A.2. Fundamentals of Neuro-Imaging

Introduction

Contemporary neurosurgical practice relies heavily on imaging for the diagnosis and management of neurosurgical diseases. The following section describes the different imaging techniques in use in neurosurgery and some examples of their applications.

a. Plain X-ray

With the advent of CT and MRI, the use of radiographic images in neurosurgery has declined. However, plain x-ray is easily accessible, quick, and inexpensive, and still provides valuable information, especially in spinal disease. Although plain x ray is no longer as useful in intracranial disease as it was in previous decades, it can be helpful in evaluating the anatomy of cranial sutures, paranasal and frontal sinuses, and the sella turcica in preoperative planning.

i. X ray of the cervical spine

One characteristic feature of the cervical vertebrae is the presence of the transverse foramen, or foramen transversarium in each transverse process for the passage of the vertebral arteries. There are three types of vertebrae: typical or subaxial cervical vertebrae (C3-6), the atlas (C1), and the axis (C2).

X ray is particularly important in the diagnosis of cervical spinal trauma and degenerative disease. Two thirds of significant spinal pathology can be detected with the cross-table lateral view (Gehweiler). It is important to visualize the cervico-thoracic junction (C7-T1) with this view since significant injury can occur at the lower cervical levels. A swimmer’s view, in which one arm is raised above the head, can be done to better visualize the lower c-spine in the patient with shoulders that obscure the cervico-thoracic junction on cross-table lateral projections.

Other important projections include the open mouth odontoid view, the anteroposterior (AP) view and flexion-extension views. The lateral, AP, and odontoid views can be done with the patient supine on a backboard. Flexion and extension views are performed with the patient upright, and should only be done in cooperative patients with normal mental status after their other projections have been read as normal. Flexion-extension radiographs are important in diagnosing cervical spinal instability in patients with neck pain and no recognized bony abnormality, though patients with acute paraspinal muscle spasm may not demonstrate abnormal motion on flexion-extension x-rays.

These same projections are useful in the diagnosis of degenerative disease of the cervical spine. Oblique views may also be used for examining the intervertebral foramina when there is a question of nerve root compression.

ii. X ray of the thoracic spine

Again, understanding the anatomy of the spine is essential before one can adequately interpret a thoracic or lumbar x-ray. The unique feature of the thoracic vertebra is the presence of costal facets for articulation with the heads of the ribs.

X ray of the thoracic spine is not as useful as in the cervical spine because much of the anatomy is obscured by the ribs. In the trauma setting, however, plain radiographs are still important. Good quality AP and lateral views can be obtained with the patient on a backboard. Fractures, subluxation, and loss of vertebral body height should be detectable on these views.

iii. X-ray of the lumbosacral spine

The largest vertebrae are found in the lumbar region and can be distinguished by their lack of costal facets and transverse foramina, and by their large spinous processes and small transverse processes. The five sacral vertebrae are fused into a wedge shaped bone that articulates with the L5 facets and the ilia.

Useful projections in the lumbosacral spine include AP, lateral, flexion-extension, and oblique views. AP and lateral views are good in the trauma setting because they can be done supine on a backboard, and can detect fractures and subluxation. Ligamentous instability can be demonstrated on flexion-extension views if there is displacement of one vertebra in relation to the adjacent vertebrae (spondylolisthesis). Oblique views can demonstrate spondylolysis, an acquired or congenital separation of the pars interarticularis, which may lead to spondylolisthesis. Again, flexion-extension x-rays can potentially demonstrate segmental instability.

b. Computed Tomography

The introduction of computed tomography (CT) in the mid 1970’s transformed the neurosurgeon’s ability to diagnose intracranial and spinal pathology. The different densities on CT images are related to the x-ray attenuation properties of the tissues being examined and can be quantified in Hounsfield units (Villarelli). These range from +1000 for bone to -1000 for air, with water being defined as zero Hounsfield units. Denser tissues (bone, foreign bodies) appear white on CT and less dense tissues (air or water) appear black. The addition of contrast makes tissues that enhance appear more dense or white.

CT is a good imaging modality for diagnosis of acute neurosurgical lesions in the head and spine. Little preparation of the patient is needed and the scans are performed and processed within minutes. CT is able to diagnose intracranial hemorrhage, fractures, edema, mass lesions, hydrocephalus, and infarction.

c. Angiography

The first successful angiogram by performed by Egas Moniz in 1927. It was used in the pre-CT and pre-MRI era not only to evaluate cerebral aneurysms and arteriovenous malformations (AVMs), but also ventricular anatomy, shift, and mass effect on cerebral vasculature from mass lesions or edema. Infarction is evidenced by vessel occlusion.

Advances in the use of microcatheters and digital imaging have transformed angiography from a purely diagnostic modality to one that also affords treatment. Superselective angiography with deposition of coils and balloons is now used for the definitive treatment of selected cerebral aneurysms and also in conjunction with surgery and radiosurgery of AVMs. Neurointerventionalists can also treat cerebral vasospasm after subarachnoid hemorrhage with superselective intra-arterial papaverine or balloon angioplasty.

d. Magnetic Resonance Imaging

A significant advance in neuroimaging has been magnetic resonance imaging (MRI). Although a discussion of MRI physics is beyond the scope of this forum, the appearance of normal and abnormal structures on MR images depend on the differences in proton content and their spin properties (Wehrli). Three different acquisitions of MR images are important in interpreting MRI of the brain or spine, T1, T2, and proton density. Gadolinium is a non-iodinated contrast material that is hyperintense on T1 images. Normal brain tissue with an intact blood-brain barrier is impermeable to injected contrast agents. Areas with impaired (e.g. tumor, infection, vascular anomaly) or absent (e.g. pituitary) blood-brain barrier are permeable to contrast agents and, therefore, show preferential enhancement.

e. Imaging in Intracranial Disease

i. Cranial Trauma

Trauma is the leading cause of death in children and young adults in the United States. Head injury is responsible for mortality in over 50% of these cases (Brocker). CT is important in the evaluation of head trauma, because it can quickly show the neurosurgeon if the patient has an operative lesion. These different windows, bone, brain, and blood are obtained from the same CT.

aa. Skull fractures

The initial head CT scan can detect skull fractures in two thirds of all head injured patients (Macpherson). Fractures do not correlate with severity of head injury.

There are three types of skull fractures, linear, depressed, and diastatic. Linear fractures are nondisplaced and may be associated with epidural hematoma. Depressed fractures are defined by displacement of the diploic tables of the skull in relation to one another. These are more often the result of impact with objects of smaller surface area, and are more often associated with parenchymal injury (Macpherson). Diastatic fractures are fractures along suture lines, and occur primarily in children. Skull fractures become problematic in children when there is associated tear of the dura and the patient develops an outpouching of brain tissue and meninges called a leptomeningeal cyst or growing skull fracture. Surgical repair is needed in this situation.

Fractures may be described as open or closed. An open fracture occurs when there is an overlying scalp laceration leading to potential communication between the intracranial space and the environment.

Fractures of the skull base may produce dural tears that communicate with paranasal sinuses or mastoid air cells. Clinically, these may be evident as a CSF leak from the nose (rhinorrhea) or ear (otorrhea). On CT, they may be recognized as pneumocephalus (air), which is characterized as very low-density (black) areas, near paranasal sinuses. Occasionally fractures may be visible on thin cut CT images through the skull base. Fractures through the temporal bone may disrupt the course of the facial nerve (CN VII) resulting in a complete ipsilateral facial paralysis.

bb. Epidural hematoma

An epidural hematoma (EDH) is a collection of blood between the skull and the dura mater usually resulting from a fracture shearing the middle meningeal artery or a dural venous sinus. They are found in 1-4% of patients with head trauma and represent 10% of fatalities associated with brain injury (Dharker).

EDHs are most commonly found unilaterally in the temporal area (Dharker). On noncontrast CT, EDHs appear as a biconvex or lentiform mass that is hyperdense to brain, and displaces brain tissue. Because the dura is more tightly adherent to the skull along the sutures, EDHs are usually bound by suture lines.

cc. Subdural hematoma

A subdural hematoma (SDH) is a collection of blood between dura and arachnoid mater resulting from the tearing of bridging veins after acute changes in head velocity. Acute SDHs occur in 10% to 20% of head injuries.

Chronic SDHs may occur without trauma or as a result of minor trauma, especially in the elderly patient where brain atrophy is more prevalent and pronounced. Chronic SDHs often show signs of recurrent hemorrhage (Hashimoto).

Acute SDHs appear as a hyperdense, crescent-shaped lesion on noncontrast CT. Some areas may appear iso- or hypodense, representing CSF or unclotted blood mixed with clotted blood (Osborn). As the clot ages over days to weeks, the now subacute SDH appears isodense to brain. Chronic SDHs usually appear hypodense on noncontrast CT, but may be heterogeneous if there is significant rebleeding or neovascular membrane formation.

dd. Traumatic subarachnoid hemorrhage

Subarachnoid hemorrhage (SAH) is blood between the arachnoid membrane and the pia mater of the brain. It is present in most cases of moderate to severe head trauma. On noncontrast CT it appears as a hyperdensity which follows the sulci over the cerebral convexities or in the CSF cisterns at the base of the brain.

ee. Parenchymal brain injury

Cerebral contusions, diffuse axonal injury (DAI), and brainstem hemorrhages (Duret hemorrhages) are all the manifestations on imaging of primary brain injuries. DAI occurs when there is a shearing injury to axons usually as a result of acceleration/deceleration or rotatory forces applied to the head. DAI tends to occur at the gray-white junction, the corpus callosum, or the dorsolateral brainstem (Osborn). The CT appearance of DAI is that of normal brain or diffuse edema.

Contusions are hemorrhages that occur as a result of the brain impacting the skull. Therefore, they are frequently found at the frontal and temporal poles. Contusions may also accompany depressed skull fractures. On noncontrast CT they appear as heterogeneous hyperdense areas within the brain tissue (Osborn).

MRI is more sensitive than CT in detecting DAI, which appears as multiple, poorly defined, hyperintense areas seen in the white matter on T2 weighted images (Kelly).

ii. Intracranial Hemorrhage

aa. Intracerebral hemorrhage

Intracerebral hemorrhage (ICH) can occur as a result of hypertension, amyloid angiopathy, hemorrhagic infarction, ruptured cerebral aneurysm, arteriovenous malformation (AVM), hemorrhagic tumors or cysts, encephalitis, or vasculitis. CT is easily accessible, fast, and clearly shows presence or absence of blood. Since these patients may deteriorate rapidly or have an acute onset resembling ischemic stroke, rapid diagnosis is critical. If one suspects vascular malformation or tumoral hemorrhage, an MRI with contrast or cerebral angiography should be performed in addition to the CT.

Hypertension is the most common cause of intracerebral hemorrhage in the adult population (Bozzola). These hemorrhages are thought to result from rupture of microaneurysms (Charcot-Bouchard aneurysms) found on deep perforating arteries, especially in the putamen, followed by the thalamus, pons, cerebellum, and subcortical white matter (Laissy).

Hemorrhagic infarction can result from either arterial or venous infarcts. In 5 to 15% of cases, an ischemic infarct will convert to a hemorrhagic infarct, usually within 24 to 48 h, as a result of reperfusion. CT will show hypodensity in a vascular distribution but there may be heterogeneous hyperdensities within that region (Osborn). Venous infarcts are much less common than arterial and are often associated with thrombosis of a dural sinus. On CT, venous infarcts demonstrate patchy areas of edema with petechial hemorrhages (Osborn).

Intracranial tumors may present as an ICH. Contributing factors include neovascularity, necrosis, direct vascular invasion, and a coagulopathic state (Leeds). Primary tumors prone to hemorrhage include glioblastoma multiforme, oligodendroglioma, pituitary adenoma, and hemangioblastoma. Metastases particularly prone to hemorrhage include melanoma, renal cell carcinoma, and choriocarcinoma, as well as lung CA (Osborn). Extensive edema surrounding a hematoma should raise suspicion that there may be an underlying lesion. Contrast CT or MRI should be done in this situation.

iii. Intracranial Vascular Disease

aa. Aneurysm and subarachnoid hemorrhage

The most common cause of nontraumatic subarachnoid hemorrhage (SAH) is a ruptured intracranial aneurysm (Bozzolo). Other sources include arteriovenous malformation and venous hemorrhage. CT is the test of choice for diagnosis of SAH. Once SAH is detected on CT and aneurysm is suspected, angiography should be performed expeditiously.

On CT, acute SAH is high density compared to brain, and appears mainly in the basal cisterns (aneurysms in the Circle of Willis), sylvian fissure (middle cerebral, terminal internal carotid, posterior communicating artery aneurysms), interhemispheric fissure (anterior cerebral and anterior communicating artery aneurysms), and fourth ventricle (posterior inferior cerebellar artery aneurysms). Subacute and chronic SAH is not usually visible on CT since most SAH detectable by CT is cleared from the CSF within one week (Van Gijn).

Cerebral angiography remains the gold standard for the diagnosis of cerebral aneurysm. The goal of angiography is not only to detect any and all aneurysms, but to clearly define the anatomy of the aneurysm neck, identify adjacent perforating arteries, define possible collateral circulation, and assess for vasospasm. To determine which aneurysm has ruptured when multiple aneurysms are present, it is helpful to correlate the clot location on CT with aneurysm location on angiography. Also, ruptured aneurysms tend to be larger, more irregular, or have outpouchings.

MRI is not as useful for detecting acute subarachnoid hemorrhage because of the heterogeneous appearance on MRI sequences. MR angiography is a promising modality. Currently, MRA does not adequately characterize aneurysm neck and perforator anatomy to be useful as a primary preoperative imaging study. MRI is more valuable in evaluating the three dimensional anatomy of giant aneurysms in relation to the brain or cranial nerves (Perl).

bb. AVM and other vascular malformations

There are four types of intracranial vascular malformations: AVMs, cavernous angiomas, capillary telangiectasias, and venous angiomas. AVMs are direct artery to vein fistulae that hemorrhage at a rate of 4% per year. They usually have tortuous feeding arteries, a dense nidus, and large draining veins that may be seen on CT. AVMs may have associated feeding artery aneurysm secondary to the high flow state. AVMs most commonly present as an ICH or seizure and less commonly as focal neurologic deficit from vascular steal or mass effect.

An unruptured AVM appears on CT as an isodense lesion with occasional flow voids or calcifications on non-contrast studies and enhancement of serpentine vessels with contrast administration (Osborn). If an AVM is suspected based on CT findings, the patient should undergo cerebral angiography. Angiography can clearly define feeding arteries, the actual artery to vein fistulae (nidus), and draining veins. MRI is useful in defining the cerebral anatomy around the AVM. The typical appearance of AVM on MRI is a tight "honeycomb" of flow-voids (Osborn).

Cavernous malformations/angiomas are composed of cystic vascular sinusoids lined with a vascular endothelium monolayer and no intervening neural tissue. These are slow-flow lesions and hemorrhage at approximately 0.5% per year. Like AVMs they can present with either hemorrhage or seizure. Cavernous angiomas have a classic popcorn-like appearance on CT and MRI, indicating hemorrhage of multiple ages and calcification. They often have a classical hemosiderin ring (hypointense ring on T2-weighted images). (Osborn). They show minimal to no enhancement on contrast CT or MRI and are not detectable by angiography.

Venous angiomas are collections of enlarged veins within the periventricular white matter that empty into a larger, transcortical draining vein. They may not be visible on non-contrast CT, but appear as a tuft of vessels near the ventricle on contrast CT or MRI. Angiography shows a normal arterial phase but dilated venous structures often with a "Medusa head" appearance (Osborn).

Capillary telangiectasias are nests of dilated capillaries that may have intervening normal brain tissue. These are often found in the pons, but also in the cerebral cortex or spinal cord. On CT and MRI, capillary telangiectasias may be absent or show small, poorly defined areas of enhancement. They may be seen on angiography as small areas of vascular blush (Osborn).

iv. Occlusive cerebrovascular disease

Ischemic stroke continues to be a major cause of death and disability in the United States. Neurosurgeons come in contact with patients with stroke when they have carotid stenosis and are eligible for treatment with carotid endarterectomy. Additionally, patients with subarachnoid hemorrhage are at risk of serious morbidity and mortality from ischemia and infarct secondary to cerebral vasospasm.

CT is important in the immediate diagnosis of stroke to exclude hemorrhagic causes of neurologic deficit. Hyperacute (<= 12 hours) cerebral infarcts are not detected on CT scans in 50-60% of patients. Occasionally, a hyperdense (thrombosed) artery is visible or the basal ganglia become hypodense. Acute infarcts (12 to 24 hours) will appear as loss of gray-white differentiation or sulcal effacement on non-contrast CT. At 24 to 72 hours the infarct becomes a more defined wedge-shaped hypodense area that extends to the brain. The infarcted area also becomes edematous during this time period. At 4 to 7 days the infarct becomes more hypodense and will exhibit gyral enhancement on contrast administration. Later scans (months to years) will show an area of encephalomalacia and volume loss (Osborn).

MRI can demonstrate hyperacute and acute infarction better than CT. MRI will show sulcal effacement and loss of gray-white differentiation at <= 12 hours. From 12 to 24 hours, the area of the infarct develops hyperintensity on T2 weighted images. Contrast enhancement of the affected parenchyma begins to appear at 24 to 72 hours, and becomes more striking between days 4 to 7. MRI perfusion studies can delineate ischemic zones.

Angiography plays several important roles in ischemic cerebrovascular disease. In the hyperacute stage, it may be used to treat the patients with intra-arterial thrombolytic agents. Additionally, angiography can define the vascular distribution of the infarct either by demonstrating a direct cut-off of the vessel or by showing bare or nonperfused areas. Sometimes a zone of luxury perfusion in the ischemic penumbra may be seen. It can also be used to diagnose carotid stenosis in the pre-operative planning for carotid endarterectomy, and to distinguish between near and complete occlusion of the artery (Osborn).

v. Intracranial Tumors

Describing the imaging characteristics of each type brain tumor is beyond the scope of this discussion. We will, however, provide an overview of the characteristic imaging features of common primary brain tumors in the brain parenchyma, metastatic tumors, and those tumors outside the brain parenchyma.

aa. Intra-axial Tumors

Intra-axial tumors can be divided into two subgroups, primary brain tumors and metastatic tumors. The primary tumors include gliomas (astrocytoma, anaplastic astrocytoma, glioblastoma multiforme, oligodendroglioma, and ependymoma), neuronal origin tumors, pineal region tumors, and CNS lymphomas. Metastatic disease may affect not only the brain parenchyma, but also the leptomeninges and calvarium.

a. Primary tumors. Gliomas represent approximately 40% of all intracranial tumors (Russell). Astrocytic tumors are the most common of the glial tumors. Typically, they are infiltrative or diffuse but some specific subtypes are circumscribed. Infiltrative astrocytic tumors include astrocytomas, anaplastic astrocytomas, glioblastoma multiforme, oligodendroglioma, and ependymoma. Circumscribed tumors of astrocytic origin include pilocytic astrocytomas and subependymal giant cell astrocytoma. On non-contrast CT, gliomas may be evident only as white matter edema or an ill-defined isodense white matter lesion. They are usually found supratentorially in adults but more frequently infratentorially in children. With the addition of contrast, low-grade astrocytomas enhance poorly. Anaplastic astrocytomas and glioblastomas show stronger enhancement patterns and may have areas of heterogeneity. These high-grade gliomas often show spread of edema or enhancement along white matter tracts such as the corpus callosum that indicate infiltration of tumor into normal brain. They may also show central areas of hemorrhage or necrosis. On MRI, low-grade astrocytomas are iso- or hypointense on T1 weighted images and homogeneously hyperintense on T2. They may show minimal to no enhancement with gadolinium. Anaplastic astrocytomas and glioblastoma multiforme are iso- to hypointense on T1 and heterogeneous on T2, with strong heterogeneous enhancement (Osborn). The T2 signals are more sensitive for edema, which often correlates with the degree of tumor infiltration.

Pilocytic astrocytomas are tumors of glial origin that are more common in children and young adults. These are well-circumscribed tumors located near the third or fourth ventricles and arise from the cerebellum and optic chiasm/hypothalamus. On CT and MRI, they frequently appear cystic with an enhancing, solid mural nodule (Osborn).

Oligodendrogliomas are relatively slow growing tumors arising from oligodendrocytes. They are usually found in the cerebral hemispheres, especially the frontal lobes. On imaging studies they appear as a heterogeneous, enhancing mass in the cerebral hemispheres often with calcification (Osborn).

Ependymomas are derived from ependymal cells, which line the ventricular system. Most of these tumors are found infratentorially, arising in the fourth ventricle. The supratentorial ependymomas are usually found outside the ventricular system (Palma). Supratentorial ependymomas may resemble astrocytomas on imaging. Fourth ventricular ependymomas are isodense with some areas of hyperdensity representing calcification on noncontrast CT and mildly heterogeneously enhancing on MRI. They appear to "fill" the ventricles and may extend up or down the fourth ventricle.

b. Metastases. Metastases represent one quarter to one third of all adult brain tumors (Davis). Common metastases to brain include lung, breast, melanoma, renal cell carcinoma, GI, and GU tumors. Between 60 and 85% of all metastases are multiple (Bindal). On non-contrast CT, metastases are iso- or hyperdense lesions usually found at the gray-white junction, but can occur anywhere in the brain. With contrast administration, metastases will enhance either homogeneously or peripherally. On MRI, most metastases are hypointense on T1, hyperintense on T2 and enhance with gadolinium in the same pattern as on CT (Osborn). Cerebral metastasis should be considered first in the differential diagnosis in any patient with multiple lesions since primary brain tumors are usually solitary. Extensive vasogenic edema generally surrounds the tumor. Although less common, cerebral abscess may mimic metastases on imaging and should be ruled out either clinically or by biopsy.

bb. Extra-axial tumors

The distinction between intra-axial and extra-axial tumors is important in surgical planning and prognosis. Extra-axial tumors are generally benign tumors, such as meningiomas, vestibular schwannomas, pituitary tumors, dermoids and epidermoids. Malignant extra-axial tumors include metastases, malignant meningioma, sarcoma, and chordoma.

c. **Meningiomas.** Meningiomas are the most common primary, intracranial tumor of nonglial origin (Hardman, Russell). They are derived from arachnoidal cap cells and can be found on any surface carrying arachnoid tissue. The most common locations are the sagittal sinus (parasagittal), cerebral convexity, sphenoid ridge, olfactory groove, and posterior fossa (Osborn).

Plain skull films may show hyperostosis adjacent to a meningioma and dilated vascular channels leading to the tumor. Angiography can demonstrate an extracranial blood supply as well as parasitized pial vessels. There may be a persistent vascular blush. CT will show a well-circumscribed, hyperdense mass that abuts the dura. Some meningiomas show calcification on CT and demonstrate peritumoral edema. They enhance strongly with intravenous contrast. On MRI, meningiomas are isointense to brain, enhance strongly and often have a dural tail corresponding to migration of tumor cells (Osborn).

d. **Vestibular Schwannoma.** Vestibular schwannoma or acoustic neuroma is a benign tumor arising from the nerve sheath of the vestibular portion of cranial nerve VIII. As such, they are seen only in the cerebellopontine angle, often with extension into the internal acoustic canal (IAC). On CT they are iso- or hypodense and enhance strongly. The bone windows may show widening of the IAC. On MRI, vestibular schwannomas are well circumscribed, enhancing masses that extend into the IAC (Goldberg).

e. **Pituitary Adenomas.** Pituitary adenomas represent approximately 10% of all primary intracranial tumors (Russell). They are grouped into microadenomas (<= 10 mm) and macroadenomas (> 10 mm). Most adenomas are slow growing and 50% are endocrinologically active, with the most common type being the prolactinoma (Russell). Microadenomas appear hypodense on contrast enhanced CT and MRI because the normal pituitary enhances more strongly. Macroadenomas appear as isodense intra- and suprasellar masses that enhance strongly on CT and MRI. Cysts, hemorrhage, or necrosis may also be seen in the macroadenoma.

vi. Hydrocephalus

Hydrocephalus is a condition in which the ventricles become enlarged and intracranial pressure becomes elevated. It is commonly divided into two types: communicating, which is due to the inability of the arachnoid granulations to adequately absorb CSF; non-communicating, which is caused by an obstruction of CSF flow within the ventricles. Communicating hydrocephalus may occur after subarachnoid hemorrhage if the subarachnoid blood and its by-products impair the function of the arachnoid villi. On noncontrast CT and MRI, these patients have symmetric enlargement of all ventricles, which is particularly noticeable in the third ventricle and temporal horns of the lateral ventricles. Non-communicating hydrocephalus may occur with intraventricular tumors or cysts. In these cases there is enlargement of the ventricles proximal to the occlusion and normal sized ventricles distal.

vii. Cerebral Abscess

Cerebral abscesses are foci of parenchymal bacterial infections that result from contiguous spread, direct inoculation, or hematogenous spread. Hematogenous spread from an extracranial site such as the lung often results in multiple lesions, whereas local spread from mastoid air cells or paranasal sinuses usually creates a solitary lesion (Bellar).

The appearance on CT or MRI depends on the age of the abscess. In the early cerebritis stage of cerebral abscess (3 to 5 days), CT or MRI may show a small, ill-defined area of mild enhancement at the gray-white interface. From 5 days to 2 weeks, the late cerebritis stage develops, and CT and MRI show a thin ring of enhancement around a necrotic center. During the early and late capsule stages (weeks to months), a thicker, more defined ring of enhancement forms with a surrounding area of edema (Zimmerman).

f. Imaging in Spinal Disease

i. Spinal Trauma

Prompt recognition of spinal injuries and neurologic deficits are essential in the successful treatment of the multiply injured patient (Bohlman). As described previously, plain x-ray is a fast and easy first test to evaluate spinal injuries. Most fractures and subluxations can be seen on plain x-ray, but patients with point tenderness or neurological deficit should undergo further evaluation. CT of the spine with sagittal reconstruction is very useful for identifying the anatomical detail of the fractures seen on x-ray or to find fractures not seen on plain x-ray. MRI is useful in identifying spinal cord compression or contusion and disc/ligamentous injury.

The four types of spinal injury based on direction of forces applied to the vertebral column are: 1) hyperflexion, 2) hyperextension, 3) axial loading, 4) rotational injury (Brant-Zwadzski). Hyperflexion injuries usually result in anterior wedging and compression fractures of the vertebral bodies. If sufficient flexion forces are applied to the spine, these fractures may be associated with posterior ligamentous injury or facet subluxation ("locked facets").

Hyperextension injuries are common in the cervical spine, and often result in fractures of the posterior elements such as the lamina, lateral masses, and facets. Frequently there is rupture of the anterior longitudinal ligament and disruption of the disc space. In patients with congenitally narrow spinal canals or degenerative disc disease, hyperextension can cause central cord syndrome.

Axial loading injuries are common in the cervical and thoracolumbar segments of the spine. A direct vertical force is applied to the spine as in diving or jumping injuries resulting in compression or "burst" fractures of the vertebral bodies.

Rotational injuries are usually associated with other forces such as lateral bending, flexion, or extension. These forces can result in unilateral facet dislocations and in the cervical spine.

ii. Degenerative Spinal Disease

Degenerative spinal disease is the most commonly seen disease in most neurosurgical practices. Advances in CT and MRI have been very important in the diagnosis of spinal stenosis and disc herniation.

aa. Spondylosis and spinal stenosis.

As the intervertebral discs age, they become desiccated, the annular fibers become weak, and the discs bulge or herniate. When patients develop spondylosis, they form osteophytes along the discovertebral junction that can compromise the spinal canal (Resnick). There are two forms of spinal stenosis, congenital or acquired. The acquired form is usually the result of spinal degeneration caused by bulging discs, osteophytes, and ligamentum hypertrophy, which are best visualized on CT bone windows. CT myelography (CT performed after intrathecal injection of contrast) and MRI will show compression of the thecal sac. Patients with severe prolonged stenosis may show signal abnormality with the spinal cord.

bb. Disc bulge and herniation.

Bulging of the intervertebral disc is a common phenomenon in people over age 20 and may be asymptomatic (Boden). As the annulus fibrosis ages, it becomes weaker, thus allowing the nucleus pulposus to bulge beyond the vertebral body margins. While CT or CT myelography can accurately diagnose herniated discs, MRI is the preferred test because of its ability to define the relationship of disc material to CSF, bone, and soft tissue in both axial and sagittal planes. MRI is also less invasive than CT myelography.

iii. Spinal Tumors

Spinal tumors can be divided into three groups, 1) extradural, 2) intradural extramedullary, and 3) intramedullary masses.

aa. Extradural spinal masses.

The most common extradural masses are metastases to the bone. Other extradural masses include benign and malignant tumors of bone and multiple myeloma. Metastases often present with pain, pathologic fractures, and neurologic deficit consistent with location. On plain x-ray, metastases may appear as multifocal, lytic lesions or vertebral fractures (Olcott). CT is good for delineating the bony anatomy of osteolytic areas, and, with the injection of intrathecal contrast, can show neurological element compression. Contrast MRI allows better examination of the spinal cord and soft tissues surrounding the spine. Metastatic lesions are usually multiple and strongly enhancing.

bb. Intradural extramedullary spinal masses.

Most intradural, extramedullary spinal masses are either nerve sheath tumors or meningiomas. Schwannomas and neurofibromas both originate from the Schwann cell but differ grossly and histologically. Schwannomas are well-circumscribed round or dumbbell-shape tumors that may be solid or cystic (Burger). Neurofibromas are poorly circumscribed masses, which often have nerve fibers coursing through them and are more frequently solid. The imaging characteristics of these two tumors are similar. On CT, there is often widening of the neural foramen. On T1 weighted MRI, the lesions are iso- or hyperintense and enhance strongly with contrast. On T2 weighted images, they are usually hyperintense.

They will displace but not invade the spinal cord or nerve roots within the thecal sac.

The histology of spinal meningiomas is identical to intracranial meningiomas. On MRI, they are isointense on T1 and T2 weighted images and enhance well. A dural tail may be observed.

cc. Intramedullary masses.

Intramedullary masses are found within the spinal cord parenchyma. Most are gliomas, either ependymoma or astrocytoma. Ependymomas arise from ependymal cells in the central canal. They are found in all segments of the spinal cord and may have a better cleavage plane between tumor and spinal cord than the astrocytoma. A subtype that is frequently found in the conus medullaris, the myxopapillary ependymoma, is histologically benign and has a good prognosis. Any ependymoma may undergo cystic degeneration and hemorrhage (McCormick). Their appearance is isointense to spinal cord on T1 weighted images, hyperintense on T2, and enhance homogeneously (Osborn).

Astrocytomas of the spinal cord usually involve multiple segments and diffusely widen the cord. They occur more frequently in the cervical cord. CT may show thinning of the pedicles or widening of the interpedicular distance. On MRI, they are iso- to hypointense on T1, hyperintense on T2, and enhance strongly.