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tertiary care settings, multiple strokes are usually due to emboli and not vasculitis, and dementia with myoclonus is usually Alzheimer's disease and not a prion disorder or a paraneoplastic illness. Finally, the most important task of a primary care physician faced with a patient who has a new neurologic complaint is to assess the urgency of referral to a spe cialist. Here, the imperative is to rapidly identify patients likely to have nervous system infections, acute strokes, and spinal cord compression or other treatable mass lesions and arrange for immediate care. ■ ■FURTHER READING Brazis P et al: Localization in Clinical Neurology, 8th ed. Philadelphia, Lippincott William & Wilkins, 2021. Campbell WW, Barohn RJ: DeJong's The Neurological Examination, 8th ed. Philadelphia, Lippincott William & Wilkins, 2019. Feigin VL et al: The global burden of neurological disorders: Translating evidence into policy. Lancet Neurol 19:255, 2020. GBD 2019 Diseases and Injuries Collaborators: Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. Lancet 396:1204, 2020. O'Brien M: Aids to the Examination of the Peripheral Nervous System, 6th ed. Elsevier, Amsterdam, 2023. William P. Dillon

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Neurologic Disorders Numerous noninvasive imaging options are available to clinicians evaluating patients with neurologic disorders. These include computed tomography (CT) and magnetic resonance (MR) imaging (MRI), plus their variations, including CT angiography (CTA); perfusion CT (pCT); dual-energy CT; photon counting CT; MR angiography (MRA); MR vessel wall imaging; functional MRI (fMRI); MR spectroscopy (MRS); MR neurography (MRN); diffusion-weighted MR imaging (DWI); diffusion tensor MR imaging (DTI); susceptibility-weighted MR imaging (SWI); arterial spin label imaging (ASL); and perfusion MRI (pMRI). Furthermore, a number of interventional neuroradio logic techniques have matured including catheter embolization, stent retrieval thrombectomy, aneurysm coiling and stenting, as well as numerous techniques for spine disorders including CT and fluoro scopic myelography and CT-guided spine procedures for diagnosing and treating pain and oncology, including dynamic CT myelography, radiofrequency and cold ablation techniques, image-guided blood and fibrin glue patches and transvenous embolization of cerebrospinal fluid (CSF) venous fistulae. Multidetector CTA (MDCTA) and gadoliniumenhanced MRA techniques have reduced the need for catheter-based angiography, which is now reserved for patients in whom small-vessel detail is essential for diagnosis or for whom concurrent interventional therapy is planned (Table 434-1). In general, MRI is more sensitive than CT for the detection of lesions affecting the peripheral and central nervous system (CNS). Diffusion MR, a sequence sensitive to the microscopic motion of water, is the most sensitive technique for detecting acute ischemic stroke of the brain or spinal cord and is also useful in the detection and characterization of encephalitis, abscess, Creutzfeldt-Jacob disease, cerebral tumors, and acute demyelinating lesions. CT, however, is acquired more quickly, making it a pragmatic choice for uncooperative patients, or those with suspected acute stroke, hemorrhage, and acute intracranial or spinal trauma. CT is also more sensitive than MRI for visualizing fine osseous detail and thus is appropriate for the initial imaging

TABLE 434-1 Guidelines for the Use of CT, Ultrasound, and MRI CONDITION RECOMMENDED TECHNIQUE Hemorrhage Acute parenchymal CT, MR Subacute/chronic MRI Subarachnoid hemorrhage CT, CTA, lumbar puncture → angiography Aneurysm Angiography > CTA, MRA Chronic subarachnoid blood MR with SWI Ischemic infarction Hemorrhagic infarction CT or MRI Bland infarction MRI with diffusion > CT, CTA, angiography Carotid or vertebral dissection MRI/MRA> CTA CHAPTER 434 Vertebral basilar insufficiency CTA, MRI with DWI MRA Carotid stenosis CTA, MRA > US Suspected mass lesion Neoplasm, primary or metastatic MRI ± contrast Infection/abscess MRI ± contrast Neuroimaging in Neurologic Disorders Immunosuppressed with focal findings MRI ± contrast Vascular malformation MRI ± angiography White matter disorders MRI Acute demyelinating disease MRI ± contrast Dementia MRI > CT, contrast if mass Trauma Acute trauma CT Shear injury/chronic hemorrhage MRI + SWI Headache/migraine MRI > CT Seizure First time, no focal neurologic deficits MRI > CT With neurologic deficit, or MRI ± contrast > CT immunocompromised or cancer Partial complex/refractory MRI Cranial neuropathy MRI ± contrast Meningeal disease MRI ± contrast Spine Low-back pain No neurologic deficits MRI or CT after >6 weeks With focal deficits MRI > CT Spinal stenosis MRI or CT Cervical spondylosis MRI, CT, CT myelography Infection MRI ± contrast CT Myelopathy MRI ± contrast Arteriovenous malformation MRI ± contrast angiography Abbreviations: CT, computed tomography; CTA, CT angiography; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging; SWI, susceptibilityweighted imaging. evaluation of conductive hearing loss, and lesions affecting the osseous skull and spine. MR may, however, add important diagnostic information regarding bone marrow infiltrative processes that can be difficult to detect on CT. COMPUTED TOMOGRAPHY ■ ■TECHNIQUE The CT image is a cross-sectional representation of anatomy created by a computer-generated analysis of the attenuation of x-ray beams passed through a section of the body. The x-ray beam, collimated to the desired slice width, rotates around the patient and passes through selected regions in the body. X-rays are variably attenuated by body structures and converted into light photons by ceramic scintillators as part of the detectors aligned 180° from the x-ray tube. These photons

A B FIGURE 434-1 Computed tomography (CT) angiography (CTA) of ruptured anterior cerebral artery aneurysm in a patient presenting with acute headache. A. Noncontrast CT demonstrates subarachnoid and intraventricular hemorrhage and mild obstructive hydrocephalus. B. Axial maximum-intensity projection from CTA demonstrates enlargement of the anterior cerebral artery (arrow). C. Three-dimensional surface reconstruction using a workstation confirms the anterior cerebral aneurysm and demonstrates its orientation and relationship to nearby vessels (arrow). CTA image is produced by 0.5- to 1-mm helical CT scans performed during a rapid bolus infusion of IV contrast medium. PART 13 Neurologic Disorders are then converted into electric signals. A computer calculates a “back projection” image from the 360° x-ray attenuation profile. Greater x-ray attenuation (e.g., as caused by bone) results in areas of high “density” (whiter) on the scan, whereas soft-tissue structures that have poor attenuation of x-rays, such as organs and air-filled cavities, are lower (gray-black) in density. The resolution of an image depends on the radiation dose, the detector size, collimation (slice thickness), the field of view, and the matrix size of the display. A modern CT scanner can obtain sections as thin as 0.5–1 mm with 0.4-mm in-plane resolution at a speed of 0.3 s per rotation; complete studies of the brain are completed in 1–10 s. Multidetector CT (MDCT) is now standard. Single or multiple (from 4 to 320) solid-state ceramic detectors positioned opposite to the x-ray source result in multiple slices per revolution of the beam around the patient. In helical mode, the table moves continuously through the rotating x-ray beam, generating a continuous "helix" of x-ray information that is reformatted into various slice thicknesses and planes. Advantages of MDCT include shorter scan times, reduced patient and organ motion, and the ability to acquire images dynamically during the infusion of intravenous (IV) contrast, the basis of CTA and CT perfusion (Figs. 434-1B and C). CTA is displayed in three dimensions to yield angiogram-like images (Figs. 434-1C, 434-2E and F, and see Fig. 438-3). However, the detectors, while numerous, have inefficiencies based on their physical architecture. New so-called photon-counting CT scanners use different technology for detectors, converting x-ray directly into an electric signal, rather than photon light, resulting in improved resolution, reduced electronic noise and thus dose reduction, improved spectral energy detection that reduces calcium and bone artifact, and improved contrast-to-noise ratio, which permits a reduction in the dose of contrast material required. Photon counting scanners are now able to produce CT images with 0.2 mm resolution often at reduced radiation dose (Fig. 434-3). IV iodinated contrast is used to identify vascular structures and to detect defects in the blood-brain barrier (BBB) that are caused by tumors, infarcts, and infections. In the normal CNS, only vessels and structures lacking a BBB (e.g., the pituitary gland, choroid plexus, and dura) enhance after contrast administration. While helpful in characterizing mass lesions as well as essential for the acquisition of CTA studies, the decision to use contrast material should always be considered carefully as it carries a small risk of allergic reaction and adds additional expense. ■ ■INDICATIONS CT is the primary study of choice in the evaluation of an acute change in mental status, focal neurologic findings, acute trauma to the brain and spine, suspected subarachnoid hemorrhage, and conductive hearing loss (Table 434-1). CT often is complementary to MR in the evaluation of the skull base, orbit, and osseous structures of the spine. In the spine, CT is useful in evaluating patients with osseous spinal stenosis and spondylosis, as well as in patients with failed back surgery; however, MRI is often preferred when neurologic deficits are present. CT is often acquired following intrathecal contrast injection to evaluate for spinal and intracranial CSF fistula, as well as the spinal subarachnoid space (CT myelography) in failed back surgery syndromes. ■ ■COMPLICATIONS CT is safe, fast, and reliable. Radiation exposure depends on the dose used but is normally 2–5 mSv (millisievert) for a routine brain CT study. In comparison, the average American receives about 6.2 mSv per year from all sources of radiation, including 3.1 mSv from naturally occurring sources and a similar amount from man-made sources and applications such as jet plane trips, smoke detectors, and medical imaging. While ionizing radiation can potentially induce damage to DNA, such risks are felt to be minimal at normal background radiation levels, especially at the low-dose levels related to diagnostic imaging. The risk of harm from radiation depends on the amount of dose, the delivery rate, the type of radiation, sensitivity of the tissue exposed, and the gender and age and health of the person exposed. Cancers that might develop from a radiation exposure usually have a latency period of 2–10 years or longer, after exposure. Nevertheless, for all patients, especially children, it is important to use as low a radiation dose as possible for diagnostic imaging purposes. Where feasible, MR or ultrasound is preferred. With the advent of MDCT, CTA, and CT perfusion, the diagnostic benefit must always be weighed against any increased radiation exposure. Advances in postprocessing software now permit acceptable diagnostic CT scans at 30–40% lower radiation doses compared with prior technology. The most frequent CT-related complications are those associated with use of IV contrast agents. Ionic contrast agents have been largely replaced by safer nonionic compounds. Contrast-associated acute kidney injury (CA-AKI) is a general term used to describe a sudden deterioration in renal function that occurs within 48 h following the intravascular administration of iodinated contrast medium. This rare complication appears to be more frequent with intraarterial injections during coronary angiography than with IV administration. CA-AKI from gadolinium-based contrast media probably does not occur or is exceptionally rare. CA-AKI is a correlative diagnosis and may result from hemodynamic changes, renal tubular obstruction and cell damage, or immunologic reactions to contrast agents. Although there is no accepted definition of CA-AKI, the diagnosis of AKI is made according to the Kidney Disease Improving Global Outcomes (KDIGO) criteria if one of the following occurs

B A D E H G FIGURE 434-2 Acute left hemiparesis due to right middle cerebral artery occlusion. A. Axial noncontrast computed tomography (CT) scan demonstrates high density within the right middle cerebral artery (arrow) associated with subtle low density involving the right putamen (arrowheads). B. Mean transit time CT perfusion parametric map indicating prolonged mean transit time involving the right middle cerebral territory (arrows). C. Cerebral blood volume (CBV) map shows reduced CBV involving an area within the defect shown in B, indicating a high likelihood of infarction (arrows). D. Axial maximum-intensity projection from a CT angiography (CTA) study through the circle of Willis demonstrates an abrupt occlusion of the proximal right middle cerebral artery (arrow). E. Sagittal reformation through the right internal carotid artery demonstrates a lowdensity lipid-laden plaque (arrowheads) narrowing the lumen (black arrow). F. Three-dimensional surface-rendered CTA image demonstrates calcification and narrowing of the right internal carotid artery (arrow), consistent with atherosclerotic disease. G. Coronal maximum-intensity projection from magnetic resonance angiography shows right middle cerebral artery (MCA) occlusion (arrow). H. and I. Axial diffusion-weighted image (H) and apparent diffusion-coefficient image (I) document the presence of a right middle cerebral artery infarction.

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PART 13 Neurologic Disorders FIGURE 434-3 Photon-counting CT of the temporal bone. This 0.2-mm-thick image was obtained on a photon-counting CT scanner. It demonstrates an otosclerosis lesion (arrow) at the oval window in a patient with mixed hearing loss. The resolution of this image exceeds that of conventional 64-slice CT scanners (0.625 mm) due to improved detectors (see explanation in chapter). (Courtesy of Ian Mark, MD, and the Mayo Clinic.) within 48 h after a nephrotoxic event (e.g., intravascular iodinated contrast medium exposure):

1. Absolute serum creatinine increase ≥0.3 mg/dL (>26.4 µmol/L)
2. A percentage increase in serum creatinine ≥50% (≥1.5-fold above baseline)
3. Urine output reduced to ≤0.5 mL/kg per h for at least 6 h However, other causes of acute renal failure must be excluded. The prognosis is usually favorable, with serum creatinine

levels returning to baseline within 1–2 weeks. Risk factors for contrast nephropathy are also controversial, but consensus is that the most important risk factor is preexisting severe renal insufficiency. Other proposed risk factors include diabetes mellitus, dehydration, cardiovascular disease, diuretic use, advanced age, hypertension, hyperuricemia, and multiple iodinated contrast medium doses in a short time interval (<24 h), but these have not been rigorously confirmed. Patients with diabetes and those with mild renal failure should be well hydrated prior to the administration of contrast agents; careful consideration should be given to alternative imaging techniques. Estimated glomerular filtration rate (eGFR) is a more reliable indicator of renal function compared to creatinine alone because it considers age and sex in the calculation. In one study, 15% of outpatients with a normal serum creatinine had an eGFR of

≤50 mL/min per 1.73 m2 (normal is ≥90 mL/min per 1.73 m2). The exact eGFR threshold, below which withholding IV contrast should be considered, is also controversial. The risk of contrast nephropathy is minimal in patients with eGFR >30 mL/min per 1.73 m2; however, most of these patients will have only a temporary rise in creatinine. The risk of dialysis after receiving contrast significantly increases in patients with eGFR <30 mL/min per 1.73 m2. Little evidence exists that IV iodinated contrast material is an independent risk factor for acute kidney injury in patients with eGFR ≥30 mL/min per 1.73 m2. The American College of Radiology suggests, if a threshold for risk is used at all, an eGFR of <30 mL/min per 1.73 m2 seems to have the greatest level of evidence. If contrast must be administered to a patient with an eGFR <30 mL/min per 1.73 m2, the patient should be well hydrated. The decision to administer closely spaced contrast-enhanced studies is a clinical one, as there is insufficient data on this topic. High-risk patients should, however, be treated with greater caution than the general

population. Use of other agents such as bicarbonate and acetylcysteine were previously thought to be protective against CA-AKI; however, recent meta-analyses have failed to show protection over normal saline. Patients with renal failure who require contrast administration should not have acute dialysis or continuous renal replacement therapy initiated, or alter their schedule due to the risks, costs, and lack of benefit. Below are suggested guidelines for creatinine testing prior to contrast administration. If a recent serum creatinine (within 60 days in most clinical settings) is not available, creatinine testing should be performed if the patient has any of the following risk factors: • Age >60 years or hypertension (however, this results in a large falsepositive rate for those with eGFR <30 mL/min per 1.73 m2) • Personal history of “kidney disease” as an adult, including kidney surgery, ablation, transplant, or prior dialysis • Diabetes mellitus treated with insulin or other prescribed medications • Metformin or metformin-containing drug combinations • Collagen vascular disease (e.g., systemic lupus erythematosus [SLE], scleroderma, rheumatoid arthritis) Allergy Immediate reactions following IV contrast media occur through several mechanisms. The most severe are related to allergic hypersensitivity (anaphylaxis) and range from mild hives to bronchospasm and death. The pathogenesis of allergic hypersensitivity reactions is thought to include the release of mediators such as histamine, antibody-antigen reactions, and complement activation. Severe allergic reactions occur in ~0.04% of patients receiving nonionic media, sixfold lower than with ionic media. Risk factors include a history of prior contrast reaction (fivefold increased likelihood), food and or drug allergies, and atopy (asthma and hay fever). The predictive value of specific allergies, such as those to shellfish, once thought important, is now recognized to be unreliable. Nonetheless, in patients with a history worrisome for potential allergic reaction, a noncontrast CT or MRI procedure should be considered as an alternative to contrast administration. If iodinated contrast is absolutely required, a nonionic agent should be used in conjunction with pretreatment with glucocorticoids and antihistamines (Table 434-2); however, pretreatment does not guarantee safety. Patients with allergic reactions to iodinated contrast material do not usually react to gadolinium-based MR contrast material, although such reactions can occur. It would be wise to pretreat patients with a prior allergic history to MR contrast administration in a similar fashion. Subacute (>1 h after injection) reactions are frequent and probably related to T cell–mediated immune reactions. These are typically urticarial but can occasionally be more severe. Additives or contaminants, such as calcium-chelating substances or substances eluted from rubber stoppers in bottles or syringes, may be contributory in some allergy-like contrast reactions. Drug provocation and skin testing may be required to determine both the culprit agent involved and a safe alternative. Other side effects of CT contrast include a sensation of warmth throughout the body and a metallic taste during IV administration. Extravasation of contrast media, although rare, can be painful and lead to a compartment syndrome. When this occurs, immediate consultation with plastic surgery is indicated. Patients with significant cardiac disease may be at increased risk for contrast reactions, and in these patients, limits to the volume and osmolality of the contrast media should be considered. Patients who may undergo systemic radioactive iodine therapy for thyroid disease or cancer should not receive iodinated contrast media, if possible, because this will decrease the uptake of the radioisotope into the tumor or thyroid (see the American College of Radiology Manual on Contrast Media, 2023; https://www.acr.org/-/ media/ACR/Files/Clinical-Resources/Contrast_Media.pdf). MAGNETIC RESONANCE IMAGING ■ ■TECHNIQUE MRI is a complex interaction between protons in biologic tissues, a static magnetic field (the magnet), and energy in the form of radiofrequency (Rf) waves of a specific frequency introduced by coils placed next to the body part of interest. Images are made by computerized processing of resonance information received from protons (typically hydrogen)

TABLE 434-2 Guidelines for Premedication of Patients with Prior Contrast Allergy 13 h prior to examination: Prednisone, 50 mg PO or methylprednisolone, 32 mg PO 7 h prior to examination: Prednisone, 50 mg PO or methylprednisolone, 32 mg PO 1 h prior to examination: Prednisone, 50 mg PO Diphenhydramine, 50 mg intravenously, intramuscularly, or by mouth (optional) Immediately prior to examination: Benadryl, 50 mg IV (alternatively, can be given PO 2 h prior to exam) If a patient is unable to take oral medication, 200 mg hydrocortisone IV for each dose of oral prednisone may be used If a patient is allergic to diphenhydramine in a situation where diphenhydramine would otherwise be considered, an alternate antihistamine without cross-reactivity may be considered, or the antihistamine portion of the regimen may be removed Accelerated IV Premedication 1. Methylprednisolone sodium succinate (e.g., Solu-Medrol) 40 mg IV or Hydrocortisone sodium succinate (e.g., Solu-Cortef) 200 mg IV immediately, and then every 4 h until contrast medium administration. plus Diphenhydramine 50 mg IV 1 h before contrast medium administration. This regimen is usually 4–5 h in duration. 2. Dexamethasone sodium sulfate (e.g., Decadron) 7.5 mg IV immediately, and then every 4 h until contrast medium administration plus Diphenhydramine 50 mg IV 1 h before contrast medium administration. This regimen may be useful in patients with an allergy to methylprednisolone and is also usually 4–5 h in duration. 3. Methylprednisolone sodium succinate (e.g., Solu-Medrol) 40 mg IV or hydrocortisone sodium succinate (e.g., Solu-Cortef) 200 mg IV plus Diphenhydramine 50 mg IV, each 1 h before contrast medium administration. This regimen, and all other regimens with a duration <4–5 h, has no evidence of efficacy. It may be considered in emergent situations when there are no alternatives. Note: Premedication regimens <4–5 h in duration (oral or IV) have not been shown to be effective. in the body. Field strength of the magnet is directly related to signalto-noise ratio. While 1.5-Tesla (T) and 3-T magnets are now widely available and have distinct advantages in the brain and musculoskeletal systems, even higher field magnets (7 and 11+ T) and positron emission tomography (PET)-MR machines promise increased resolution and anatomic-functional information on a variety of disorders. Lower field strength magnets (0.55 T and lower) are available, having advantages of smaller size and weight, as well as improvement in signal-to-noise and susceptibility artifacts due to de-noising software and machine learning algorithms. Spatial localization of proton signal is achieved by magnetic gradients surrounding the main magnet, which impart slight changes in magnetic field throughout the imaging volume. Rf pulses transiently excite the energy state of the hydrogen protons in the body. Rf is admin istered at a frequency specific for the proton element (hydrogen) and the field strength of the magnet. The subsequent return to equilibrium energy state (relaxation) of the hydrogen protons results in a release of specific Rf energy (the echo), which is detected by the coils that delivered the Rf pulses. Fourier analysis is used to transform the echo into the information used to form an MR image. The MR image thus consists of a map of the distribution of hydrogen protons, with signal intensity imparted by both density of hydrogen protons and differences in the relaxation times and phase (see below) of hydrogen protons on different molecules. Although clinical MRI currently makes use of the ubiquitous hydrogen proton, sodium and carbon imaging and spectroscopy are also possible, but have yet to be integrated into mainstream practice. T1 and T2 Relaxation Times The rate of return to equilibrium of perturbed protons is called the relaxation rate. The relaxation rate

TABLE 434-3 Some Common Intensities on T1- and T2-Weighted

MRI Sequences SIGNAL INTENSITY IMAGE TR TE CSF FAT BRAIN EDEMA T1W Short Short Low High Low Low T2W Long Long High High Medium High FLAIR (T2) Long Long Low High Medium High Abbreviations: CSF, cerebrospinal fluid; FLAIR, fluid-attenuated inversion recovery; TE, interval between radiofrequency pulse and signal reception; TR, interval between radiofrequency pulses; T1W and T2W, T1- and T2-weighted. varies among normal and pathologic tissues. The relaxation rate of a hydrogen proton in a tissue is influenced by local interactions with surrounding molecules and atomic neighbors. Two relaxation rates, T1 and T2, influence the signal intensity of the image. The T1 relaxation time is the time, measured in milliseconds, for 63% of the hydrogen protons to return to their normal equilibrium state, whereas the T2 relaxation is the time for 63% of the protons to become dephased owing to interactions among nearby protons. The intensity and image contrast of the signal within various tissues can be modulated by altering acquisition parameters such as the interval between Rf pulses (TR) and the time between the Rf pulse and the signal reception (TE). T1-weighted (T1W) images are produced by keeping the TR and TE relatively short, whereas using longer TR and TE times pro duces T2-weighted (T2W) images. Fat and subacute hemorrhage have relatively shorter T1 relaxation rates and thus higher signal intensity than brain on T1W images. Structures containing more water, such as CSF and edema, have long T1 and T2 relaxation rates, resulting in relatively lower signal intensity on T1W images and higher signal intensity on T2W images (Table 434-3). Gray matter contains 10–15% more water than white matter, which accounts for much of the intrin sic contrast between the two on MRI (Fig. 434-5A). T2W images are more sensitive than T1W images to edema, demyelination, infarction, and chronic hemorrhage, whereas T1W imaging is more sensitive to subacute hemorrhage and fat-containing structures. CHAPTER 434 Neuroimaging in Neurologic Disorders Many different MR pulse sequences exist, and each can be obtained with two-dimensional or three-dimensional techniques and in vari ous planes (Figs. 434-2, 434-4, and 434-5). The selection of a proper protocol that will best answer a clinical question depends on an accurate clinical history and indication for the examination. Fluid-attenuated inversion recovery (FLAIR) is a very useful pulse sequence in which the normally high signal intensity of CSF on T2W images is suppressed, improving the conspicuity of edematous lesions (Fig. 434-5B). FLAIR images are more sensitive than standard spin echo images for water-containing lesions or edema, especially those close to CSF-filled cisterns and sulci. Diffusion-weighted imaging is also routinely obtained in most brain protocols. This sequence inter rogates the microscopic motion of water, which is reduced in areas of infarction, abscess, and some tumors. Susceptibility-weighted imaging (SWI) is a gradient echo sequence that is very sensitive to alterations in local magnetic field generated by blood, calcium, and air. SWI is routinely obtained to detect microhemorrhages, such as is typical of amyloid angiopathy, hypertension, hemorrhagic metastases, traumatic brain injury, and thrombotic states (Fig. 434-6C). MR images can be generated in any plane without changing the patient’s position. Each sequence, however, is currently obtained separately and takes 1–10 min on average to complete. Three-dimensional volumetric imaging is rou tine, resulting in a volume of data that can be reformatted in any orien tation to highlight certain disease processes. Perfusion techniques such as arterial spin labeling also provide quantitative imaging information regarding cerebral blood flow, and fat-suppressed imaging obtained with T1W and T2W imaging is useful for detection of fat-containing structures as well as improving contrast with other structures such as nerves in the case of peripheral nerve imaging, skull base imaging, and spinal cord imaging. MR Contrast Material The heavy-metal element gadolinium forms the basis of all currently approved IV MR contrast agents.

A PART 13 Neurologic Disorders B FIGURE 434-4 Cerebral abscess in a patient with fever and a right hemiparesis. A. Coronal postcontrast T1-weighted image demonstrates a ring-enhancing mass in the left frontal lobe. B. Axial diffusion-weighted image demonstrates restricted diffusion (high signal intensity) within the lesion, which in this setting is highly suggestive of cerebral abscess. Gadolinium reduces the T1 and T2 relaxation times of nearby water protons in the presence of a magnetic field, resulting in a contrast enhancement on T1W images and a low signal on T2W images (the latter require a sufficient local concentration, usually in the form of an IV bolus). Unlike iodinated contrast agents, the effect of MR contrast agents depends on the presence of local hydrogen protons on which it must act to achieve the desired effect. There are multiple gadolinium agents approved in the United States for use with MRI. These dif fer according to the attached chelated moiety, which also affects the strength of chelation of the otherwise toxic gadolinium element. The chelating carrier molecule for gadolinium can be classified by whether it is macrocyclic or has linear geometry and whether it is ionic or non ionic. Macrocyclic ligands (group 2 agents) are considered more stable as the gadolinium ion is “caged” in the cavity of the ligand, and thus the rate of dissociation of gadolinium is slower compared to linear ligands (group 1 agents). Most agents are excreted by the renal system. BRAIN ACCUMULATION OF GADOLINIUM It has been shown that gadolinium can accumulate in certain areas of the brain, primarily the dentate nuclei and globus pallidus, after serial administration of all types of gadolinium-based contrast agents (GBCAs). Autopsy studies have shown all GBCAs can lead to gadolinium deposition in brain; however, most clinical studies have demonstrated that linear GBCAs have more detectable gadolinium deposition than macrocyclic GBCAs. Gadolinium deposition in the brain appears to be dose dependent and occurs in patients with no clinical evidence of kidney or liver disease. To date, there have been no reports to suggest that these deposits are associated with histologic changes that would suggest neurotoxicity, even among agents with the highest rates of deposition. GBCAs can not only deposit in the brain but also in the skin, bone, liver, and other organs. This had importance in patients with renal failure who were exposed to linear gadolinium agents in the past, resulting in a rare but serious illness of the skin and organs secondary to accumulation of toxic gadolinium (nephrogenic systemic sclerosis).

A B C FIGURE 434-5 Herpes simplex encephalitis in a patient presenting with altered mental status and fever. A. and B. Coronal (A) and axial (B) T2-weighted fluidattenuated inversion recovery images demonstrate expansion and high signal intensity involving the right medial temporal lobe and insular cortex (arrows).

C. Coronal diffusion-weighted image demonstrates high signal intensity indicating restricted diffusion involving the right medial temporal lobe and hippocampus (arrows) as well as subtle involvement of the left inferior temporal lobe (arrowhead). This is most consistent with neuronal death and can be seen in acute infarction as well as encephalitis and other inflammatory conditions. The suspected diagnosis of herpes simplex encephalitis was confirmed by cerebrospinal fluid polymerase chain reaction analysis. ALLERGIC HYPERSENSITIVITY Gadolinium-DTPA (diethylenetri aminepentaacetic acid) does not normally cross the intact BBB imme diately but will enhance lesions lacking a BBB (Fig. 434-4A) as well as areas of the brain that normally are devoid of the BBB (pituitary, dura, choroid plexus). However, gadolinium contrast slowly crosses an intact BBB over time and especially in the setting of reduced renal clearance or inflamed meninges. The agents are generally well tolerated; overall adverse events after injection range from 0.07–2.4%. True allergic reactions are rare (0.004–0.7%) but have been reported. Severe lifethreatening reactions are exceedingly rare; in one report, only 55 reac tions out of 20 million doses occurred. However, the adverse reaction rate in patients with a prior history of reaction to gadolinium is eight

A B FIGURE 434-6 Susceptibility-weighted imaging in a patient with familial cavernous malformations. A. Noncontrast computed tomography scan shows one hyperdense lesion in the right hemisphere (arrow). B. T2-weighted fast-spin echo image shows subtle low-intensity lesions (arrows). C. Susceptibility-weighted image shows numerous low-intensity lesions consistent with hemosiderin-laden cavernous malformations (arrow). times higher than normal. Other risk factors include atopy or asthma (3.7%). There is rare cross-reactivity between different classes of con trast media; a prior reaction to gadolinium-based contrast does not predict a future reaction to iodinated contrast medium, or vice versa, more than any other unrelated allergy. Gadolinium contrast material can be administered safely to children as well as adults, although these agents are generally avoided in those aged <6 months. NEPHROTOXICITY Contrast-induced renal failure does not occur with gadolinium agents. A rare complication, nephrogenic systemic fibrosis (NSF), has occurred in patients with severe renal insufficiency who have been exposed to linear (group 1 and 3) gadolinium contrast agents. The onset of NSF has been reported between 5 and 75 days following exposure; histologic features include thickened collagen bundles with surrounding clefts, mucin deposition, and increased numbers of fibrocytes and elastic fibers in skin. In addition to derma tologic symptoms, other manifestations include widespread fibrosis of the skeletal muscle, bone, lungs, pleura, pericardium, myocardium, kidney, muscle, bone, testes, and dura. The American College of Radi ology recommends that a glomerular filtration rate (GFR) assessment be obtained within 6 weeks prior to elective gadolinium-based MR contrast agent administration in patients with:

1. A history of renal disease (including solitary kidney, renal trans plant, renal tumor)
2. Age >60 years
3. History of hypertension
4. History of diabetes
5. History of severe hepatic disease, liver transplantation, or pending liver transplantation; for these patients, it is recommended that the patient's GFR assessment be nearly contemporaneous with the MR examination. The incidence of NSF in patients with severe renal dysfunction (GFR <30 mL/min per 1.73 m2) varies from 0.19 to 4%. Other risk factors for NSF include acute kidney injury, the use of nonmacrocyclic agents, and repeated or high-dose exposure to gadolinium. The American College of Radiology Committee on Drugs and Contrast Media considers the risk of NSF among patients exposed to standard or lower doses of group 2 gadolinium agents (macrocyclic agents) to be sufficiently low or possibly nonexistent such that the assessment of renal function is optional prior to administration. Group 2 agents are strongly preferred in patients at risk for NSF. Renal function, dialysis status, or informed consent are not recommended prior to injection of group 2 agents, but deference is made to local practice preferences. Patients receiving any group 1 (linear) or 3 gadolinium-containing agents should be consid ered at risk of NSF if they are on dialysis (of any form); have severe or end-stage chronic renal disease (eGFR <30 mL/min per 1.73 m2) with out dialysis; have eGFR of 30–40 mL/min per 1.73 m2 without dialysis

CHAPTER 434 C (as the GFR may fluctuate); or have acute renal insufficiency. The use of gadolinium in young children and infants is discouraged due to the unknown risks and their immature renal systems. Neuroimaging in Neurologic Disorders ■ ■COMPLICATIONS AND CONTRAINDICATIONS From the patient's perspective, an MRI examination can be intimidat ing, and a higher level of cooperation is required than with CT. The patient lies on a table that is moved into a long, narrow gap within the magnet. Approximately 5% of the population experiences severe claustrophobia in the MR environment. This can be reduced by mild sedation but remains a problem for some. Movement of the patient during an MR examination may distort all the images in sequence; therefore, uncooperative patients should either be sedated for the MR study or scanned with CT. Generally, children aged <8 years usually require anesthesia monitored sedation to complete the MR examina tion without motion degradation. MRI is considered safe for patients, even at 3- to 7-T field strengths. Serious injuries have been caused, however, by attraction of external ferromagnetic objects into the magnet, which act as missiles if brought too close to the magnet. Likewise, ferromagnetic implants, such as aneurysm clips, may torque within the magnet, causing damage to vessels and even death. Metallic foreign bodies in the eye have moved and caused intraocular hemorrhage; screening for ocular metallic fragments is indicated in those with a history of metal work or ocular metallic foreign bodies. Implanted cardiac pacemakers are generally a contraindication to MRI owing to the risk of induced arrhythmias; however, some newer pacemakers have been shown to be safe, and if necessary, MR may be performed if the pacemaker can be safely turned off during the scan. All health care personnel and patients must be screened and educated thoroughly to prevent such disasters because the magnet is always "on." Table 434-4 lists common contraindications for MRI. MAGNETIC RESONANCE ANGIOGRAPHY On routine spin echo MR sequences, moving protons (e.g., flowing blood, CSF) exhibit complex MR signals that range from high to low signal intensity relative to background stationary tissue. Fast-flowing blood returns no signal (flow void) on routine T1W or T2W spin echo MR images. Slower-flowing blood, as occurs in veins or distal to arte rial stenosis, may appear high in signal. MR angiography makes use of pulse sequences called gradient echo sequences that increase the signal intensity of moving protons in contrast to suppressed low signal back ground intensity of stationary tissue. This results in a stack of images, which can be reformatted in any plane to highlight vascular anatomy and relationships. Several types of MRA techniques exist. Time-of-flight (TOF) MRA is normally done without contrast administration and relies on the sup pression of nonmoving tissue to provide a low-intensity background

TABLE 434-4 Common Contraindications to Magnetic Resonance Imaging Cardiac pacemaker or permanent pacemaker leads Internal defibrillatory device Cochlear prostheses Bone growth stimulators Spinal cord stimulators Electronic infusion devices Intracranial aneurysm clips (some but not all) Ocular implants (some) or ocular metallic foreign body McGee stapedectomy piston prosthesis DuraPhase penile implant Swan-Ganz catheter Magnetic stoma plugs Magnetic dental implants Magnetic sphincters Ferromagnetic inferior vena cava filters, coils, stents—safe 6 weeks after implantation Tattooed eyeliner (contains ferromagnetic material and may irritate eyes) PART 13 Neurologic Disorders Note: See also http://www.mrisafety.com. for the high signal intensity of flowing blood entering the section. A typical TOF MRA sequence results in a series of contiguous, thin MR sections (0.6–0.9 mm thick), which can be viewed as a stack and manipulated to create an angiographic image data set that can be refor matted and viewed in various planes and angles, much like that seen with conventional angiography (Fig. 434-2G). Phase-contrast MRA has a longer acquisition time than TOF MRA, but in addition to providing anatomic information like that of TOF imaging, it can be used to reveal the velocity and direction of blood flow in each vessel. MRA is also often acquired during infusion of IV gadolinium con trast material. Advantages include faster imaging times (1–2 min vs 10 min), fewer flow-related artifacts, and four-dimensional temporal imaging resulting in arterial and venous phases. Recently, contrastenhanced MRA has become the standard for assessment of the extra cranial vascular structures. This technique entails rapid imaging using coronal three-dimensional TOF sequences during a bolus infusion of gadolinium contrast agent. MRA has lower spatial resolution compared with conventional film-based angiography and, therefore, is inherently less sensitive to detection of small-vessel abnormalities, such as vasculitis and distal vasospasm. MRA is also less sensitive to slowly flowing blood and thus may not reliably differentiate complete from near-complete occlusions. Motion, either by the patient or by anatomic structures, may distort the MRA images, creating artifacts. These limitations notwithstanding, MRA has proved useful in evaluation of the extracranial carotid and vertebral circulation as well as of larger-caliber intracranial arteries and dural sinuses. It has also proved useful in the noninvasive detection of intracranial aneurysms and vascular malformations. Vessel wall MR imaging (VWI) is an MR technique that relies on sup pression of all moving protons within vessels and CSF, combined with IV contrast administration (Fig. 434-7). Unlike MRA, VWI is a high spatial resolution, three-dimensional, T1W technique used to assess pathology of the vessel wall itself. This technique can be used to detect, characterize, and differentiate such pathologies as atherosclerosis, vas culitis (e.g., primary angiitis of the central nervous system [PACNS]), and vasculopathies such as reversible cerebral vasoconstriction syn drome (RCVS) and has been used to assess the wall of aneurysms. ECHO-PLANAR MRI Echo-planar MRI (EPI) forms the basis of several important MR imag ing sequences. EPI uses fast gradients that are switched on and off at high speeds to create the information used to form an image. With EPI, all the information required for processing an image is accumulated in milliseconds, and the information for the entire brain can be obtained in <1–2 min, depending on the degree of resolution required or desired.

Fast MRI reduces patient and organ motion and is the basis of perfusion imaging during contrast infusion and kinematic motion studies. EPI is also the sequence used to obtain diffusion-weighted imaging (DWI) and tractography (DTI), as well as functional MRI (fMRI) and arterial spin-labeled (ASL) perfusion studies (Figs. 434-2H, 434-4, 434-5C, and 434-7; and Fig. 437-13). Perfusion and diffusion imaging are EPI techniques that are useful in early detection of ischemic injury of the brain and may be useful together to demonstrate infarcted tissue as well as ischemic but potentially viable tissue at risk of infarction (e.g., the ischemic penumbra). DWI assesses microscopic motion of water; water protons that move reduce signal intensity on diffusion-weighted images. Pathology that reduces microscopic water motion results in relatively higher signal. Infarcted tissue reduces the water motion within cells and in the interstitial tissues, resulting in high signal on DWI. DWI is the most sensitive technique for detection of acute cerebral infarction of <7 days in duration (Fig. 434-2H). It is also quite sensitive for detecting dying or dead brain tissue secondary to encephalitis, as well as abscess and purulent formations (Fig. 434-4B). Perfusion MRI can be performed by the acquisition of fast EPI during a rapid IV bolus of gadolinium contrast material or by noncontrast ASL techniques. With contrast perfusion imaging, parametric maps of relative cerebral blood volume, mean transit time (MTT), time to maximum (tMAX), and cerebral blood flow can be derived. Prolonged MTT and tMAX and reduction in cerebral blood volume and cerebral blood flow are typical of infarction. In the setting of reduced blood flow, a prolonged MTT of contrast but normal or elevated cerebral blood volume may indicate tissue supplied by slower collateral flow that is at risk of infarction. Perfusion MRI imaging can also be used in the assessment of brain tumors to differentiate intraaxial primary tumors, whose BBB is relatively intact, from extraaxial tumors or metastases, which demonstrate a relatively more permeable BBB. DTI is derived from diffusion MRI sequences. This technique assesses the direction and integrity of protons flowing within white matter architecture. It has proven valuable in the assessment of subcortical white matter tract anatomy prior to brain tumor surgery, as well as in determining normal and abnormal white matter architecture in congenital and acquired pathologies such as traumatic brain injury and assessing the integrity of peripheral nerves and spinal cord lesions (Fig. 434-8). fMRI is an EPI technique that localizes regions of activity in the brain following task activation or at rest (so-called resting-state fMRI). Neuronal activity elicits a slight increase in the delivery of oxygenated blood flow to a specific region of activated brain. This results in an alteration in the balance of oxyhemoglobin and deoxyhemoglobin, which yields a 2–3% increase in signal intensity within veins and local capillaries. Currently, preoperative somatosensory, motor, and auditory cortex localization is performed, and methods to assess motor and language function are in development. This technique has proved useful to neuroscientists interested in interrogating the localization of specific brain functions. ARTERIAL SPIN LABELING ASL is a quantitative noninvasive MR technique that measures cerebral blood flow (Fig. 434-7). Blood traversing in the neck is labeled by an MR pulse and then imaged in the brain after a short (2 s) delay. The signal is reflective of blood flow. ASL has become almost standard in many MR protocols because it is relatively fast to acquire and does not require contrast administration. Increased cerebral flow is more easily identified than slow flow, which can be sometimes difficult to quantify. This technique has also been useful in detecting shunting in arteriovenous malformations and fistulas, as well as increased blood flow in brain tumors, and in patients after transient ischemic attack, seizure, or migraine. MAGNETIC RESONANCE NEUROGRAPHY MRN is an MR technique that shows promise in detecting increased signal in irritated, inflamed, or infiltrated peripheral nerves. T1W and T2W imaging are obtained with fat-suppressed fast-spin echo imag ing or short inversion recovery sequences. Inflamed peripheral nerves will demonstrate high signal on T2W imaging. MRN is indicated in

A C E FIGURE 434-7 Arterial spin label and vessel wall imaging in a 25-year-old woman with focal cerebral arteriopathy. The patient had an 8-month history of intermittent weakness of the right side with spasms. Imaging shows evidence of cerebral ischemia. Cerebrospinal fluid was transiently inflammatory. A. Diffusion-weighted image shows focal region of reduced diffusion in left parietal lobe. B. T2 fluid-attenuated inversion recovery images show several foci of high signal in left deep subcortical white matter. C. Arterial spin label image demonstrates reduced cerebral blood flow in left parietal lobe (arrows). D. Three-dimensional (3D) T1 image without contrast administration. E. 3D T1-weighted cube vessel wall image following gadolinium contrast shows focal enhancement of the left proximal middle cerebral artery (arrow).

F. 3D time-of-flight magnetic resonance angiography shows focal narrowing of the left supraclinoid internal carotid artery and proximal middle cerebral artery (arrow).

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A PART 13 Neurologic Disorders D C FIGURE 434-8 Diffusion tractography in cerebral glioma. A, B and C are images showing a left temporal mass lesion (T) that medially displaces the inferior longitudinal fasciculus (arrow). D. Different patient showing: Associative and descending pathways in a healthy subject (A) and in a patient with parietal lobe glioblastoma (B) presenting with a language deficit: the mass causes a disruption of the arcuate-SLF complex, in particular of its anterior portion (SLF III). Also shown are bilateral optic tract and left optic radiation pathways in a healthy subject (C) and in a patient with left occipital grade II oligoastrocytoma (D): the mass causes a disruption of the left optic radiation. Shown in neurologic orientation, i.e., the left brain appears on the left side of the image. AF, long segment of the arcuate fascicle; CST, corticospinal tract; IFOF, inferior fronto-occipital fascicle; ILF, inferior longitudinal fascicle; SLF III, superior longitudinal fascicle III or anterior segment of the arcuate fascicle; SLF-tp, temporo-parietal portion of the superior longitudinal fascicle or posterior segment of the arcuate fascicle; T, tumor; UF, uncinated fascicle. (Part D used with permission from Eduardo Caverzasi and Roland Henry.) patients with radiculopathy whose conventional MR studies of the spine (cervical or lumbar) are normal or in those suspected of periph eral nerve entrapment or trauma. This technique is now also being used to assess peripheral nerve damage after trauma or from compres sive and autoimmune neuropathies. POSITRON EMISSION TOMOGRAPHY PET relies on the detection of positrons emitted during the decay of a radionuclide that has been injected into a patient. The most fre quently used moiety is 2-[18F] fluoro-2-deoxy-d-glucose (FDG), which is an analogue of glucose and is taken up by cells competitively with 2-deoxyglucose. Many other radioisotopes are used in other indica tions. With FDG, multiple images of glucose uptake activity are formed 45–60 min after IV administration of FDG. Images reveal differences in regional glucose activity among normal and pathologic brain struc tures. FDG-PET is used primarily for the detection of extracranial metastatic disease; however, a lower activity of FDG in the parietal lobes is associated with Alzheimer’s disease, a finding that may simply reflect atrophy that occurs in the later stages of the disease. Combina tion PET-CT scanners, in which both CT and PET are obtained at one sitting, have largely replaced PET scans alone. MR-PET scanners have also been developed and may prove useful for imaging the brain and other organs without the radiation exposure of CT. More recent PET ligand developments include beta-amyloid and tau PET tracers (Chap. 442). Studies have shown an increased percentage of amyloid deposition in patients with Alzheimer’s disease compared with mild cognitive impairment and healthy controls; however, up to 25% of cognitively “normal” older patients show abnormalities on amyloid

B PET imaging. This may either reflect subclinical disease processes or a variation of normal. Tau imaging may be more specific for Alzheimer’s disease, and clinical studies are in progress. MYELOGRAPHY ■ ■TECHNIQUE Myelography involves the intrathecal instillation of specially for mulated water-soluble iodinated contrast medium into the lumbar or cervical subarachnoid space. CT scanning is typically performed after myelography to better demonstrate the spinal cord and roots, which appear as filling defects in the opacified subarachnoid space. CT myelography, in which CT is performed after the subarachnoid injection of a small amount of contrast material, has replaced conven tional myelography for many indications, thereby reducing exposure to radiation and contrast media. CT is obtained at a slice thickness of

~2.5 mm and reconstructed at 0.625-mm thick slices, which can quickly be reformatted in sagittal and coronal planes, equivalent to traditional myelography projections. ■ ■INDICATIONS CT myelography and MRI have largely replaced conventional myelog raphy for the diagnosis of diseases of the spinal canal and cord

(Table 434-1). Remaining indications for conventional plain film myelography include the evaluation of suspected meningeal or arach noid cysts and the localization of CSF fistulas. Conventional myelog raphy and CT myelography provide the most precise information in patients with failed back syndrome following spinal fusion procedures.

■ ■CONTRAINDICATIONS Myelography is relatively safe; however, it should be performed with caution in any patient with elevated intracranial pressure, evidence of a spinal block, or a history of allergic reaction to intrathecal contrast media. In patients with a suspected spinal block, MR is the preferred imaging technique. If myelography is necessary, only a small amount of contrast medium should be instilled below the block to minimize the risk of neurologic deterioration. Lumbar puncture (LP) is to be avoided in patients with bleeding disorders and those with infections of the overlying soft tissues. Anticoagulant therapy should be withheld prior to elective LP to avoid epidural or intradural hemorrhage, unless required in emergent situations (Chap. S3). ■ ■COMPLICATIONS Headache is the most frequent complication of myelography and is reported to occur in 5–30% of patients. Nausea and vomiting may also occur rarely. Postural headache (post-LP headache) is generally due to continued epidural leakage of CSF from the dural puncture site. A higher incidence is noted among younger women and with the use of larger gauge cutting-type spinal needles. If significant headache persists for >48 h, placement of an epidural blood patch should be considered. Vasovagal syncope may occur during LP; it is accentuated by the upright position used during conventional lumbar myelography. Adequate hydration before and after myelography will reduce the incidence of this complication. Management of LP headache is discussed in Chap. 17. Hearing loss is a rare complication of myelography. It may result from a direct toxic effect of the contrast medium or from an alteration of the pressure equilibrium between CSF and perilymph in the inner ear. Puncture of the spinal cord is a rare but serious complication of cervical (C1–2) or high LP. The risk of cord puncture is greatest in patients with spinal stenosis, Chiari malformations, or conditions that reduce CSF volume. CT myelography following a lumbar injec tion and MRI are safer alternatives to cervical puncture. Reactions to intrathecal contrast administration are rare; aseptic meningitis and encephalopathy are reported rare complications. The latter is usually dose related and associated with contrast entering the intracranial sub arachnoid space. Seizures rarely occur following myelography, histori cally reported in 0.1–0.3% of patients. Risk factors include a preexisting seizure disorder and the use of a total iodine dose of >4500 mg. Other reported complications include hyperthermia, hallucinations, depres sion, and anxiety states. These side effects have been reduced by the development of nonionic, water-soluble contrast agents as well as by head elevation and generous hydration following myelography. SPINE INTERVENTIONS ■ ■DISKOGRAPHY The evaluation of back pain and radiculopathy (Chap. 18) may require diagnostic procedures that attempt either to reproduce the patient’s pain or relieve it, indicating its correct source prior to lumbar fusion. Diskography is now rarely indicated. It is performed by CT or fluoro scopic placement of a 22- to 25-gauge needle into the intervertebral disk and subsequent injection of 1–3 mL of contrast media. The intra discal pressure is recorded, as is an assessment of the patient’s response to the injection of contrast material. Little or no pain is felt during injection of a normal disk, which does not accept much more than 1 mL of contrast material, even at pressures as high as 415–690 kPa (60–100 lb./in2). CT and plain films are obtained following the proce dure. Concerns have been raised that diskography may contribute to an accelerated rate of disk degeneration; furthermore, patients who suffer from depression or anxiety are more likely to find diskography painful, and in some cases, the procedure-associated pain became persistent, lasting a year or longer. Thus, it is rarely used as a reliable biomarker of pain generation. Newer spectroscopic disc techniques are being explored for the detection of painful degenerative disks. ■ ■SELECTIVE NERVE ROOT AND EPIDURAL

SPINAL INJECTIONS Percutaneous selective nerve root and epidural administration of glucocorticoid and anesthetic mixtures may be both therapeutic and

diagnostic. Typically, 1–2 mL of an equal mixture of a long-acting glu cocorticoid such as betamethasone or dexamethasone combined with a long-acting anesthetic such as bupivacaine is instilled under CT or fluoroscopic guidance in the intraspinal epidural space or adjacent to an existing nerve root in question as a pain source. This can also be per formed into the facet joints, or around the medial nerve branches that supply innervation to the facet joints as well. Radiofrequency ablation of the medial branches that supply sensation to the facet joints is com monly performed, and ablation techniques of the basivertebral nerves that conduct the sensation from degenerative disks have proven useful in certain cases of painful disk degeneration. Cement placement into compression fractures of the vertebral bodies, so-called vertebroplasty and kyphoplasty techniques, are commonly performed for pain-gen erating fractures, especially in elderly patients or those with pathologic fractures.

ANGIOGRAPHY Catheter angiography is indicated for evaluating intracranial small-ves sel pathology (e.g., vasculitis), for assessing vascular malformations and aneurysms, and in endovascular therapeutic procedures (Table 434-1). As noted above, angiography has been replaced for many indications by CT/CTA or MRI/MRA. CHAPTER 434 Neuroimaging in Neurologic Disorders Angiography carries the greatest risk of morbidity of all diagnostic imaging procedures, owing to the necessity of inserting a catheter into a blood vessel, directing the catheter to the required location, inject ing contrast material to visualize the vessel, and removing the catheter while maintaining hemostasis. Therapeutic transcatheter procedures (see below) have become important options for the treatment of some cerebrovascular diseases. The decision to undertake a diagnostic or therapeutic angiographic procedure requires careful assessment of the goals of the investigation and its attendant risks. Patients undergoing angiography should be well hydrated before and after the procedure. Because the femoral route is used most, the femoral artery must be compressed after the procedure to prevent a hematoma from developing. The puncture site and distal pulses should be evaluated carefully after the procedure; complications can include thigh hematoma or lower-extremity emboli. ■ ■COMPLICATIONS A common femoral arterial puncture provides retrograde access via the aorta to the aortic arch and great vessels. The most feared complication of cerebral angiography is stroke. Thrombus can form on or inside the tip of the catheter, rarely arterial dissection or perforation can occur, and atherosclerotic thrombus or plaque can be dislodged by the catheter or guide wire or by the force of injection and can embolize distally in the cerebral circulation. Risk factors for ischemic complications include limited experience on the part of the angiographer, atherosclerosis, vasospasm, low cardiac output, decreased oxygen-carrying capacity, advanced age, and prior history of migraine. The risk of a neurologic complication varies but is ~4% for transient ischemic attack and stroke, 0.5% for permanent deficit, and <0.1% for death. Nonionic contrast material is used exclusively in cerebral angiography. Nonionic contrast injected into the cerebral vasculature can be neurotoxic if the BBB is breached, either by an underlying disease or by the injection of hyperosmolar contrast agent. Patients with dolichoectasia of the basilar artery can suffer reversible brainstem dysfunction and acute short-term memory loss during angiography, owing to the slow percolation of the contrast material and the consequent prolonged exposure of the brain. Rarely, an intracranial aneurysm ruptures during an angiographic contrast injection, causing subarachnoid hemorrhage, perhaps because of injection under high pressure. ■ ■SPINAL ANGIOGRAPHY Spinal angiography is indicated to evaluate the location of vascular malformations and to identify the artery of Adamkiewicz (Chap. 453) prior to aortic aneurysm repair. The procedure is lengthy and requires the use of relatively large volumes of contrast; the incidence of serious complications, including paraparesis, subjective visual blurring, and altered speech, is <1%. Gadolinium-enhanced MRA has been

Revision #1
Created 2026-01-06 16:35:40 UTC by Omar Ayman
Updated 2026-01-06 16:35:40 UTC by Omar Ayman