition, the choice of examination is not always obvious before the diagnosis is established. For example, in patients with nonfocal headache, MR scans are more sensitive than CT scans for detecting most intracranial abnormalities. However, if the headache is produced by subarachnoid hemorrhage, CT would be a much better examination than MR imaging, because subarachnoid hemorrhage is nearly invisible on MR images. Choice of examinations may also be limited by what is locally available. If MR imaging is unavailable, or if the MR scanner is of poor quality or the interpreting radiologist is inadequately trained in MR image interpretation, then CT would be an excellent examination for evaluating most neurologic disorders.

Next, it is important to realize that the least expensive examination is not always the best first choice, even in this cost-conscious age. For example, most suspected skull fractures should be evaluated with CT scanning and not with plain films, despite the significant cost differential, because what is really important in management decisions is not the fracture itself but the potential underlying brain injury. Some neurologic diseases require multiple radiologic studies for accurate evaluation. Complex partial seizures refractory to medical management frequently require multiple examinations to localize the seizure focus prior to temporal lobectomy. Such a workup normally includes MR imaging and ictal/interictal SPECT and/or PET scanning of the brain, as well as a cerebral arteriogram to identify cerebral dominance.

Finally, certain examinations are contraindicated in certain patients, and an alternative test must suffice. Patients with ferromagnetic cerebral aneurysm clips or pacemakers should not undergo MR imaging. Patients with a strong history of allergic reaction to iodinated contrast media should not routinely undergo contrast-enhanced CT scanning, unless they are pretreated with anti-inflammatory agents (ie, steroids). MR scanning is frequently unsuccessful in claustrophobic or uncooperative patients unless they are sedated.

Congenital Anomalies

Congenital anomalies of the brain are best evaluated by MR imaging. MR imaging is the best examination for demonstrating intracranial anatomy. It provides excellent discrimination between gray matter and white matter, superb views of the posterior fossa and craniocervical junction, and, most importantly, the ability to view the brain in any plane. MR imaging has, for all practical purposes, completely replaced CT for this indication. The one exception is in evaluation of osseous structures including various craniofacial anomalies and in suspected premature fusion of the cranial sutures.

Craniocerebral Trauma

CT is the preferred modality for studying practically all acute head injuries. Examination times are short, intracranial hemorrhage is well demonstrated, and skull fractures are readily apparent. Unstable patients can also be easily monitored. Intravenous administration of contrast agents is unnecessary in the usual trauma setting. CTA and occasionally MRA are
utilized with increasing frequency to assess for vascular injury associated with blunt or penetrating trauma. CTA is typically the first-line evaluation for dissection or laceration, particularly when a displaced fracture crosses a vascular foramen or in the case of penetrating vessel injury. Occasionally, cerebral arteriography is performed to look for carotid or vertebral artery injury, particularly when CTA or MRA are inconclusive or when there is an anticipated endovascular treatment of the injured vessel.

Although MR imaging is not routinely performed in the acute trauma setting, it may sometimes be helpful in patients with neurologic deficits unexplained by a head CT examination. For example, traumatic brainstem hemorrhages are often difficult to see on CT scans but are usually quite obvious on MR images. MR imaging is also useful in demonstrating tiny shear lesions within the brain in diffuse axonal injury and in assessing the brain in remote head trauma.

## Intracranial Hemorrhage

The best examination to perform in most cases of suspected acute intracranial hemorrhage is a head CT scan. CT scans can be obtained quickly, allowing rapid initiation of treatment, and they are very good at demonstrating all types of intracranial hemorrhage, including subarachnoid blood. Because most nontraumatic subarachnoid hemorrhage (SAH) is secondary to a ruptured cerebral aneurysm, CTA is now performed routinely following a conventional head CT demonstrating SAH. In most cases, the CTA is adequate for aneurysm detection and characterization prior to surgical or endovascular treatment. MR imaging takes much longer to perform in a potentially unstable patient, and subarachnoid hemorrhage may be difficult to see. However, MR imaging is more useful in the subacute or chronic setting, especially because it gives information about when a hemorrhagic event occurred. This information might be useful in such settings as nonaccidental head trauma (e.g., child abuse). MR imaging is also very sensitive to petechial hemorrhage that frequently accompanies a cerebral infarction and could potentially help to identify an underlying cause for an intracranial hemorrhage (e.g., tumor, arteriovenous malformation, occluded dural sinus). Cerebral arteriography is generally reserved when the etiology of hemorrhage is not discernable by CTA/MRA, when it is necessary to evaluate the flow dynamics of a vascular lesion or for planning endovascular treatment.

## Aneurysms

Although cerebral arteriography has traditionally been considered the “gold standard” for cerebral aneurysm evaluation, CTA has supplanted catheter arteriography as the first-line imaging modality for aneurysm detection. The current literature varies slightly; however, CTA is reported to have excellent sensitivity (greater than 95% for aneurysms measuring 4 mm or larger) as well as high specificity. In most cases, CTA is adequate for surgical or endovascular treatment planning. If CTA fails to identify a suspected aneurysm following SAH, cerebral arteriography will typically be performed. Cerebral arteriography not only allows aneurysm identification, but also provides other critical preoperative information such as aneurysm orientation, presence of vasospasm, location of adjacent vessels, and collateral intracranial circulation. Arteriography also helps to determine which aneurysm has bled when more than one aneurysm is present. As mentioned previously, interventional neuroradiologists can treat aneurysms, usually in nonsurgical patients, by placing thrombosing material (i.e., coils) within the aneurysm itself via an endovascular approach.

Although most patients with symptomatic cerebral aneurysms present with subarachnoid hemorrhage, some aneurysms act like intracranial masses. These situations usually warrant evaluation by MR imaging as a first examination. The same is sometimes true with posterior communicating artery aneurysms (which can produce symptoms related to the adjacent third cranial nerve) or with aneurysms arising from the internal carotid artery as it courses through the cavernous sinus (which can affect any of the cranial nerves that lie within this structure, including cranial nerves III, IV, V, or VI).

## Vascular Malformations

Patients with a vascular malformation (e.g., arteriovenous malformation, cavernous angioma, venous angioma, or capillary telangiectasia) often seek medical attention after an intracranial hemorrhage or a seizure. In this setting, the first test that should be performed is either a CT examination (to look for intracranial hemorrhage) or MR imaging. Although an intracranial hemorrhage is usually very obvious on a CT scan, the vascular malformation itself may be difficult, if not impossible, to see unless intravenous contrast material is administered. MR imaging, on the other hand, is quite sensitive for detecting vascular malformations, whether they have bled or not. The choice of the initial examination for evaluation of a vascular malformation can be difficult. Usually, patients undergo noncontrast head CT scanning to look for intracranial hemorrhage when they come to the emergency department. This is usually followed by CTA, particularly if an arteriovenous malformation (AVM) is suspected. Otherwise, the head CT is followed by gadolinium-enhanced MR imaging to further characterize the CT findings. If a true high-flow arteriovenous malformation is suspected, either clinically or from a cross-sectional imaging study, then cerebral arteriography is performed. In contrast to cerebral aneurysms, catheter angiography is still performed routinely to evaluate AVMs. This is done because catheter angiography provides details of flow dynamics within the AVM and demonstrates certain anatomic features that are necessary to elucidate prior to initiation of treatment. As spatial resolution and dynamic
sequences improve, CT or MR angiography may someday replace conventional arteriography in the workup of these lesions, as with aneurysms.

### Infarction

Today, most patients with suspected cerebral infarction undergo CT scanning in the acute setting, even though infarctions are demonstrated earlier and are more obvious on MR imaging. So why is CT usually performed first? The answer is that clinicians who manage stroke patients are not so interested in seeing the infarct itself. Infarct location is usually suspected from the physical examination, and acute infarcts may not even be visible on CT scans for 12 to 24 hours after onset of stroke symptoms. Clinicians are very interested, though, to know if a stroke is secondary to something besides an infarct (eg, intracranial hemorrhage, brain tumor), or if an infarct is hemorrhagic, because thrombolytic agents would be contraindicated in this setting. CT can quickly answer both of these questions. MR imaging, specifically diffusion-weighted imaging, can sensitively detect acute infarctions and is typically ordered in cases of high clinical suspicion, when the initial CT study is nondiagnostic or when brainstem or posterior fossa infarcts are suspected.

The underlying cause of most cerebral infarctions is thromboembolism related to atherosclerosis. A CT/CTA or MR/MRA (including DW and PW MR imaging) study may provide a positive imaging diagnosis of brain infarction, reveal the extent and location of vessel occlusion, demonstrate the volume and severity of ischemic tissue, and predict final infarct size and clinical prognosis. CT and MR perfusion can identify areas of completed infarct (ie, infarct core) and potentially salvageable surrounding brain parenchyma at risk of infarction (ie, ischemic penumbra). Ultrasonography and cerebral arteriography can also be performed in the setting of stroke or transient ischemic attack to identify vascular stenoses or occlusions; these examinations are usually reserved for patients who might be candidates for carotid endarterectomy. Functional examinations (SPECT and PET) have also been used in patients with stroke-like symptoms to identify regions of the brain at risk for infarction. These studies are not widely available and therefore do not enter into the imaging algorithm for most stroke patients.

### Brain Tumors and Tumor-like Conditions

The best examination to order in the setting of suspected brain tumor is a contrast-enhanced MR scan. This is true for primary neoplasms as well as for metastatic disease. MR imaging is especially useful in identifying tumors of the pituitary region, brainstem, and posterior fossa, including the cerebellopontine angle.

Although MR imaging is the preferred examination for intracranial neoplasms, it is occasionally supplemented by a CT scan, which can give important pretreatment information not provided by MR images. For example, CT can demonstrate tumor calcification, occasionally a useful factor in differentiating between types of neoplasms. Also, CT is very useful in identifying bone destruction in skull-base lesions.

In most medical centers, MR imaging is performed to assess brain tumor response to treatment. Anatomic imaging is often supplemented with some type of physiologic imaging including MR perfusion, MR spectroscopy, and PET scanning. Perfusion MRI, MRS, and PET scanning can frequently differentiate recurrent tumor from postradiation tissue necrosis, which can mimic tumor on an MR or a CT scan. MR perfusion imaging also provides functional information regarding the vascular density (ie, neovascularity) of a tumor, which may help to predict tumor grade or help guide a potential biopsy site.

Today, cerebral arteriography is rarely performed for brain tumor evaluation except to map the blood supply of very vascular tumors (ie, juvenile angiofibromas, paragangliomas) preoperatively. Such lesions can also be embolized prior to surgery in order to minimize intraoperative blood loss by injecting various materials into feeding vessels to occlude them.

### Infection

Intracranial infections are best evaluated by contrast-enhanced MR imaging. Abscesses, cerebritis, subdural empyema, and other infectious or inflammatory processes are all very well demonstrated. MR imaging is especially useful in assessing patients with acquired immunodeficiency syndrome (AIDS). Not only does it allow identification of secondary infections (eg, toxoplasmosis, cryptococcosis, progressive multifocal leukoencephalopathy), but it is also exquisitely sensitive to the white matter changes produced by the human immunodeficiency virus itself. CT scanning is less sensitive than MR imaging in the detection of intracranial infections and should be reserved for patients in whom MR imaging is contraindicated. Cerebral arteriography is only useful in one particular situation, suspected vasculitis. Involvement of brain arteries and arterioles in this condition requires arteriography for diagnostic confirmation.

### Inherited and Acquired Metabolic, White Matter, and Neurodegenerative Diseases

As with suspected intracranial infections, this large and diverse group of diseases is best evaluated with MR imaging, which sensitively detects white matter abnormalities. In fact, one of the very first clear indications for MR imaging was in the workup of suspected multiple sclerosis. Although brain abnormalities in these conditions may be quite obvious on MR imaging, there is one problem: many of these conditions appear very similar, and an exact diagnosis may not be possible.
In patients with dementia and suspected neurodegenerative disease, PET imaging is currently the procedure of choice for diagnostic evaluation.

# Seizure and Epilepsy

Seizure is a common clinical indication for imaging the brain, particularly in the emergency setting. CT is the best modality to screen for multiple underlying causes of seizure including hemorrhage, mass lesion, or vascular malformation. CT is also very useful to assess for secondary trauma that may occur during a seizure. MRI is often subsequently performed depending on various factors including the patient's age, clinical presentation, and type of seizure, or in the case of epilepsy. MRI is superior to CT in evaluating fine cerebral anatomy because of its excellent soft-tissue contrast and the absence of beam hardening artifact, as well as its multiplanar capability. Particular MR protocols are utilized to discriminate the hippocampal structures and to detect other epileptogenic foci, including various cortical malformations, neoplasms, and vascular malformations.

In the case of medically refractory epilepsy, patients may pursue surgery for more definitive treatment. During surgical planning, additional functional imaging performed includes ictal SPECT and interictal PET. These studies help confirm a suspected epileptogenic focus, which demonstrates increased activity during or immediately following a seizure (SPECT) versus decreased metabolic activity between seizures (PET). Cerebral arteriography is often performed prior to epilepsy surgery in order to establish cerebral dominance by intracarotid sodium amytal injection (Wada test). Following catheter injection of amytal into the internal carotid artery, function within the corresponding cerebral hemisphere is temporarily depressed, allowing for neurological testing of memory and language in the contralateral hemisphere.

## EXERCISE 12-1. CONGENITAL ANOMALIES

12-1. In Case 12-1, what is the major abnormality (Figure 12-11 A, B)?
   - A. Enlarged ventricles
   - B. Cyst in the posterior fossa
   - C. Lack of brain cleavage into two hemispheres
   - D. Herniation of intracranial contents through a skull defect
   - E. Abnormal migration of gray matter

12-2. In Case 12-2, what is the etiology of the patient’s seizures (Figure 12-12 A, B)?
   - A. Brain tumor
   - B. Gray matter in the wrong place (ie, heterotopic gray matter)
   - C. Congenital infection
   - D. Nodules along ventricles in a patient with tuberous sclerosis
   - E. Infarction of periventricular white matter

## Radiologic Findings

12-1. In this case, the corpus callosum (curved arrow) is absent on the sagittal T1 MR image (Figure 12-11 A). Also note other midline abnormalities, including abnormal tissue at the bridge of the nose (large arrow) and a posterior cyst (small arrows). Coronal T1-weighted MR image (Figure 12-11 B) demonstrates a
monoventricle (small arrows) and thalamic fusion (curved arrow). Also note the lack of separation of the two hemispheres (large arrow) (C is the correct answer to Question 12-1).

12-2. In this case, T1-weighted (Figure 12-12 A) and T2-weighted (Figure 12-12 B) MR images show abnormal tissue lining the lateral ventricle (arrows). Signal of this tissue follows that of normal gray matter (arrowheads) on both T1- and T2-weighted images (B is the correct answer to Question 12-2).

Discussion

Two common reasons for performing MR scans in young infants are illustrated by the cases in this section. Infants with craniofacial anomalies frequently have underlying congenital malformations of the CNS. Seizures, too, may be the first sign of an underlying brain malformation. As discussed in the section on technique selection, whenever a congenital brain anomaly is suspected, MR imaging is the best examination to perform.

Insults to the developing brain lead to predictable alterations of brain morphology. By analyzing patterns of altered brain morphology, we can often determine which stage of CNS development has been disrupted. This analysis, combined with knowledge of neuroembryology, has allowed for the development of systems to classify congenital anomalies of the CNS. One simplified classification system divides congenital malformations into disorders of organogenesis (which include abnormalities of neural tube closure, diverticulation/cleavage, sulcation/cellular migration, and size, as well as destructive lesions acquired in utero), disorders of histogenesis (ie, neurocutaneous syndromes), and disorders of cytogenesis (ie, congenital neoplasms). Readers are referred to the suggested readings at the end of this chapter for further information on this topic.

The patient in Case 12-1 has alobar holoprosencephaly, a classic example of disordered ventral induction. In this condition, there is complete (alobar) or partial (semilobar, lobar) failure of separation of the forebrain (prosencephalon) into two hemispheres. In alobar holoprosencephaly, the most severe form of this disorder, there is no separation of the two hemispheres at all. The thalami are fused, a central monoventricle is present, and there is no corpus callosum. Infants with this form of holoprosencephaly frequently have severe facial anomalies.

In Case 12-2, the patient has heterotopic gray matter lining the lateral ventricles. This congenital anomaly is one type of disordered cellular migration. Neurons that make up the gray matter of the cerebral cortex actually develop along the edges of the lateral and third ventricles within the so-called germinal matrix zone. They then migrate outward to their final cortical location. If this normal neuronal migration is disrupted, a normal cortex may not develop, and foci of gray matter may be present in abnormal locations along the migration route. Collections of these normal neurons in abnormal locations are called gray matter heterotopias.

Several different types of heterotopias have been described. The case presented in this section demonstrates a focal nodular gray matter heterotopia involving the subependymal region.
at the edge of the lateral ventricles. Seizures frequently occur in patients with this condition, as in the patient in Case 12-2. Because MR imaging usually provides an exact diagnosis of this condition, biopsies of CNS tissue are unnecessary.

In contrast to focal nodular heterotopias, diffuse (or laminar) heterotopias are commonly seen within or adjacent to the cortex, while “band” type heterotopias are located deep to the normal cortex, in a subcortical location, separated by a thin interface of white matter (Figure 12-13). Band-type heterotopias are well defined, with smooth margins, demonstrating signal intensities identical to those of normal gray matter. Mass effect on the underlying white matter or deep gray structures may be seen, and the sulcation pattern of the brain superficial to the heterotopia may be abnormal. Associated CNS anomalies may be present, such as agenesis of the corpus callosum, holoprosencephaly, or herniation of brain tissue (encephaloceles). Although at first glance the cortex may appear to be markedly thickened, closer examination will reveal an additional band of gray matter in a subcortical location, which may or may not demonstrate increased $^{18}$F-FDG activity on a PET scan. This band of heterotopia is known to be associated with intractable seizures, occurring earlier than in the focal type, as well as severe developmental delay.
Several types of Chiari malformations were initially described by the German pathologist Hans Chiari, who classified these congenital hindbrain anomalies into three types. In each case, abnormal descent of cerebellar tissue into the cervical canal is demonstrated. A Chiari I malformation is associated with a relatively small posterior fossa and a normal-sized cerebellum. Consequently, elongated peglike cerebellar tonsils extend below the foramen magnum with effacement of the corresponding CSF spaces. There is often dorsal tilting of the dens, which may indent the brainstem. There is no association between Chiari I malformations and neural tube defects; however, the spine should be imaged because of the common coexistence of a syrinx.

In contrast to Chiari I, the Chiari II malformation is very highly associated with myelomeningocele and generally supratentorial abnormalities. The posterior fossa is small with herniation of cerebellar tonsils, vermis, and medulla below the foramen magnum. Because the cervical cord is somewhat fixed in position by the dentate ligaments, this downward displacement results in a characteristic cervicomедullary kink. The fourth ventricle is low-lying and elongated as well, with distortion of the cerebral aqueduct and tectum (so-called tectal beaking), often resulting in hydrocephalus. The superior cerebellum towers superiorly through a widened tentorium incisura, with the remainder of the cerebellum wrapping around the brainstem. Supratentorial abnormalities include agenesis or hypoplasia of the corpus callosum, enlarged massa intermedia, deficiency of the falx resulting in interdigitation of cortical gyri across the midline, and enlarged occipital horns (colpocephaly) (Figure 12-14). Chiari III malformations are associated with occipital or high cervical encephaloceles, containing cerebellar tissue, with or without brainstem.

Disorders of histogenesis include the neurocutaneous syndromes, which are a heterogeneous group of disorders with CNS and, for the most part, cutaneous manifestations. Visceral and connective tissue abnormalities may be prominent. Common disorders within this group include neurofibromatosis types I and II, tuberous sclerosis, von Hippel-Lindau disease, and Sturge-Weber syndrome, where the abnormal lesions corresponding to these entities are neurogenic tumors, tubers, hemangioblastomas, and angiomas, respectively.
Neurofibromatosis type 1 is the most common of all the neurocutaneous syndromes, accounting for 90% of all neurofibromatosis cases, and is the only entity discussed here. It is transmitted on the long arm of chromosome 17 and is a disease of childhood. Autosomal dominant transmission occurs in 50%, and the remainder appear sporadically as new mutations in a patient with no known family history of the disease. The diagnosis is established when two or more of the following criteria are present: (1) six or more café-au-lait spots (brown skin pigmentation), (2) two or more Lisch nodules (hamartomas) of the iris, (3) two or more neurofibromas, (4) one or more plexiform neurofibromas, (5) axillary freckling, (6) one or more bone dysplasias (ie, dysplasia of the greater sphenoid wing), (7) optic nerve glioma, or (8) first-degree relative with neurofibromatosis type 1.

The optic pathway gliomas are generally nonaggressive (low-grade) pilocytic astrocytomas, which present in childhood and may not affect vision until greatly increased in size (Figure 12-15 A). Cerebellar, brainstem, and cerebral astrocytomas may additionally be seen. High T2 signal intensity foci may be identified within the peduncles or deep gray matter of the cerebellum, brainstem, basal ganglia (particularly the globus pallidus), and supratentorial white matter (Figure 12-15 B). The nature of these lesions remains unresolved.

### EXERCISE 12-2. STROKE

12-3. In Case 12-3, what is the most likely diagnosis (Figure 12-16 A,B)?
- A. Intracranial abscess
- B. Arachnoid cyst
- C. Metastatic brain tumor
- D. Primary brain tumor
- E. Cerebral infarction

12-4. In Case 12-4, what is the likely cause of the patient’s problem (Figure 12-17 A,B)?
- A. Brainstem infarction
- B. Brainstem compression from cerebellar infarction
- C. Brainstem tumor
- D. Cerebellar astrocytoma
- E. Posterior fossa hemorrhage

12-5. In Case 12-5, what is the most likely diagnosis (Figure 12-18)?
- A. Thalamic glioma
- B. Subarachnoid hemorrhage
- C. Metastatic disease
- D. Hypertensive hemorrhage in the basal ganglia
- E. Cerebral contusion
Figure 12-16. (A,B) Case 12-3. Axial noncontrast head CT images in a 56-year-old male with history of hypertension and diabetes who presents to the emergency department with left hemiparesis.

Figure 12-17. (A,B) Case 12-4. Axial T2-weighted (A) and sagittal T1-weighted (B) images in a 66-year-old woman who presents with gradual onset of nausea, dizziness, and ataxia. The patient became comatose 24 hours after the onset of symptoms.
Radiologic Findings

12-3. In this case, the axial CT image (Figure 12-16 A) demonstrates a well-defined area of hypodensity (white arrows) in the right middle cerebral artery (MCA) territory. There is secondary mass effect on the surrounding brain parenchyma with effacement of the cortical sulci. In a more inferior axial image (Figure 12-16 B), note the bright right MCA (arrowhead) corresponding to an acute thrombus in the main trunk of this vessel (E is the correct answer to Question 12-3).

12-4. In this case, the axial T2-weighted MR image (Figure 12-17 A) shows areas of increased T2 signal (arrows) corresponding to edema within the cerebellum. A sagittal T1-weighted image (Figure 12-17 B) shows a swollen cerebellum, as well as upward transtentorial (arrowhead) and downward tonsillar (curved arrow) herniation of cerebellar tissue. Also note compression of the brainstem (small arrows) and fourth ventricle (asterisk). These changes are compatible with a recent cerebellar infarction with brainstem compression caused by the swollen cerebellum (B is the correct answer to Question 12-4).

12-5. In this case, an axial CT scan (Figure 12-18) demonstrates a large, hyperdense intraparenchymal hemorrhage centered in the right basal ganglia (black arrow) with surrounding edema and mass effect (double white arrows). Intraventricular extension of hemorrhage is present (black arrowheads) with entrapment of the left lateral ventricle secondary to midline shift (single white arrow). This is most likely secondary to the patient’s known hypertension (D is the correct answer to Question 12-5).

Discussion

Stroke is a lay term for neurologic dysfunction. The usual image of a stroke patient is that of an elderly individual with hemiparesis, often associated with abnormal speech. There are actually many different causes of stroke. These include cerebral infarction, intracerebral hemorrhage, subarachnoid hemorrhage, and miscellaneous causes such as dural sinus occlusion with associated venous infarction. Although these conditions may have similar clinical presentations, they have different treatments and prognoses.

The vast majority of strokes are cerebral infarctions associated with atherosclerosis. The radiologic manifestations of cerebral infarction vary with time. The head CT scan of the patient in Case 12-3 was obtained several days after the onset of symptoms and shows typical findings of a subacute infarct in a major vascular territory, in this case, the right middle cerebral artery region. By this time, the infarct is a very well-defined area of low attenuation compared to normal surrounding brain. There is associated mass effect from the edematous tissue. Acute infarcts (less than 24 hours since onset of symptoms) may be difficult to identify on head CT scans, if at all. However, diffusion-weighted MR imaging often demonstrates brain abnormalities within hours of symptom onset. Subtle changes on head CT scans in acute infarction can sometimes be seen, but may be overlooked if the examination is not closely scrutinized. Sometimes the only apparent change on CT scans is a subtle loss of gray matter/white matter differentiation in the area of infarction. CT scanning is performed in acute cerebral infarction because scans can be quickly obtained, and CT is a very good test for identifying intracranial hemorrhage, an important finding for management considerations. Institutions that are involved in the early management of stroke often have a stroke imaging protocol whereby noncontrast CT is typically obtained along with CT angiography (Figure 12-19 A, B) as well as CT perfusion. If the infarct is not obvious on the initial CT scan, an MR scan is usually obtained to verify high clinical suspicion.

An acute or subacute infarction will exhibit a diffusion signal abnormality that reflects the restricted movement of water molecules and typically persists for 1 to 2 weeks within infarcted tissue (Figure 12-19 C). T2-weighted imaging...
Figure 12-19. CT angiographic images corresponding to Case 12-3. (A) 3-D vascular rendering demonstrating occluded right superior MCA branch (arrow) and (B) axial CT showing generalized poor intravascular contrast opacification of the right MCA territory (white arrows) relative to the left (black arrows). Subsequent diffusion-weighted (C) and
demonstrates increased signal within the infarcted territory due to the presence of cytotoxic edema (Figure 12-19 D). Intravascular enhancement extending into the cortical sulci may be seen in the acute to early subacute phase of infarct, generally related to prolonged intravascular opacification from slow vascular flow (Figure 12-19 E). Within several days of a cerebral infarction, parenchymal enhancement is commonly identified along the cortex, which usually has a bandlike, tubular, or gyriform appearance and may persist for several weeks. Solid or ring-enhancing areas, as well as more amorphous-appearing patterns of enhancement, can occasionally occur.

Case 12-4 illustrates an important point to consider when deciding which test to order in the setting of acute stroke. In this case, the patient’s symptoms were worrisome for a brainstem process. CT scanning of the brainstem and posterior fossa is frequently degraded by streak artifacts emanating from the dense bone of the skull base. Subtle (and sometimes not so subtle) abnormalities may not be apparent. Therefore, for most neurologic conditions that involve the brainstem or posterior fossa, MR scans are much better at depicting an abnormality. Notice that the patient in Case 12-4 did not in fact have a brainstem infarct, as was suspected clinically, but rather had brainstem compression from a large cerebellar infarct.

Case 12-5 illustrates how essential an imaging examination is in managing stroke as the patient initially had signs of cerebral infarction. The CT scan demonstrated an obvious basal ganglia hemorrhage, probably secondary to the patient’s hypertension. Management of these two conditions is considerably different. Hypertension is the main cause of nontraumatic intracranial hemorrhage. In adults, these hemmorhages typically occur in the putamen/external capsule. Other locations for hypertensive hemorrhage include the thalamus, pons, cerebellum, and, rarely, subcortical white matter. Acute parenchymal hematomas, as in this case, are usually hyperdense on CT scans. With time these lesions become darker and eventually appear as round or slitlike cavities. The MR imaging appearance of a parenchymal hematoma is complex and depends largely on the presence of hemoglobin breakdown products within the clot.

EXERCISE 12-3. BRAIN TUMORS

12-6. In Case 12-6, what is the most likely diagnosis (Figure 12-20 A-C)?
A. Extra-axial brain tumor
B. Intra-axial brain tumor
C. Frontal contusion
D. Subdural hematoma
E. Encephalocele
12-7. In Case 12-7, what is the most likely cause of the patient’s symptoms (Figure 12-21 A, B)?
A. Multiple sclerosis
B. Inner ear abnormality
C. Intraventricular meningioma
D. Hematoma
E. Malignant brain tumor

12-8. In Case 12-8, what is the most likely explanation for the patient’s mental status changes (Figure 12-22 A, B)?
A. Metastatic disease
B. Intracranial hemorrhage
C. Small infarcts
D. Sarcoidosis
E. Arteriovenous malformation

▲ Figure 12-20. Case 12-6. Noncontrast sagittal T1-weighted (A) and axial T2-weighted (B) images, as well as postcontrast axial T1-weighted image (C) in a 33-year-old Hispanic man who presents with a syncopal episode and involuntary tremors.
Figure 12-21. A, B. Case 12-7. Initial coronal T2 FLAIR-weighted (A) and axial contrast-enhanced T1-weighted (B) images in a 48-year-old woman who presents with a history of headaches and seizures.

Figure 12-22. Case 12-8. A contrast-enhanced axial CT scan (A) and a gadolinium-enhanced axial T1-weighted MR image (B) in a 58-year-old man who presents with a history of lung cancer and mental status changes.
Radiologic Findings

12-6. In this case, the sagittal T1-weighted image before contrast administration shows an extra-axial, left frontal convexity mass (Figure 12-20 A, arrows). This homogenous-appearing, smoothly margined, mass (arrows) is isointense to the normal gray matter (Figure 12-20 A), and is sometimes difficult to differentiate from normal brain tissue on unenhanced T1 images. On T2-weighted imaging, the mass has a heterogeneous appearance, but is predominantly isointense to gray matter (Figure 12-20 B). The mass is circumscribed by a thin rim (pseudocapsule) of increased T2 signal (long arrows), as well as margined by a more peripherally located band of T2 signal hypointensity along its medial and posterior borders (short arrows). There is distortion of the adjacent brain parenchyma, with compression of the left lateral ventricle, and a mild shift of the midline structures to the right. Following intravenous GdDTPA administration, the mass enhances uniformly (arrows), and dural tails are identified (arrowheads), allowing easy identification (Figure 12-20 C). These features are fairly typical of a meningioma (A is the correct answer to Question 12-6).

12-7. In this case, a coronal T2 FLAIR-weighted MR image (Figure 12-21 A) demonstrates a large area of signal hyperintensity involving the inferior frontal regions (large white arrows) and right temporal lobe (small white arrow), with extension into the corpus callosum (curved arrows). On the infused axial view, at the level of the body of the corpus callosum (Figure 12-21 B), subtle, ill-defined enhancement is present within the right cerebral hemisphere (arrowhead) with patchy enhancement (arrows) extending into the body of the corpus callosum. This is one appearance of a malignant brain tumor, in this case, an anaplastic oligodendroglioma (E is the correct answer to Question 12-7).

12-8. In this case, a contrast-enhanced axial CT scan shows no definite abnormality (Figure 12-22 A). A gadolinium-enhanced axial T1-weighted MR image shows multiple enhancing lesions (arrows) within the brain parenchyma (Figure 12-22 B). In a patient with known lung cancer, metastatic disease is the most likely explanation for multiple intracranial enhancing lesions (A is the correct answer to Question 12-8).

Discussion

Brain tumors can be classified in a variety of ways. The traditional classification of intracranial neoplasms is based on histology. In this system, brain tumors are either primary (they arise from the brain and its linings) or secondary (they arise from somewhere outside the CNS, ie, metastases). Primary tumors, which account for approximately two-thirds of all brain neoplasms, can be subdivided into glial and nonglial tumors. Secondary tumors, especially from lung and breast cancer, account for the remaining one-third of brain neoplasms. Metastases are most commonly parenchymal, but can also involve the skull and meninges.

Brain tumors can also be classified according to patient age and general tumor location (ie, adult or child, supratentorial or infratentorial). Finally, brain tumors can be classified according to the specific anatomic region involved. For example, we can generate lists of brain tumors that specifically affect the pineal or the pituitary regions.

Case 12-6 illustrates a useful principle for interpreting studies of patients with suspected brain tumors. It is very important to first decide whether a mass is within the brain parenchyma (intra-axial) or outside the brain (extra-axial). Extra-axial masses usually turn out to be meningiomas, many of which can be removed surgically with a very low incidence of recurrence. Intra-axial masses frequently turn out to be astrocytomas, and the prognosis is less favorable.

The patient in Case 12-6 has an extra-axial, dural-based, frontal convexity mass that markedly enhances with Gd-DTPA. Meningiomas comprise 15% to 20% of intracranial tumors, predominantly occur in females, and exhibit a peak age incidence of 45 years. They are the most common nonglial primary CNS tumors. They can occur anywhere within the head but typically occur along the dural venous sinuses. The parasagittal region and cerebral convexities are the most common locations. Anterior basal or olfactory groove meningiomas account for 5% to 10% of intracranial meningiomas. Anosmia results from involvement of the olfactory tracts by the tumor. These expansile lesions are slow-growing, and the ensuing mass effect on the adjacent brain parenchyma is gradual. The absence of reactive edema in a subset of these lesions can be seen as a result of their slow growth. These masses usually demonstrate intense and uniform enhancement, independent of tumor size. A layer of thickened dural enhancement (“dural tail”) is commonly seen extending away from the base of the meningioma. In many cases, this finding represents reactive thickening without tumor involvement.

Case 12-7 demonstrates a large, infiltrating (aggressive or high-grade) glioma involving the majority of the right frontotemporal lobe, with extension into the corpus callosum. Although there is some overlap of the MR imaging features characteristically seen with these invasive neoplasms and their less aggressive (lower-grade) counterparts, the imaging features of higher-grade neoplasms, on the whole, are distinctly different from those seen with lower-grade lesions. High-grade gliomas, namely anaplastic astrocytomas and oligodendrogliomas (as in this case), as well as glioblastoma multiforme (the most highly malignant glioma), demonstrate heterogeneous signal characteristics, generally a reflection of the variable cellularity, in addition
Other types of malignant gliomas, such as glioblastoma multiforme, typically demonstrate intense enhancement. The corpus callosum is often involved by a high-grade glial tumor, which may grow medially from an adjacent hemispheric source or may arise independently within this structure. “Wings” may extend symmetrically or asymmetrically into both cerebral hemispheres, exhibiting a butterfly-type appearance (Figure 12-24), appropriately termed butterfly glioma. Perfusion studies on high-grade gliomas generally show increased blood flow and volume, reflecting the increased vascular density and permeability of these tumors. In contrast, low-grade gliomas may appear only as a region of amorphous signal abnormality (most obvious on T2-weighted images), often without associated enhancement or perfusion abnormality.

Case 12-8 illustrates a very important point to remember when working up patients with suspected metastatic disease to the brain: MR imaging is considerably more sensitive than CT in detecting metastases. This is not a trivial point, because surgical resection of single, not multiple, brain lesions is sometimes performed. Conversely, the successful application of radiotherapy protocols relies on sensitively and accurately detecting the entire metastatic tumor burden. Metastatic disease to the brain has a variety of
manifestations, the most common being parenchymal involvement. Typical hematogenous brain metastases demonstrate solid or ringlike enhancement on CT or MR scans, occur near gray matter/white matter junctions, and are usually surrounded by a marked amount of edema. They most commonly metastasize from lung or breast primaries.

EXERCISE 12-4. INTRACRANIAL INFECTIONS

12-9. In Case 12-9, what is the most likely diagnosis (Figure 12-25 A, B)?
A. Frontal contusion
B. Aneurysm with intraventricular hemorrhage
C. Parietal lobe abscess
D. Intracranial lymphoma
E. Cerebritis

12-10. In Case 12-10, the location of the abnormality is pathognomonic for which type of infection (Figure 12-26 A, B)?
A. Toxoplasmosis
B. Tuberculosis
C. Cryptococcus
D. Herpes
E. Staphylococcus

A Figure 12-24. A 76-year-old woman presents with a 6-month history of progressive gait ataxia and frequent falling. Coronal contrast-enhanced T1-weighted MR image of a glioblastoma multiforme is shown. An enhancing mass (white arrows) extends through the corpus callosum (black arrows) into both hemispheres.

A Figure 12-25. Case 12-9. Postcontrast axial T1-weighted (A) and diffusion-weighted MR (B) images in a 75-year-old man who presents with a history of recurrent lymphoma complicated by multiple infections and new mental status changes.
12-11. In Case 12-11, the major differential diagnosis for this lesion is toxoplasmosis versus (Figure 12-27)
A. *Cryptococcus*
B. Intracranial lymphoma
C. Sarcoidosis
D. Metastatic disease
E. Cytomegalovirus (CMV)

**Radiologic Findings**

12-9. In this case, the contrast-enhanced MR scan shows a ring-enhancing lesion (arrows) in the left parietal lobe with decreased surrounding T1 signal (Figure 12-25 A). A diffusion signal abnormality is present on the corresponding diffusion-weighted image (Figure 12-25 B), within the central aspect of the lesion, and is found to be compatible with an area of restricted water motion. The patient’s history is compatible with an intracranial infection, and the demonstrated MR imaging findings favor an abscess (C is the correct answer to Question 12-9.)

12-10. In this case, the T2-weighted MR image (Figure 12-26 A) shows increased signal in the medial and anterior aspects of the right temporal lobe (single arrow) with small focus of T2 hypointensity (double arrows) consistent with the presence of blood products. Postcontrast axial T1 (Figure 12-26 B) shows abnormal patchy

▲ Figure 12-26. Case 12-10. Axial T2 (A) and axial T1 postcontrast images (B) in a 42-year-old female who presents with mental status changes.

▲ Figure 12-27. Case 12-11. An axial contrast-enhanced T1-weighted MR image in a 43-year-old man who presents with headache and weakness.
A host of infectious diseases can involve the brain and its coverings. Because the CNS has a limited number of ways of responding to an infectious agent, many intracranial infections appear identical on neuroimaging studies. It is, therefore, very important to closely correlate the imaging findings with the clinical presentation and other diagnostic tests, such as lumbar puncture or stereotactic brain aspiration. For our purposes, it is useful to classify CNS infections according to the intracranial compartment involved, especially because this has treatment implications. Intracranial infections can be either parenchymal or extraparenchymal. Parenchymal manifestations include cerebritis/abscess and encephalitis. Extraparenchymal disease includes epidural abscess, subdural empyema, and leptomeningitis. Bacterial, viral, fungal, and parasitic agents can all affect the CNS. Although a few infectious agents preferentially involve a particular anatomic compartment of the CNS, most are not site specific.

Case 12-9 demonstrates the classic ring-enhancing lesion of an abscess, in this case, due to *Nocardia*. No specific features of this abscess distinguish it from a typical pyogenic abscess. The diffusion signal abnormality has been postulated to arise from restricted water motion in the presence of viscous, purulent material within the abscess cavity and can mimic an area of acute ischemia. Cerebral infection by *Nocardia* usually arises from a pulmonary focus in an immunocompromised host. Similarly, most pyogenic abscesses are the result of hematogenous dissemination from a non-CNS source. Pyogenic brain abscesses can also result from direct extension of an infectious process from an adjacent area (eg, sinusitis or mastoiditis) or from trauma (eg, penetrating wound or surgery).

Abscesses usually occur at gray matter/white matter junctions, although they can occur anywhere in the brain. Patients frequently present with seizures or symptoms related to intracranial mass effect. If abscesses develop near the brain surface, they may rupture into the subarachnoid space, producing meningitis; they may also produce a ventriculitis if they rupture into the ventricular system. Most abscesses are treated surgically.

Herpes encephalitis (Case 12-10) is caused by the herpes simplex virus (HSV). Older children and adults are usually infected by HSV-1, either primarily or as a result of reactivation of a latent virus. The ensuing necrotizing encephalitis in this condition typically involves the temporal and inferior frontal lobes, insular cortex, and cingulate gyrus. Focal abnormalities of attenuation (on CT) or signal (on MR) in these characteristic locations, often with enhancement after contrast administration, are practically pathognomonic of HSV-1 encephalitis. Early diagnosis of this condition is extremely important, because antiviral therapy can significantly affect patient outcome.

Neonatal herpes simplex infection differs from infection in the older child and adult. The offending organism is usually HSV-2, which may be acquired in utero or during birth from mothers with genital herpes. HSV-2 infection can produce severe destructive changes within the developing brain. Unlike HSV-1 infection in older children and adults, neonatal herpes encephalitis can involve any area of the brain, having no predilection for the temporal lobe.

Patients with AIDS (Case 12-11) commonly develop intracranial infections during the course of their disease. Human immunodeficiency virus (HIV) itself can directly infect the CNS, producing encephalopathy in up to 60% of AIDS patients. The most common neuroimaging finding in HIV encephalopathy is cerebral atrophy, often with patchy white matter hypodensity (on CT) or T2 hyperintensity (on MR imaging) from demyelination and gliosis (Figure 12-28). Other common CNS infections in the immunocompromised AIDS patient include toxoplasmosis, cryptococcosis, and progressive multifocal leukoencephalopathy (from a polyomavirus infection).

Toxoplasmosis usually presents as multiple lesions of varying size and demonstrates ring enhancement with surrounding edema on CT or MR imaging. Lesions commonly occur in the basal ganglia or at the gray matter/white matter junction within the cerebral hemispheres. Individual masses may have a solid appearance or demonstrate central necrosis or hemorrhage. The enhancement pattern is variable; both rim-enhancing and more solidly enhancing lesions can be seen. Their appearance is almost identical to that of primary intracranial lymphoma, another common intracranial condition in AIDS. Metabolic studies, such as PET or SPECT scans (no increase in 18F-FDG activity with toxoplasmosis, increased with lymphoma), MR spectroscopy (no choline elevation in toxoplasmosis, elevated in lymphoma), and perfusion-weighted sequences (lower cerebral blood volume in toxoplasmosis) may assist in distinguishing these pathologies.

Meningitis is the most frequent manifestation of cryptococcosis in AIDS, although parenchymal lesions, termed cryptococcomas, are occasionally encountered. In progressive
multifocal leukoencephalopathy, extensive areas of white matter demyelination are shown on MR imaging. A number of other intracranial infections can occur in AIDS patients, and the reader is referred to the suggested readings at the end of this chapter for sources of further information.

**EXERCISE 12-5. HEAD TRAUMA**

12-12. In Case 12-12, what is the diagnosis (Figure 12-29 A, B)?
A. Subdural hematoma
B. Cerebral contusion
C. Epidural hematoma
D. Meningioma
E. Subdural hygroma

12-13. In Case 12-13, what is the main radiologic finding (Figure 12-30)?
A. Subdural hematoma
B. Epidural hematoma
C. Duret hemorrhage
D. Cerebral contusions
E. Shearing injuries

**Radiologic Findings**

12-12. In this case, a predominantly high-density, extra-axial, hemorrhagic collection (black arrows) is producing mass effect on the right frontal lobe on an Axial T2-weighted image shows white matter high signal (arrows). Also note the diffuse prominence of gyri and sulci (arrowheads) and sylvian fissures (asterisks), compatible with cerebral atrophy.

**Figure 12-28.** An 8-year-old girl with AIDS and new onset of seizures. Axial T2-weighted image shows white matter high signal (arrows). Also note the diffuse prominence of gyri and sulci (arrowheads) and sylvian fissures (asterisks), compatible with cerebral atrophy.

**Figure 12-29.** Case 12-12. Axial noncontrast head CT with soft tissue (A) and bone windows (B) in an 18-year-old male who is found unconscious following a motor vehicle collision.
unenhanced head CT scan (Figure 12-29 A). Mass effect results in marked distortion of the underlying cortex and leftward subfalcine herniation (white arrow) (Figure 12-29 A). A linear nondisplaced fracture is present along the anterior aspect of the right parietal bone (black arrow) (Figure 12-29 B). The biconvex appearance of this lesion is typical of an epidural hematoma, which is the acute finding in this case (C is the correct answer to Question 12-12).

12-13. In this case, there are multiple areas of increased attenuation within the frontal lobes, especially on the left (arrows) (Figure 12-30). These areas correspond to multiple hemorrhagic contusions involving the brain parenchyma (D is the correct answer to Question 12-13).

Discussion

Intracranial abnormalities in head trauma can be classified as either primary or secondary. Primary lesions occur at the moment of injury and include skull fractures, extracerebral hemorrhage (eg, epidural or subdural hematomas, subarachnoid hemorrhage), and intracerebral hemorrhage (eg, brain contusion, brainstem injury, diffuse axonal injury).

The secondary effects of head trauma are actually complications of the primary intracranial injury. Elevated intracranial pressure and cerebral herniation are responsible for most of the secondary effects of head trauma, which in many cases may be more devastating to the patients than the initial injury.

Epidural hematoma is usually associated with skull fractures that lacerate the middle meningeal artery or a dural sinus. Up to one-half of patients with epidural hematomas have a lucid interval after the head trauma occurs. On CT, epidural hematomas usually appear as biconvex, high-attenuation, extra-axial masses. Most are located in the temporoparietal area. Underlying skull fractures are common. Intracranial brain herniation may also be a prominent feature in this condition. One important imaging feature in epidural hematomas is that they do not cross skull sutures, but may cross the midline.

Subdural hematoma, on the other hand, is usually a crescent-shaped extra-axial collection that may cross suture lines, but is confined by the dural reflections (Figure 12-31). These lesions are more lethal than are epidural hematomas; the subdural hematoma mortality rate is over 50%. CT can usually, but not always, distinguish between epidural hematomas and subdural hematomas. Subdural hematomas are a commonly identified abnormality in the abused child (nonaccidental trauma). CT scans are obtained to detect the
presence of subdural hematomas (Figure 12-32). A brain MRI, however, can more sensitively delineate small extra-axial hematomas, subdural hematomas of varying ages, and coexisting cortical contusions or shearing injuries. A shearing injury (or diffuse axonal injury) is associated with an overall poor prognosis and is recognized as small petechial hemorrhages at the gray-white junction and in the corpus callosum. Interhemispheric (para- and intrafalcial) subdural hematomas may arise from tearing of bridging veins along the falx cerebri in shaking injuries and are nearly pathognomonic for nonaccidental trauma. Retinal hemorrhages may be present and are also suspicious, especially if bilateral. In addition, cerebral ischemia/infarction and multiple, complex, unexplained skull fractures may be associated findings.

Cerebral contusions (Case 12-13) are the second most common form of brain parenchymal injury in primary head trauma (diffuse axonal injury is the most common parenchymal injury). Cerebral contusions can be thought of as brain bruises. They result either from the brain striking a bony ridge inside the skull during rapid acceleration/deceleration, as occurs in a motor vehicle accident, or from a depressed

**Figure 12-31.** Axial noncontrast head CT obtained on a 67-year-old male after a fall. A large, crescentic hyperdense extra-axial hemorrhage layers over the left cerebral convexity (black arrow) and extends along the posterior falx (black arrowhead). Secondary mass effect on the adjacent brain parenchyma with effacement of the left lateral ventricle and rightward shift of the midline structures (white arrowhead).

**Figure 12-32.** Noncontrast axial CT images (A, B) in a 21-day-old male following nonaccidental trauma. Large, bilateral subdural hematomas layer over the tentorium cerebelli in (A) (closed arrows) and within the interhemispheric fissure in (B) (arrow). In addition, a small amount of subarachnoid hemorrhage is seen within the quadrigeminal plate cistern in (A) (open arrows), as well as within the left lateral ventricle (not shown). Loss of the normal cerebral gray-white differentiation is demonstrated. These features are nearly pathognomonic for nonaccidental trauma with diffuse anoxic insult.
skull fracture. These lesions tend to occur in particular anatomic locations, especially the undersurfaces and poles of the frontal and temporal lobes (Figure 12-33). CT scans show areas of low attenuation (edema) and hemorrhage at the site of injury. Delayed hemorrhage, 1 to 2 days after a head injury, is common with contusions.

EXERCISE 12-6. INTRACRANIAL VASCULAR ABNORMALITIES

12-14. In Case 12-14, what is the reason for the abnormality on the CT scan (Figure 12-34 A–C)?
A. Cerebral aneurysm
B. Arteriovenous malformation
C. Head trauma
D. Carotid dissection
E. Vasculitis

Radiologic Findings

12-14. In this case, the CT scan (Figure 12-34 A) shows extensive subarachnoid hemorrhage filling the basal cisterns, more pronounced on the right (black arrows), with extension of hemorrhage into the interhemispheric and Sylvian fissures. Enlargement of the temporal horns (white arrows) is indicative of early hydrocephalus. An oblique craniocaudal view from a CT angiogram (Figure 12-34 B) shows a 4-mm saccular aneurysm arising from the right paraclinoid internal carotid artery (arrow), most likely posterior communicating artery origin. A lateral view taken from a right common carotid catheter angiogram (Figure 12-34 C) confirms a posterior communicating artery origin aneurysm (black arrow) with upward distortion of the normal anterior cerebral artery configuration secondary to hydrocephalus (black arrowheads). (A is the correct answer to Question 12-14.)

12-15. In this case, the noncontrast CT scan (Figure 12-35 A) shows a lobulated, hyperdense mass (black arrows) centered in the medial right occipital lobe with effacement of the right occipital horn. Accompanying axial T2 MRI (Figure 12-35 B) reveals a nidus of low signal vascular “flow-voids” (white arrowheads) in the occipital lobe with a more prominent draining vein extending into the quadrigeminal plate cistern (white arrow). A subsequent catheter angiogram (Figure 12-35 C) of the right vertebral artery (curved arrow) confirms a high-flow vascular lesion with a tangle of vessels (double black arrows) and early venous opacification (arrowhead) characteristic of an arteriovenous malformation. (B is the correct answer to Question 12-15.)

Discussion

Cerebrovascular disorders (strokes) were discussed in Exercise 12-2, which dealt mainly with cerebral infarction secondary to atherosclerosis. For information on other causes of cerebral infarction, the reader is referred to the suggested readings at the end of this chapter. This section addresses two other common vascular conditions affecting the CNS: aneurysms and vascular malformations.

Most cerebral aneurysms, such as Case 12-14, are saccular or “berry” aneurysms. These focal arterial dilations tend to occur at cerebral arterial branch points. They have traditionally
been thought to develop at congenitally weak areas of a blood vessel wall. Recent evidence, however, has questioned this view, and many now believe that saccular aneurysms are probably acquired lesions from abnormal hemodynamic stresses that damage the arterial wall.

Intracranial aneurysms are usually asymptomatic until they rupture, at which time the patient typically presents with a severe headache resulting from subarachnoid hemorrhage. The vast majority of nontraumatic SAHs occur as a result of aneurysm rupture. CT is very good at demonstrating SAH. Patients usually undergo CT angiography whenever nontraumatic SAH is detected, and occasionally cerebral arteriography.

Common locations for intracranial aneurysms include the anterior communicating artery, the internal carotid artery at the origin of the posterior communicating artery, and the middle cerebral artery trifurcation. Posterior fossa aneurysms are less common; they make up only around 10% of all intracranial aneurysms and typically arise from the basilar artery tip.

Vascular malformations can be divided into four major types: true arteriovenous malformations (as demonstrated in...
Figure 12-35. Case 12-15. Axial noncontrast CT (A) and T2-weighted MRI (B) and catheter angiogram (C) in a 22-year-old male who complains of persistent right-sided headache.
Case 12-15), cavernous hemangiomas, venous angiomas, and capillary telangiectasias. AVMs are congenital lesions consisting of a tangle of abnormal blood vessels, usually within the brain parenchyma, that are fed by enlarged cerebral arteries and drained by dilated, tortuous veins. Because there is no normal intervening brain parenchyma for the blood to flow through, blood is rapidly shunted from the arterial to the venous side. This shunting is dramatically demonstrated on cerebral arteriography. Patients with AVMs usually present with intracranial hemorrhage or seizures. MR imaging or contrast-enhanced CT can demonstrate the tortuous vascular channels of most AVMs, although cerebral arteriography is the definitive study in this condition.

The other intracranial vascular malformations have very characteristic appearances on MR imaging, although they are frequently invisible on cerebral arteriography. Patients with these “low-pressure” malformations can present with headaches, seizures, or, rarely, intracranial hemorrhage. Many of these lesions, however, are incidentally discovered on MR scans performed for other reasons.

**EXERCISE 12-7. WHITE MATTER DISEASES**

12-16. In Case 12-16, what is the most likely diagnosis (Figure 12-36 A, B)?

A. Pseudotumor cerebri  
B. Metastatic disease  
C. Septic emboli  
D. Radiation necrosis  
E. Multiple sclerosis

12-17. In Case 12-17, what is most likely responsible for the abnormalities seen on the MR image (Figure 12-37 A, B)?

A. Cardiac arrhythmia  
B. Chronic hypertension  
C. Remote trauma  
D. Hepatic failure  
E. Carbon monoxide poisoning

**Radiologic Findings**

12-16. In this case, sagittal T1-weighted and axial FLAIR MR images (Figure 12-36 A, B) show multiple foci of abnormal signal within the periventricular white matter (arrows). These lesions are quite characteristic of multiple sclerosis (E is the correct answer to Question 12-16). The patient’s visual difficulties were due to optic neuritis, a common abnormality in multiple sclerosis.

12-17. In this case, there are patchy areas of increased T2 signal (arrows) within the periventricular white matter.

▲ Figure 12-36. A, B. Case 12-16. T1-weighted parasagittal (A) and axial T2 FLAIR images (B) in a 48-year-old female who presents with a history of weakness and visual changes.
(Figure 12-37). Usually seen in elderly hypertensive patients, these lesions correspond to focal areas of demyelination secondary to deep white matter ischemia (B is the correct answer to Question 12-17).

**Discussion**

Diseases that primarily affect the cerebral white matter have a host of causes. Unfortunately, very few of these conditions have specific appearances on CT or MR scans. Neuroimaging is usually performed to determine whether there are changes within the brain that are compatible with one of the white matter diseases and to rule out other conditions that might mimic white matter disease.

White matter diseases include both inherited and acquired conditions. They can be further subdivided into demyelinating conditions (destruction or injury of normally formed myelin) and dysmyelinating conditions (abnormal formation or maintenance of myelin, usually because of an enzyme deficiency). The dysmyelinating conditions are rare and, for the most part, include the leukodystrophies, such as adrenoleukodystrophy and metachromatic leukodystrophy. Although the MR appearance can be striking in some of these diseases, it is often nonspecific. These conditions are not discussed here.

Multiple sclerosis (MS) (Case 12-16) is the most common demyelinating disease. Because there is no generally accepted etiology for MS, it is also referred to as a primary demyelinating disease. Secondary demyelinating conditions are those caused by a known agent or event. MS usually occurs in young adults and more often in women than men (approximately 2:1). The disease is characterized by a relapsing and remitting course and by varying neurologic symptoms, depending on the location of the lesion within the CNS. Although diagnosis of MS is usually based on clinical criteria, MR imaging can be a very helpful confirmatory test. Typical MS plaques appear as ovoid, T2 signal hyperintensities within the periventricular and deep white matter. Lesions are also common within the corpus callosum, brainstem, cerebellar peduncles, spinal cord, and optic nerves. MS plaque enhancement on gadolinium-infused MR images suggests active disease (ie, breakdown of the BBB). Confluent areas of T2 signal abnormality in the periventricular white matter are common in severe cases.

Ischemic demyelination (Case 12-17) is usually seen in patients with small-vessel disease (such as from long-standing hypertension). This condition, also called leukoaraiosis (white matter softening), occurs because of hypertension-induced arteriolar sclerosis of penetrating medullary arteries that supply the deep white matter of the brain. This leads to a
Figure 12-38. Case 12-18. Coronal fast multiplanar inversion recovery (FMPIR) MRI (A), axial ictal SPECT (B), and coronal interictal PET images (C) in a 34-year-old female with a long-standing history of medical refractory epilepsy who presents with increasing seizure frequency.
reduction in white matter blood flow with accompanying ischemic demyelination. This condition occurs most commonly in older patients and is associated with small-vessel brain infarcts (lacunar infarcts). MR imaging usually demonstrates patchy areas of increased T2 signal in the deep white matter. The lesions are often bilaterally symmetric and periventricular in distribution.

EXERCISE 12-8. SEIZURE AND EPILEPSY

12-18. In Case 12-18, what is the most likely diagnosis (Figure 12-38 A–C)?
A. Alzheimer’s dementia
B. Gray matter heterotopia
C. Hemimegalencephaly
D. Mesial temporal sclerosis
E. Multiple sclerosis

Radiologic Findings

12-18. Coronal FMPIR MRI (Figure 12-38 A) demonstrates marked atrophy of the left hippocampus with loss of normal laminar architecture (white arrowhead). Ictal SPECT (Figure 12-38 B) shows increased radiotracer uptake in the left medial temporal lobe (double arrows), whereas the interictal PET (Figure 12-38 C) demonstrates diminished metabolic activity in the left temporal lobe (black arrow). The constellation of findings is highly suggestive of mesial temporal sclerosis (D is the correct answer to Question 12-18). Pronounced cerebellar atrophy (Figure 12-38 A) in this case is the result of long-standing antiepileptic medication (white arrows).

Discussion

Although a comprehensive review of seizure and epilepsy classification is beyond the scope of this section, it is important to note the central role that imaging serves in the evaluation and management of these patients. The etiology of seizure varies significantly with patient age. In young children (3 months to 5 years), fever is the most common precipitant of seizure. The exact pathophysiology is not fully understood; however, there is likely a relationship to an inflammatory cascade as well as a low seizure threshold in young children. Imaging is generally not performed in the setting of a simple febrile seizure (seizures that last less than 15 minutes, are generalized, and do not recur in a 24-hour period). Febrile seizures that do not meet these criteria are classified as complex and imply a more serious underlying abnormality including meningitis, abscess, or encephalitis, for which imaging may be indicated. Other potential causes of seizure in young children include cerebral anoxia, metabolic abnormalities, cortical malformations (refer to Case 12-2), infection, or inherited neurocutaneous diseases such as tuberous sclerosis.

In older children and adults, common causes of seizure include vascular malformations, cerebral injury due to prior trauma or ischemia, or underlying tumor, among others. Note-worthy tumors associated with intractable seizure include ganglioglioma, dysembryoplastic neuroepithelial tumor (DNET), and pleomorphic xanthoastrocytoma; these generally occur in childhood or in young adulthood.

The most common cause of medically refractory epilepsy is mesial temporal (hippocampal) sclerosis. Although this entity is most commonly seen in adult patients, there is likely a link to febrile seizures earlier in childhood or other remote cerebral insult such as trauma or infection. On MR imaging, there is characteristic atrophy and gliosis of the hippocampus, often with dilation of the ipsilateral temporal horn due to volume loss. There may be atrophy and gliosis of ipsilateral fornix and mamillary body as well. These patients are potential candidates for temporal lobectomy, and additional imaging with ictal SPECT and interictal PET is generally performed as described earlier.

SUGGESTED READING

The spine is critical for normal human function, providing structure, support, and protection of the spinal cord and spinal nerves. Given the wide range of pathologic conditions that can affect the spine, recognition of normal anatomy and variants, differentiation from abnormal anatomy, and diagnosis of different pathologic conditions are the goals of spine imaging.

It is assumed that the reader is already familiar with basic spine anatomy learned early in medical school. With such a foundation, this chapter on the imaging appearance of the spine will serve to solidify and perhaps even enhance this knowledge base.

The purpose of this chapter is to review the different techniques employed in spine imaging, to emphasize normal anatomy as depicted with these techniques, and to highlight the appearance of certain common lesions. Relative advantages and disadvantages of the various imaging modalities are reviewed within the context of an overall imaging strategy. It is not intended that the reader will be an accomplished spine radiologist after reading this chapter. Rather, it is hoped that the reader will gain basic familiarity with normal imaging anatomy and the appearance of certain types of abnormalities, as well as a sense of which test might be the best to order for a given clinical circumstance.

**TECHNIQUES**

Prior to the advent of computed tomography (CT) in the 1970s, spine imaging consisted primarily of plain-film radiography and an adjunct test, myelography, to be discussed later. Spine imaging was revolutionized by CT, and, subsequently, magnetic resonance (MR) imaging, which for the first time allowed direct acquisition of axial, sagittal, and coronal (multiplanar) images, allowing for better spatial and contrast resolution. Not until the era of CT could the spinal cord be visualized and evaluated. These imaging modalities have so changed the face of diagnosis and treatment of spine pathology that virtually no neurosurgeon today would undertake spine surgery without first obtaining a CT and/or MR imaging study.

This section reviews the major modalities currently employed to image the spine. The highly specialized technique of spinal arteriography, which is used principally to detect vascular malformations, is beyond the scope of this review.
Nuclear medicine scanning also is not discussed, because it is seldom used as a primary diagnostic study in the evaluation of spine disease (though spinal metastases are frequently diagnosed with whole-body isotope bone scanning).

**Plain Radiograph**

Plain films are conventional radiographs, which are commonly referred to as x-rays. They may be obtained in a frontal projection—anteroposterior (AP) or posteroanterior (PA); the difference is insignificant in the spine—a lateral projection (side view), or an oblique projection (Figures 13-1, 13-2, and 13-3). Plain films are most useful for the visualization of bony structures. Soft-tissue structures (everything but bone) are largely radiolucent and cannot be seen clearly on plain films unless abnormal density such as calcification is present. Although plain films depict bone anatomy quite well, certain structures may be obscured by other structures in front of or behind them. For instance, on a lateral projection, both pedicles would be superimposed on one another (Figures 13-1 B and 13-3 B). For this reason, multiple views are always obtained as part of a routine examination.

On conventional radiographs, bony structures appear white. This appearance is referred to as “radiodense” or simply “dense.” Normally, mineralized bones have a recognizable radiodensity, which should always be assessed when viewing

![Figure 13-1](image). Plain film of normal cervical spine. (A) Anteroposterior view. (B) Lateral view. Arrowheads indicate prevertebral soft-tissue stripe. Note normal lordosis and continuity of spinolaminar line (dashed line).
x-rays. Certain pathologic conditions (eg, osteopenia and osteolytic metastases) can result in decreased bone density, and other conditions (eg, osteoblastic metastases and some exotic diseases) may result in abnormally increased bone density.

After bone density is assessed, the next evaluation should be the alignment of the spine. A normal spine should show cervical and lumbar lordosis (anterior convexity) (Figures 13-1 and 13-3) and thoracic kyphosis (posterior convexity). Abnormalities in alignment may result from incorrect positioning of the patient or be a reflection of an underlying problem. Such abnormalities may be minor, such as straightening or reversal of normal cervical lordosis in the case of muscle spasm. Abnormal curvature, such as scoliosis, may be idiopathic, congenital, or secondary to an underlying lesion. Major alterations in alignment, such as subluxation, can result from trauma. In assessing alignment, it is important to determine whether the vertebral bodies, as well as the posterior elements (ie, spinous processes, pedicles, and laminae), are appropriately positioned. The spinal cord rests within the spinal canal formed by the foramen within each vertebra, but the cord is not visible on plain films. Its location is thus defined by identifying the boundaries of the spinal canal. The anterior margin of the spinal canal is the posterior aspect of the vertebral body, and the posterior limit of the spinal canal can be approximated by locating, on a lateral radiograph, the junction of the spinous process and the laminae. Identification of the spinolaminar line also helps in the evaluation of alignment (Figure 13-1 B).
Most anatomic features of the spine are readily identifiable on plain radiographs (Figures 13-1, 13-2, and 13-3) such as vertebral bodies, facet joints, disk spaces, pedicles, laminae, transverse and spinous processes, and the neural foramen, whereas certain other areas can be evaluated only on specialized views. For instance, the open-mouth view facilitates visualization of the atlantoaxial (C1-2) articulation and provides an additional view of the dens (Figure 13-1 D). This view is an essential component of a trauma workup. Oblique views allow visualization of the neural foramen in the cervical spine (lateral views are used for this purpose in the thoracolumbar spine) (Figure 13-1 C). The neuroforamina are formed by the pedicles of the vertebrae above and below (Figures 13-1 C and 13-3 B) and allow for the exit of the spinal nerves from the spinal canal. There are 8 pairs of cervical spinal nerves, 12 pairs of thoracic spinal nerves, and 5 pairs of lumbar spinal nerves. Abnormal bony projections, known as osteophytes, are a common manifestation of degenerative spine disease and, if present within the neural foramen, may be a cause of nerve root compression. Spinal nerves also can be compressed by disk herniations, but this type of neural compression cannot be diagnosed by means of plain films alone.

Small bony structures, such as the cervical transverse foramen (for the vertebral artery) and the small facets for rib articulation in the thoracic spine, are not well visualized on plain radiographs. Because “soft-tissue” structures are also poorly demonstrated on plain radiographs, the intervertebral disk is not well seen with x-rays unless it is calcified (and therefore dense). However, differences in the soft-tissue density can impart additional information. In the cervical spine, for instance, calcification in the region of the carotid artery bifurcation may suggest atherosclerotic vascular narrowing. In the evaluation of cervical trauma, one should always assess the width of the normal soft-tissue stripe that is anterior to
the vertebral bodies (Figure 13-1 B). This prevertebral soft-tissue stripe may become widened in cervical spine trauma (prompting a closer search for fracture) and also in certain inflammatory conditions. When reviewing thoracic or lumbar spine films, attention to the soft tissues may facilitate diagnosis of a host of conditions ranging from pneumonia and lung cancer to retroperitoneal diseases and abdominal aortic aneurysms. Therefore, it is important not to focus only on the spine when interpreting spine radiographs.

Myelography

Contrast myelography has been around since its accidental discovery in 1922, when Sicard and Forestier, intending to administer extradural lipiodol to treat sciatica, inadvertently introduced the material into the subarachnoid space. This radiopaque oil was noted to move freely, and it was immediately recognized that with the use of fluoroscopy (real-time radiography) and conventional radiography, this procedure would be useful for diagnosing intraspinal tumors. Lipiodol quickly replaced air as the medium of choice for myelography (air is lucent and is therefore a “negative” contrast agent; iodinized oils such as lipiodol and, later, the popular Pantopaque (iophendylate) are dense and therefore “positive” contrast agents). Following Mixter and Barr’s 1934 report on the syndrome of herniated intervertebral disk, myelography became a widely used test. In the 1980s, the wide availability of less toxic water-soluble agents and, finally, nonionic contrast agents such as iopamidol and iohexol made myelography a readily tolerated procedure.
Myelography is employed most commonly to evaluate for disk herniations and to rule out spinal cord compression caused by tumor or trauma. In many parts of the United States, CT and MR imaging have all but replaced myelography. However, in many locations, myelography is still performed. A myelogram is often followed by a postmyelogram CT examination, which is addressed later.

The technique for performing myelography is simple. The patient is placed prone on a fluoroscopy table. Under fluoroscopic guidance, a lumbar puncture (LP) is made with an 18- to 22-gauge spinal needle (a fluoroscopically guided LP is much easier than an LP performed on a sick patient on the ward in the decubitus position). Cerebrospinal fluid (CSF) is then drawn for laboratory tests if needed, and contrast material is placed into the subarachnoid space. Once instillation of the contrast agent is fluoroscopically confirmed, the needle can be withdrawn and the spine studied. Depending on the spinal level to be examined, the patient can be standing, flat, or in Trendelenburg position. Typically, multiple views including lateral, AP, and oblique views are obtained. In the lumbar region, the cauda equina nerve roots are well visualized (Figure 13-4 A). The conus medullaris, usually at L1-2, also can be seen. In the thoracic and cervical levels, the spinal cord can be seen as a “negative” shadow within the dense contrast, and its size and shape can therefore be evaluated (Figure 13-4 B). Cervical spinal nerves are also well seen (Figure 13-4 B). The presence of any lesions and their precise location relative to the dura usually can be determined on the basis of the myelographic appearance. For instance, lesions may be extradural, intradural but extramedullary (not in the spinal cord), or intramedullary (within the spinal cord).

**Computed Tomography**

CT utilizes x-rays to obtain images by means of multiple sources and detectors surrounding the patient in a radial fashion. This is why the patient appears to be entering a large doughnut-shaped device during the CT examination. The
data obtained are processed by a computer, which then generates an image. Nowadays, with multidetector CT, image reconstruction in coronal, sagittal, and oblique planes in addition to the source axial images allows for improved spatial resolution. Once the raw data are obtained, images can be displayed with different “windows” and “level” values that take advantage of density (“attenuation” in CT terminology) differences between tissues. For instance, filming a set of soft-tissue windows allows differentiation of soft-tissue structures that are very similar in attenuation to adjacent structures (eg, muscle and fluid). This is one of the key features of CT, whereas plain films usually cannot distinguish between the different soft tissues as well. In the spine, CT makes it possible to discriminate between CSF, nerve roots, and ligaments, for instance. Therefore, a CT examination can demonstrate the ligamentum flavum, nerve roots, epidural fat, and other structures that cannot be identified discretely on plain films (Figure 13-5 A). Additionally, images can be obtained with a bone algorithm, whose window and level gives detailed information about bony structures (Figure 13-5 B), although on such images, little soft-tissue information is available.

CT is widely used to image the spine in the evaluation of many pathologic conditions. Most common indications include trauma, spine tumors, and degenerative disk disease (ie, to rule out disk herniation in patients with myelopathy or radiculopathy). Assuming a normal appearance on plain films, CT is often the first study ordered in the evaluation of patients with back pain.

CT Myelography

As mentioned earlier, in patients who have undergone myelography, CT is often obtained immediately afterwards (Figure 13-6). It has been shown that a postmyelogram CT is more sensitive in the detection of pathologic conditions than is either test alone. This is particularly true for lesions within the spinal canal, such as disk herniations or tumors unassociated with a bony component. The presence of subarachnoid contrast allows dramatic visualization of the cauda equina nerve roots and spinal cord in a way that cannot be achieved with regular CT.

MR Imaging

Since the early 1980s, MR imaging has gained widespread acceptance as the most sensitive imaging modality in the study of spine disease. MR imaging undeniably allows visualization of intraspinal anatomy with much higher contrast...
The ability to image directly in the sagittal and coronal planes contributes a great deal to the evaluation of the diseased spine. A description of the physics of MR imaging is beyond the scope of this chapter, and the reader is referred elsewhere for this information. Because dense cortical bone has few mobile protons (which are necessary to create an MR signal), MR imaging is sometimes limited in its ability to demonstrate either osteophytes that may be a source of clinical symptoms or calcific components of other lesions. In such cases, CT with its superb depiction of bony detail may be useful as an adjunct examination. On the other hand, MR imaging is very sensitive in its ability to detect abnormalities in bone marrow. The vertebral bodies normally contain a large amount of bone marrow, and an abnormal appearance may be seen in a variety of disorders, such as anemia, infection, and metastatic disease.

MR images can be obtained with a variety of “sequences.” The most commonly utilized are called “spin-echo,” and these can be “weighted” for either T1 or T2. (A thorough explanation of these parameters can be found elsewhere). On a T1-weighted image, normal adult (yellow/fatty) bone marrow has a “high signal” (i.e., it is hyperintense, whitish in color), and CSF has a “low signal” (i.e., it is hypointense, or black in color). Neural tissue, such as the spinal cord or nerve roots, is intermediate in signal intensity (Figure 13-7 A). Cortical bone, lacking mobile protons to produce a signal, is hypointense on all pulse sequences. On T2-weighted images, marrow becomes lower in signal intensity, CSF becomes hyperintense, and neural tissue maintains an intermediate signal intensity. However, the spinal cord appears relatively lower in signal intensity, surrounded as it is by CSF that is hyperintense (Figure 13-7 B). The intervertebral disks in normal individuals are typically of intermediate signal on T1-weighted images and, because of their water content, appear hyperintense on T2-weighted images. Any alterations in the expected normal signal intensity for an anatomic structure should prompt a search for either a technical or a pathologic explanation for the abnormal signal. Postcontrast imaging, scanning after administration of intravenous gadolinium (gadopentetate dimeglumine) or other paramagnetic contrast agents, adds valuable information to either clarify questions raised by the precontrast imaging results or permit detection of lesions that were invisible without contrast. In recent years, the use of fat suppression has increased the utility of contrast-enhanced imaging of the spine, particularly in the evaluation of lesions within the spinal canal (Figure 13-8) and bone.
A great many clinical circumstances may necessitate spine imaging. The purpose of this section is to convey a sense of which techniques would be most appropriate for the given clinical setting. In some instances, the choice is clear. In others, the test to be performed is determined by the technology available, and often the decision is influenced by the preferences of the person ordering the test. In some clinical settings, more than one imaging modality is acceptable as a first test. If the clinician consults with the radiologist before deciding on the initial test, unnecessary examinations may be avoided. Perhaps most importantly, however, if the clinician consults with the radiologist and conveys to him or her the clinical information, imaging often can be tailored to hone in on the most likely site or type of abnormality.

**Figure 13-7.** Normal MR images. (A) T1-weighted sagittal, cervicothoracic spine. The spinal cord is very easily seen. Note that the CSF anterior and posterior to the cord is hypointense, or low signal intensity. The high signal arising from the vertebral body bone marrow (arrows) is due to the fat content. The disk spaces are readily visualized and are of lower signal intensity (arrowheads). This is the normal relative appearance of bone marrow and disk on T1-weighted images. Any reversal (ie, disk is brighter or higher in signal intensity than marrow) should raise the suspicion of marrow disease. (B) T2-weighted sagittal cervical spine. CSF is now very hyperintense, and the spinal cord appears to have relatively low signal intensity. The disks (arrowheads), because of their water content (when normal), appear higher in signal intensity when compared with the T1-weighted image. The bone marrow, on the other hand, is lower in signal intensity (fat fades on T2).
Still, general guidelines can be established to help decide which imaging test is appropriate. What follows is a brief outline providing general imaging recommendations for common clinical problems related to the spine. Only rarely is a particular test the only useful one for a suspected abnormality. In many cases, any of the modalities would be useful as a baseline examination, with the understanding that additional imaging might be required to answer all clinical questions.

## Trauma

Plain films still are used as an initial examination for the evaluation of spine trauma in stable and alert patients. This is followed by CT scan, especially if other parts of the body are being assessed, the patient has altered consciousness, or the clinical examination is positive or equivocal. In the characterization of complex fractures, for conditions in which plain films were inadequate (eg, the cervical thoracic junction), or when additional information is required (eg, to rule out canal compromise by a bone fragment), CT is the best imaging study. In certain circumstances, such as suspected spinal cord injury (contusion or transaction), hemorrhage within the spinal canal, or ligamentous injury, MR imaging is indicated. It is also useful in evaluating the patient with delayed onset of neurological dysfunction after trauma to rule out myelomalacia (softening) of the spinal cord or posttraumatic syrinx.

## Back Pain

Back pain is one of the most common medical complaints. Though most cases are caused by muscle strains, new or persistent severe pain, sciatica (a shooting pain down the leg), or neurologic deficits such as weakness, decreased sensation, or abnormal reflexes should prompt a search for an underlying structural abnormality. The most common pathologic conditions are related to bony degenerative disease (osteoarthritis) or intervertebral disk abnormalities. Though disk herniations (protrusion or extrusion of the nucleus pulposus beyond the annulus fibrosus) are not visible on plain films, degenerative changes are generally quite apparent, and any unsuspected lesions such as compression fractures or metastatic disease (both of which are common in older patients) may be detected. For patients with a suspected herniated disk, MR imaging is the most sensitive examination. CT when combined with intrathecal contrast (CT myelography) is still a good examination for the detection of disk herniation, and it can be useful in patients who are unable to obtain an MRI. MRI is most sensitive for detecting disk herniation and is especially useful for the identification of other pathologic conditions that might mimic disk herniation, such as lesions of the conus medullaris or metastatic disease. A possible exception to the use of MR imaging as a first-line cross-sectional imaging procedure in degenerative spine disease is for patients suspected of having foraminal nerve impingement by an osteophyte. Osteophytes are small, sharp projections of bone that occur in patients with osteoarthritis, and they may impinge on the spinal cord or nerve roots. Such osteophytes in the cervical spine may be difficult to characterize with MR imaging unless special sequences are employed. However, it is not always possible to differentiate clinically between patients who have disk herniations and those whose nerves are compressed by osteophytes, and MR imaging is the best test to order for these patients.

## Myelopathy

In patients who are suspected of having a myelopathy (a true cord syndrome as opposed to radicular symptoms),...
MR imaging is unequivocally the first study to be performed. MR imaging is the only imaging procedure that allows direct visualization of the spinal cord, and it is effective for diagnosing or excluding primary spinal cord lesions such as infarct, tumor, hemorrhage, or inflammatory conditions (eg, multiple sclerosis, idiopathic transverse myelitis, or sarcoidosis).

**Congenital Spine Lesions**

A variety of congenital lesions may affect the spine. Plain films may be useful to initially survey the spine, but ultimately MR imaging is the modality of choice. Multidetector CT with multiplanar reconstruction abilities is gaining usefulness in evaluation of bone lesions and defects.

**Metastatic Disease**

If metastatic disease in the spine is suspected, plain films are an economical way to carry out a preliminary evaluation for bony lesions. However, plain films do not demonstrate such abnormalities until a significant amount of destruction has taken place. MR imaging, on the other hand, is quite sensitive to replacement of normal bone marrow by tumor and can establish the diagnosis much earlier. Addition of gadolinium-enhanced MR imaging improves detection of bone lesions and of intraspinal spread of tumor to the subarachnoid space (carcinomatous meningitis or leptomeningeal carcinomatosis), if this is suspected clinically.

**EXERCISE 13-1. DEGENERATIVE SPINE DISEASE**

13-1. What is the abnormality in Case 13-1 (Figure 13-9)?
   A. The bones are too dense.
   B. The bones are not dense enough (osteopenia).
   C. There is a destructive bony lesion.
   D. There is an abnormality of alignment.
   E. There is a soft-tissue abnormality.

13-2. In Case 13-2, the lesion represented by an arrow in Figure 13-10 is most likely to be
   A. a right-sided L4-5 herniated nucleus pulposus.
   B. an extradural tumor.
   C. an epidural abscess.
   D. an intradural mass.
   E. a bony lesion.

13-3. In Case 13-3, the lateral cervical spine plain film in Figure 13-11 suggests that the most likely diagnosis is
   A. degenerative disk disease at C2-3 and C3-4.
   B. neoplastic disease at C4.
   C. degenerative disk disease at C5-6 and C6-7.
   D. traumatic injury.
   E. disk space infection at C5-6 and C6-7.
Radiologic Findings

13-1. In this case, there is subtle anterior displacement of the L5 vertebral body relative to S1, known as spondylolisthesis (D is the correct answer to Question 13-1).

13-2. In this case, an extradural defect is seen at and below the L4-5 disk space, and the right L5 nerve root does not fill. These changes are most likely caused by a disk herniation (A is the correct answer to Question 13-2). Note the normal filling of the right L4 nerve root (arrowheads).

13-3. In this case, there is disk space narrowing, and osteophytes are seen at the C5-6 and C6-7 disk spaces (C is the correct answer to Question 13-3).

Discussion

Degenerative osteoarthropathy may affect different parts of the spine. When the facet joints are involved, the result is often bony osteophytes, which may project into the neural foramen or spinal canal and compress neural structures. When the disk space is affected, bony changes in the vertebral body endplate can occur. In addition, the intervertebral disk itself may be affected, and disk herniation can occur as a result. Differentiation between disk bulge (generalized extension of the disk, less than 3 mm beyond the edges of the apophyses, with no significant compression of cord or thecal sac) and herniation (protrusion or extrusion, with possible compression of nerves or thecal sac) is not always possible. Treatment decisions must be based on clinical as well as radiologic data.

In Case 13-1 (author’s spine), the spondylolisthesis of L5 over S1 is a result of a defect in the pars interarticularis. This is the junction of the superior and inferior articular facet of a given vertebra (Figures 13-3 C and 13-12 A). Spondylolysis, as this defect is known, is usually caused by a chronic stress fracture, though rarely it can be congenital or acute. If, as is commonly the case, the spondylolysis is bilateral, the vertebral body is essentially disconnected from the posterior elements, and this allows the anterior slipping, or spondylolisthesis, shown in Figure 13-9. This entity is included here because it is quite common and predisposes to premature degenerative disease. In older patients, spondylolisthesis can be secondary to degenerative disease in the absence of a pars defect, and this “nonlytic” form is known as pseudospondylolisthesis or degenerative spondylolisthesis. When present, the spondylolysis defect is readily identified on oblique lumbar plain films, as a “broken neck on the Scottie dog” (Figure 13-12 B). The lysis defect is also readily detected on CT (Figure 13-12 C), although it may superficially resemble a facet joint.

Disk herniations are a common medical problem. Though they can usually be diagnosed with noninvasive CT or MR imaging, myelography is still employed in some places to diagnose disk herniations. In Case 13-2, Figure 13-10 shows an extradural defect, seen as an area of low density distorting the lateral aspect of the thecal sac, deviating the nerve roots. This is the typical appearance of a herniated nucleus pulposus (HNP) on myelography. We see the effect of the herniated disk rather than visualizing the actual disk abnormality. On a CT study, the herniated disk can also be visualized (Figure 13-13 A). Most of the myelographic filling defect can be seen to be below the L4-5 disk space, secondary to inferior migration of disk material. This helps explain why the patient had an L5 radiculopathy. The right L4 nerve root (arrowheads in Figure 13-10) had already exited and would be unaffected by an L4-5 HNP unless it was far lateral (Figure 13-13 B). As previously mentioned, MR imaging is excellent in detecting disk herniations (Figures 13-13 B, C) and eliminates the need for painful, invasive procedures such as myelography.

Osteophytic ridging is a common manifestation of degenerative bone disease and in the cervical spine may cause myelopathy (if the cord is compressed) or radiculopathy (if a nerve root is compressed). In Case 13-3, Figure 13-11 shows marked narrowing and osteophyte formation at C5-6 and C6-7. An oblique

Figure 13-11. Case 13-3. Plain film of the cervical spine (lateral view) of a 53-year-old woman who presents with neck and right arm pain.
Defect in pars interarticularis L5 S1

Figure 13-12. (A) Diagram of spondylolisthesis of L5 over S1 caused by spondylolysis of L5. (B) Oblique plain film of lumbar spine (same patient as in Figure 13-9) demonstrates a spondylolysis or pars defect on the right side at L5 (arrows). Note the intact pars at L4 (∗). (C) CT bone window of a different patient shows spondylolysis defects (arrows). Though these resemble facet joints, they are more horizontal in orientation and more irregular, lacking a smooth cortical margin.

Radiograph is useful in identifying the foraminal compromise that can result if osteophytes occur in that location (Figure 13-14 A). Myelography can demonstrate effacement of nerve roots (Figure 13-14 B). CT, with or without intrathecal contrast material, is excellent in depicting foraminal stenosis caused by osteophytes (Figure 13-14 C). MR imaging may be limited in its ability to depict subtle bony abnormalities, although utilization of newer high-resolution sequences have resulted in improved detection of foraminal stenosis.

Exercise 13-2. Neoplastic Spine Disease

13-4. In Case 13-4, what does this the AP view from a thoracic myelogram in Figure 13-15 show?

A. A bony abnormality
B. An extradural mass
C. An intradural-extradural mass
D. An intramedullary mass
E. A really big disk herniation
**Figure 13-13.** (A) Axial CT (same patient as in Figure 13-10) just below the L4–5 disk space shows compression of the right anterolateral aspect of the thecal sac by the HNP (arrow). The image was obtained below the L4–5 disk space, indicating inferior migration of herniated disk material. (B) Axial T1-weighted MR image of a different patient shows a far lateral right-sided HNP (arrows) with replacement of normal foraminal fat by intermediate signal representing the disk. Note normal perineural fat (arrowheads) in the left neural foramen. A far lateral HNP such as this would probably be missed if only myelography were performed. (C) Sagittal T2-weighted image shows a midline disk herniation at C5–6 that is compressing the spinal cord (arrowheads).

13-5. In Case 13-5, what is the most likely diagnosis (Figure 13-16)?
A. Sacroiliitis  
B. A sacral tumor  
C. Constipation  
D. Osteoporosis  
E. Uterine malignancy

13-6. In Case 13-6, on the lateral cervical spine radiograph in Figure 13-17, what is the main radiologic finding?
A. A lesion of the C7 spinous process  
B. An osteoblastic bony lesion  
C. An abnormality of alignment  
D. A destructive lesion at C2  
E. A fracture
In Case 13-7, Figure 13-18, what diagnostic possibilities should be most seriously considered?

A. Congenital or traumatic lesions
B. Metabolic or endocrine disease
C. Myeloma or metastatic disease
D. Infectious or inflammatory disease
E. Degenerative or inflammatory disease

**Radiologic Findings**

13-4. In this case, the patient has a lower thoracic primary spinal cord astrocytoma (D is the correct answer to Question 13-4). The cord is normal inferiorly but is seen to get wider toward the middle of the image. The contrast column on either side of the lesion is narrowed, most noticeably on the patient's right. This lesion has caused a “block” to the flow of contrast. Subsequent postmyelography CT (Figure 13-19 A) confirmed the spinal cord enlargement. An MR image demonstrated the tumor (Figure 13-19 B) within the spinal cord.
Case 13-5. A 70-year-old woman presents with a 5-year history of back pain and recent onset of paresthesia in the groin and inner thighs (saddle distribution).

Case 13-6. A 63-year-old man presents with severe upper neck pain not responding to anti-inflammatory medication.

In this case, the plain film shows a large destructive mass replacing most of the lower sacrum (B is the correct answer to Question 13-5). Notice how normal bone disappears below the midsacrum. A CT showed a large destructive mass with areas of calcification (Figure 13-20).

Case 13-6. A 63-year-old man presents with severe upper neck pain not responding to anti-inflammatory medication.
In this case, the plain film shows that the body of C2 has been destroyed (lytic destruction) (D is the correct answer to Question 13-6).

In this case, the CT image shows multiple small areas of lytic bony destruction. This is characteristic of either multiple myeloma or metastatic disease (C is the correct answer to Question 13-7).

**Discussion**

Primary tumors of the spine can arise from the bone or the neural elements. In Case 13-4, the diagnosis was primary spinal cord glioma. The two most common spinal cord tumors are astrocytomas and ependymomas. As with this patient, the diagnosis may be elusive for some time while other diseases such as disk herniation are ruled out. This patient even had a normal lumbar MR examination several months prior to the myelogram. Although the thoracolumbar junction is usually visualized on a lumbar MR imaging study, this tumor (at T10) was just missed. A thoracic MR examination would certainly have made the diagnosis, but the patient’s doctor ordered a myelogram. Spinal cord tumors are generally very difficult to treat. The more malignant ones, usually astrocytomas, are associated with a poor prognosis. Ependymomas, because they are less infiltrative and more readily resectable, are associated with a much better prognosis.

Primary bone tumors can be benign or malignant. In the sacrum, giant-cell tumor is the most common benign tumor. The most common primary sacral malignancy is chordoma. This is the diagnosis in Case 13-5. Chordomas develop from remnants of the embryonic notochord and represent 2% to 4% of primary malignant bone tumors. The sacrum is the most common site for chordoma, accounting for 50% of these lesions. The skull base accounts for 35% and other vertebrae

**Figure 13-18.** Case 13-7. A CT bone window in a 65-year-old man who presents with back pain.

**Figure 13-19.** (A) Axial postmyelographic CT demonstrates enlargement of the spinal cord (asterisk), representing tumor, with narrowing of the subarachnoid/contrast space surrounding the cord. (B) Sagittal T2-weighted MR image shows the tumor and resulting enlargement of the thoracic spinal cord, with areas of central hyperintense signal (arrows) probably representing necrosis.
Virtually any tumor may metastasize to the spine. In general, certain tumors tend to result in osteoblastic or dense metastases, and prostate adenocarcinoma falls in this category. Other primary malignancies, such as those in the lung and breast, tend to have osteolytic, destructive spine metastases. The patient in Case 13-6 had lung carcinoma, and Figure 13-17 represents a hematogenous spread of tumor to the C2 vertebral body. Metastatic disease may affect the spine by other mechanisms. Tumors adjacent to the spine may grow directly into it (Figures 13-21 A, B). This may occur in lung carcinoma and lesions such as neuroblastoma or lymphoma (with retroperitoneal/paraspinal lymphadenopathy). Finally, the spinal canal may be affected by spread of malignant neoplasm. Rarely, a metastatic lesion may occur in the spinal cord itself, usually as a terminal event. Metastatic disease may occur in the subarachnoid space by two methods. First, an intracranial malignancy (ie, glioma, medulloblastoma) can seed the subarachnoid space. These are known as “drop” metastases. Hematogenous spread to the subarachnoid space may occur in non-CNS primary tumors. Such involvement is known as leptomeningeal carcinomatosis or carcinomatous meningitis (see Figure 13-8) and is associated with a very poor prognosis.

Multiple myeloma is a disseminated malignancy caused by a proliferation of plasmacytes, typically occurring in the middle-aged and elderly, with a slight male predominance. The
spine may be affected primarily or secondarily, and bone pain caused by pathologic compression fracture is the most common symptom. Plain films may be normal early in the course of the disease or show only mild osteopenia. Later, multiple, small, lytic, “punched out” lesions may be seen. CT is very sensitive, and Figure 13-18 shows the typical CT appearance of multiple myeloma. The findings, however, would be indistinguishable from those of small lytic metastases of other origin, and for this reason, metastases and myeloma are often mentioned together in the context of multiple small lytic bony lesions. MR imaging of multiple myeloma may have different appearances, but the typical pattern would be multiple, small foci of decreased signal intensity replacing the normal hyperintense bone marrow on T1-weighted images (Figure 13-22).

**EXERCISE 13-3. SPINE TRAUMA**

13-8. What is the most likely diagnosis in Case 13-8 (Figure 13-23)?
A. Spinal tumor, aggravated by trauma
B. Abnormality of bone density
C. Disruption of facet joints at multiple levels
D. Subluxation of L4 over L5
E. L2 compression fracture with kyphotic angulation

**Figure 13-22.** Sagittal T1-weighted MR image of the thoracic spine shows multiple small hypointense foci of myeloma (arrows) replacing normal bone marrow. Compression fractures are also seen, indicated by loss of height of several upper thoracic vertebral bodies. The spinal cord is intact, but spread of tumor or retropulsion of fractured bone could result in cord compression. Note that metastatic tumor other than myeloma could have an identical appearance.

**Figure 13-23.** Case 13-8. A 23-year-old woman was involved in a motor vehicle accident.
13-9. Regarding the patient in Case 13-9 shown in Figure 13-24, which of the following is true?
   A. The condition probably predated the trauma.
   B. The prospects for a full recovery are good.
   C. Surgical repair will likely be successful.
   D. The patient will probably never have normal neurologic function below C6.
   E. The spinal cord is intact.

13-10. In Case 13-10, the MRI in Figure 13-25 most likely demonstrates
   A. delayed posttraumatic syrinx.
   B. subluxation.
   C. spinal cord tumor.
   D. abnormal bone marrow.
   E. disk abnormality.

▲ Figure 13-24. Case 13-9. A 21-year-old quadriplegic woman had a motor vehicle accident 4 weeks ago.

▲ Figure 13-25. (A,B) Case 13-10. A 38-year-old woman presents slowly with progressive upper extremity and upper trunk sensory deficits 3 years after a motor vehicle accident.
Radiologic Findings

13-8. In this case, there is a compression fracture of the L2 vertebral body with kyphotic angulation (E is the correct answer to Question 13-8).

13-9. In this case, the sagittal T1-weighted MR image shows a complete subluxation of C6 on C7 and a complete transection of the cervical spinal cord at that level. In all likelihood this patient will never regain use of her legs or have any normal neurologic function below C6 (D is the correct answer to Question 13-9).

13-10. In this case, the sagittal T2-weighted MR image shows a high signal abnormality (arrow) within the upper thoracic spinal cord, and on the axial T2-weighted image, an epicenter in the central canal region is confirmed. This is a typical appearance of syringomyelia or syrinx (A is the correct answer to Question 13-10).

Discussion

Spinal trauma is a major medical problem, usually caused by motor vehicle and occupational accidents. Accurate and complete diagnosis is essential to maintain spine stability and ensure preservation of neurologic function. As mentioned previously, plain films are commonly obtained initially. However, additional imaging tests are often necessary to fully evaluate a case of spine trauma, especially in high-risk injury cases, patients with clinical signs and symptoms, or those with altered cognition. In Case 13-8, there was clinical concern that the spinal canal was compromised. Small bony fragments within the spinal canal may not be visible with plain film alone. For this reason, CT was performed (Figures 13-26 A, B). This allowed a better appreciation of the extent of the fractures and ruled out neural compression. An example of spinal canal compromise is shown in Figure 13-26 C.

Figure 13-26. (A) Axial CT bone window shows different components of the fracture (arrows). The spinal canal was intact. Note the separation of the facet joint on the right (arrowhead). (B) Three-dimensional reconstruction shows compression of L2 and fracture sites. Such reconstructions are sometimes useful in cases of spine trauma. (C) Axial CT bone window of a different patient demonstrates multiple fractures and retropulsion of a bone fragment, causing narrowing of the spinal canal (arrows).
In severe trauma, the spinal cord may be affected. Contusions may occur with or without fracture/subluxation, and MR imaging would be required for diagnosis. In a severe fracture/subluxation, the spinal cord can be completely transected. In Case 13-9, the patient was known to have a severe C6-7 subluxation, but because of obesity, plain film and CT imaging were very limited. In this case, only MR imaging was able to demonstrate the full extent of her spinal cord injury.

Rarely, patients who have recovered from an acute spinal injury experience a delayed onset of neurologic symptoms, occurring 1 to 15 years after the trauma. This suggests the possibility of delayed posttraumatic syrinx (Case 13-10). Symptoms include pain on coughing or exertion, sensory disturbances, or motor deficits. MR imaging is essential for diagnosis. The condition is sometimes amenable to surgical shunting. Syringomyelia can also be idiopathic or can be secondary to certain congenital or inflammatory conditions. Imaging often cannot distinguish among different possible etiologies, and history is important.

**EXERCISE 13-4. SPINE INFECTION AND INFLAMMATION**

13-11. What is the most likely diagnosis in Case 13-11 (Figure 13-27)?
A. Spine metastases  
B. Posttraumatic changes  
C. Discitis and osteomyelitis  
D. Epidural abscess  
E. Degenerative changes

13-12. Regarding Case 13-12, what is the main abnormality visualized in Figure 13-28?
A. None  
B. Artifact  
C. Subarachnoid lesion  
D. Intramedullary lesion  
E. Syrinx

![Figure 13-27.](A.B) Case 13-11. A 44-year-old male with history of intravenous drug use presents to the emergency department with neck pain.
Radiologic Findings

13-11. In this case, there is discitis and osteomyelitis (C is the correct answer to Question 13-11). Enhancement is identified within the C3-4 and C4-5 intervertebral disks with involvement of the adjacent vertebral bodies on the sagittal T1-weighted postcontrast images (Figure 13-27 A) and an increase in the T2 hyperintensity in Figure 13-27 B. Additionally, enhancement, T2 hyperintensity, and increased thickness within the prevertebral soft tissues from C2-C5 levels (arrowhead) is present. There is linear epidural enhancement seen at the C5 level (arrow).

13-12. In this case, the sagittal T2-weighted image demonstrates an intramedullary T2 hyperintense lesion at the C6 level that on the axial image is localized to the left posterior cord (D is the correct answer to Question 13-12).

Discussion

Spine infections include vertebral osteomyelitis and discitis, which occur most commonly as a result of hematogenous spread. Penetrating trauma, contiguous spread from adjacent infection, or iatrogenic causes are additional routes of dissemination. The presenting feature is usually pain. A majority of the lesions occur in the lumbar spine, followed by the thoracic spine, with peak incidences between 60 and 80 years of age. *Staphylococcus aureus* is the most common organism in adults. Epidural abscess can result as a complication of osteomyelitis and is commonly associated with diabetics, patients with chronic renal failure, alcoholics, and intravenous drug users. Ventral location of the epidural abscess is usually seen in cases secondary to osteomyelitis. MR imaging has a specificity, sensitivity, and accuracy of 92%, 96%, and 94%, respectively, for detection of vertebral osteomyelitis. Imaging characteristics include increase in T1 hypointensity and T2 hyperintensity, and increased thickness within the prevertebral soft tissues from C2-C5 levels (arrowhead) is present. There is linear epidural enhancement seen at the C5 level (arrow).

Inflammatory diseases of the spinal cord can result from both infectious and noninfectious causes. The noninfective etiologies are more common and include disorders such as multiple sclerosis, acute disseminated encephalomyelitis.