

Brain Tumor Imaging and Surgical Management

The Neurosurgeon's Perspective

W. James Thoman, MD, MSBE, Mario Ammirati, MD, MBA, Louis P. Caragine, Jr., MD, PhD, John M. McGregor, MD, Atom Sarkar, MD, PhD, and E. Antonio Chiocca, MD, PhD

Abstract: Advances in imaging technologies have influenced neurosurgical techniques and decisions and have enabled previously impossible resections, and neurosurgeons rely on the various modalities to make surgery as safe as possible. We look at the different technologies that have developed and how they are used by neurosurgeons, in combination with the knowledge of anatomy, to evaluate brain and spinal tumors and make surgical decisions that improve treatment outcomes.

Key Words: brain tumor imaging, MRI, neurosurgeon's perspective, neurosurgical oncology

(Top Magn Reson Imaging 2006;17:121-126)

From a historical perspective, advances in neuroimaging technology over the past 100 years have provided neurosurgeons with a variety of imaging modalities to help them plan safe surgical removal of tumors with minimal adverse effect on patients. The infancy of central nervous system (CNS) imaging began with plain x-ray film, which can be traced back to the beginning of the 20th century, when Arthur Schuller published his comprehensive studies on plain skull films. Schuller was the first to demonstrate that shifts in calcified pineal gland that were seen on skull films could help in localizing intra-axial tumors. This was followed by the introduction of ventriculography by Walter E. Dandy, who initially injected air in the ventricular system (pneumoencephalogram) to look at the geometry of the ventricle. Any displacement or change in the morphology of the ventricular system would help in localizing tumors. It also helped in understanding the physiology of hydrocephalus. Subsequently, Egas Moniz developed cerebral angiography, which allowed him to study the anatomy of cerebral vasculature. Moniz noted that because any intracranial lesion could cause shifting in normal cerebral vasculature, detection of such shift could help localizing the lesion. Moniz's method was probably the most accurate of the 3 techniques mentioned above for localizing intracranial lesions.¹ Continued refinements of these technologies remained the mainstay of

neuroimaging for neurosurgeons until the advent of computed tomography (CT) and magnetic resonance imaging (MRI).

Neurosurgical oncology can be subdivided by tumors affecting the spine and those that are intracranial or skull based. The imaging modalities in evaluating these lesions include plain x-ray, CT scan, MRI, angiography, nuclear medicine scintigraphy, ultrasound, and myelography. Of these, magnetic resonance (MR) has become the workhorse of neuro-oncology imaging, and its new capabilities, including functional MRI (cortical activation), MR angiography, and MR spectroscopy, have played a greater role in differentiating tumors and in surgical planning. Although the conventional myelogram has been mostly replaced by spine MR study, CT-myelogram remains a valuable tool for patients unable to undergo MRI, complicated cases in which MRI cannot provide adequate information, and special cases needing detailed bony anatomy and its relationships to the neurostructures. From the neurosurgeon's perspective, anatomical and/or functional tumor imaging is intended to provide essential information for optimal delineation and characterization of a lesion and its 3-dimensional (3-D) spatial relationship to normal structures for surgical plan (biopsy, resection, recurrence vs necrosis, etc) with the aim to improve the treatment outcome by reducing morbidity and mortality.

IMAGING FOR INTRACRANIAL TUMORS

Considerations in evaluating intracranial-based tumors are whether the tumor is extra-axial versus intra-axial and the degree of its enhancement. Extra-axial tumors, including skull-, meningeal-, intraventricular-, and nerve-based tumors, may show a mass with distinguishable margins between the lesion and the brain; enhancing dura (such as dural tail in meningioma) or leptomeninges (such as cerebrospinal fluid seeding); cranial nerve enhancement with or without mass effect (primary or secondary tumor respectively); absence or minimal parenchymal edema; lack of necrosis; relatively lower signal intensity (SI) on T2-weighted (T2W) imaging; and associated skull abnormalities (such as hyperostosis). Based upon anatomical location, MR relaxation time, and tissue characteristics, some imaging features of intra-axial or parenchymal tumors can help preoperative differentiation from extra-axial tumors. Some of these imaging features include the presence of necrosis, enhancement patterns, surrounding edema, tumor margins, calcification, vascularity, and MR SI characteristics. The margins of intra-axial tumors can be either poorly or well defined, as seen in infiltrating primary parenchymal lesions (gliomas) versus well-defined

From the Department of Neurological Surgery, The Ohio State University Medical Center, Columbus, OH.

Reprints: E. Antonio Chiocca, MD, PhD, Department of Neurological Surgery, The Ohio State University Medical Center, N-1021 Doan Hall, 410 West Tenth Avenue, Columbus, OH 43210-1240 (e-mail: EA.Chiocca@osumc.edu).

Copyright © 2006 by Lippincott Williams & Wilkins

metastatic lesion of extra-CNS origin. Except for the occasional cortical primary or secondary lesions, intra-axial tumors typically do not show dural or leptomeningeal enhancement, and gliomas may show no enhancement or the extent of enhancement may be far less than that of the SI changes associated with the mass. The extent of intra-axial tumor edema is typically much greater than that of the extra-axial tumor.

Plain X-ray Films

The use of plain x-ray films in the evaluation of intracranial tumor is decreasing concomitantly with advances in CT imaging (3-D reconstruction of skull). In the early days of neurosurgery, plain films were used to evaluate the anatomy of the sella and of the pineal gland. Pituitary adenomas usually caused an enlarged sella, whereas craniopharyngiomas eroded the posterior clinoid. A calcified pineal gland is a common finding in adults, which is visible on plain x-rays. Any displacement of the pineal gland from its normal position may suggest intracranial pathology.² Sellar masses are much better evaluated with MRI, and findings involving the pineal gland warrant further studies.

Plain films are still useful in evaluating skull lesions caused by fibrous dysplasia, multiple myeloma, epidermoid, metastatic, or other lesions. The advantage of plain films over CT is that they image the entire skull rather than only the axial cuts of CT. With lateral and anteroposterior views of the skull, it is easier for the neurosurgeon to localize a skull lesion for resection or biopsy. Plain films are quick and easy to obtain. However, these advantages are limited because scout films are obtained with CT and the possibility of 3-D skull reconstruction exists.

Computed Tomography

A CT of the head is usually the first study obtained in the emergency department when patients complain of symptoms suggesting intracranial pathology. This is the first exposure to brain tumors that most neurosurgeons see on initial consultation. Computed tomography is still the screening modality of choice to evaluate for hemorrhage. They are quick to obtain, and most CT scanning of the head can be performed within 1 minute. Computed tomography is extremely sensitive to the calcification found in specific intracranial tumors, including craniopharyngioma, oligodendroglioma, neurocytoma, retinoblastoma, and meningioma. Computed tomography is also very sensitive to acute hemorrhage, which can be seen in some tumors, for example, melanoma. Finally, CT is the most accurate imaging modality for looking at bony structures, making it very helpful in evaluating lesions that are skull based or that invade the bony structure of the skull.

In patients unable to undergo MRI, contrast agent may be used with CT to delineate intracranial tumor. The contrast extravasates into the parenchyma in areas of blood-brain barrier breakdown. Although not as good as contrast-enhanced MRI, the CT can delineate ring-enhancing lesion, such as astrocytoma (especially glioblastoma multiforme), metastases (especially lung), abscess, lymphoma, and radiation necrosis. Computed tomography can also be used with a stereotactic guidance system during surgery. Finally, the

convenience of the technology allows CT to be the first imaging modality postoperatively for any complication or acute changes for the patient's well being.

Magnetic Resonance Imaging

Magnetic resonance imaging is the primary tool of the neurosurgeon for preoperative planning. The standard pulse sequences are the T1-weighted (T1W) and T2W imaging. T1-weighted images are used for tissue discrimination, and with the use of MR contrast agent, T1W allows enhancing lesions to become hyperintense on MRI. The T2W images are very sensitive to the presence of water and therefore ideal for visualizing edema. Also, flow voids indicative of vascularity are often visualized on T2W images. Furthermore, addition of intravenous gadolinium contrast allows better indication of tumor vascularity as well as of surrounding arteries and veins.

In addition, postoperative MRI with and without contrast done within 24 to 48 hours of surgery is important to most neurosurgeons to determine the extent of the surgical resection. This is especially true in the case of fourth ventricular ependymoma in children, where gross total resection can result in a cure. Postoperative MRI is also required by the neuro-oncologist and radiation-oncologist in planning postsurgical treatment. Other MRI modalities useful for tumor surgery include fluid attenuation inversion recovery (FLAIR), MR angiography, MR venography, functional MRI (fMRI), diffusion tensor MRI, and MR spectroscopy. Although the same MRI modalities are used for stereotactic radiosurgery, there are some required specific variations of imaging protocols in which the images are acquired. For these procedures, accurate imaging is of utmost importance to minimize radiation exposure of normal brain and brain structures. Finally, advances in nanotechnology have made their way into MRI of tumors and may help neurosurgeons at the time of surgery.

Neurosurgeons may vary the order in which they evaluate MRI based on their preferences. Starting with T2W images, the neurosurgeon can evaluate the ventricular space for hydrocephalus and the vasculature by looking for flow voids. This allows the neurosurgeon to quantitate edema and mass effect of the tumor by looking for shift in the ventricular system. Precontrast and postcontrast T1W images may then be evaluated. Ideally, images of all 3 orthogonal planes (axial, sagittal, and coronal) should be available to optimally evaluate the extent of a lesion and its 3-D spatial relationship to the surrounding critical normal structures. Although not specific, the degree of enhancement can differentiate to some extent low- and high-grade gliomas, which may help for selecting a biopsy site or to determine the aggressiveness of surgical resection. FLAIR images are helpful to differentiate the enhancement from small cortical vessels and early small metastasis. Ultimately, other lesions mimicking pathologies, including demyelination, inflammation, ischemia, vascular malformations, and central venous occlusive disease, need to be excluded preoperatively.

Vascular mapping is another important piece of imaging information for surgical planning. Magnetic resonance angiography and MR venography give the neurosurgeon

further information on both the vascularity of a tumor and the mass effect on surrounding arteries and veins caused by a tumor. This may prompt the neurosurgeon to contemplate embolization if a tumor is extremely vascular. Magnetic resonance venography can reveal important venous relationship, which may be critical during the resection of a tumor adjacent to dural sinuses or veins draining into the sinuses. This may be the case in meningiomas where knowledge of adjacent veins and patency of surrounding sinus may prevent the risk of venous infarct postoperatively.

For tumors adjacent to eloquent brain, functional MRI (fMRI) has become a routine tool for preoperative planning. With fMRI, the neurosurgeon has the ability to localize the anatomy of the motor strip, speech areas, and memory centers as they relate to an adjacent tumor. To further define anatomy, diffusion tensor MRI enables visualization of the white matter tracts, which may become invested by (glioma or multiple sclerosis) or displaced by (glioma, metastasis or abscess) a brain lesion. This knowledge is important because damage to white matter tracts during surgery may cause deficits similar to those from cortical damage. Both these technologies allow the neurosurgeon to define the best plane possible for safe removal of tumors with minimal morbidity.

Another MRI modality useful to the neurosurgeon is MR spectroscopy, which demonstrates the chemical composition in a chosen area of an MR scan. The 3 peaks of interest in MR spectroscopy are the phosphocreatine, choline, and *N*-acetyl aspartate peaks. By looking at the relationship between these peaks, MR spectroscopy can potentially help differentiate tumors from radiation necrosis and other abnormal signals.

There are 2 special concerns when obtaining MR images for stereotactic radiosurgery of tumors with either a gamma-knife or a linear accelerator-based system. The imaging sequences must maximize the detection of the tumor, its margins, and its anatomical relationship to the surrounding critical normal structures. In addition, it is essential that the image data be acquired such that the images can be used realistically for treatment planning and target delineation. Proper planning images have to provide sufficient spatial resolution for accuracy in target delineation during radiosurgery and must include visualization of fiducials. With frame-based stereotaxy, orientation of the frame is more important than of the head, so the images should not be rotated or angled. Usually, the MR images should be acquired with 1- to 3-mm slices, without skip or overlap, and the fiducials must be visible on the image set. MRI protocols can vary based on tumor type and location. For both intra- (such as glioma and metastasis) and extra-axial (such as meningiomas, schwannomas, and trigeminal nerves) tumors, T1W, high spatial resolution (1-3 mm) 3-D gradient echo recoiled volume type acquisition is essential for the contrast MR study, whereas FLAIR is critical to outline edema and/or nonenhancing parts of the lesion. For metastatic lesions images that cover the entire brain are preferred to look for early and the extent of metastatic deposits that are potential targets. A double dose of MR contrast agent is preferred, particularly for metastatic lesions to enhance the detection rate. For pituitary tumors, multiplanar orthogonal thin slice



FIGURE 1. The neurosurgeon uses an intraoperative navigation system based upon intraoperative MR imaging for real-time monitoring of the progress of tumor resection.

images are needed to delineate the extent of tumor and its close proximity to the optic apparatus.

Intraoperative MR can provide the capability to monitor real-time information during surgery and thus enhance tumor resection and minimize collateral damage (Fig. 1). The quality of imaging is generally inferior to that of standard MRI and may present some challenges during surgery (deformity of the brain, surgically induced changes, etc), yet intraoperative MR does provide valuable imaging-guided means for direct monitoring of the progress of resection to avoid critical structures aiming for better outcome (Fig. 2).

Advancement in nanotechnology may further revolutionize acquisition of contrast-enhanced MR images. Nanomedicine is the medical use of fabricated materials whose dimensions are generally less than 100 nm. Such products have their genesis in biomaterials laboratories and are finding more frequent clinical applications. The use of iron oxide nanoparticles is an excellent example of the application of these nanomaterials to the imaging of intracranial brain tumors. Unlike typical gadolinium-labeled MR contrast agents, iron oxide nanoparticles continue to reveal MRI contrast 24 to 36 hours after administration.³ Such prolonged residence of iron oxide contrast suggests that it could still be present after diagnostic imaging at the time of an operative resection. As such, this offers the tantalizing potential of linking fluorescent markers to the nanoparticles, which could allow for their direct intraoperative visualization and provide neurosurgeons with yet another tool to aid in the process of preoperative planning to intraoperative resection of brain tumors.⁴

Although MRI is the study of choice to evaluate tumors, it has some limitation. Compared with CT, MR is less sensitive in detecting tumor calcification and has only limited use for evaluating bony lesions. Also, patients with pacemakers or any other non-MR-compatible metallic implants cannot undergo MR evaluation for brain tumors.

Angiography

Angiography remains the standard criterion for evaluating the cerebral vasculature to which MR angiography, MR

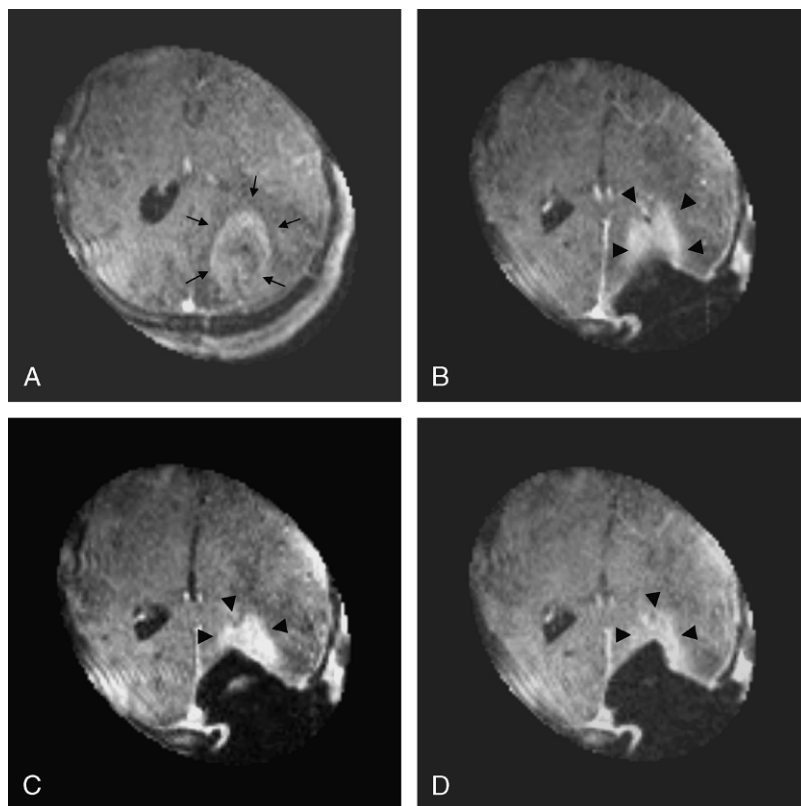


FIGURE 2. A left occipital glioblastoma multiforme is shown on perioperative MR (A, arrows), and the progress of excision is demonstrated in sequential intraoperative MR images (B, C, and D), showing progressive reduction of tumor volume and associated changes induced by the surgery (arrow heads).

venography, and CT angiography are compared. Angiography has a role in evaluating intracranial lesions by defining both arterial and venous anatomy as well as the vascular supply of brain lesions. This allows the neurosurgeon to identify major arteries and veins that are often displaced by the mass effect of the tumor and that may be encountered during surgery. Venous anatomy can be just as important, especially when one considers the risks of venous infarct. Understanding the cerebral vasculature anatomy is important for surgical planning to remove tumors. Angiography also has diagnostic value because highly vascular tumors are more likely to be malignant.

Angiography can also play a more proactive role in the treatment of brain tumors. Embolization has been successful in limiting blood loss in very vascular tumors, such as paraganglioma, large meningioma, and hemangiopericytoma, all extra-axial lesions. Embolization is not always indicated for the management of intra-axial tumors. Embolization can be accomplished with particles, such as polyvinyl alcohol, Embosphere, and more recently, Onyx, *N*-butyl cyanoacrylate, and other agents being introduced to the market. Although the risks of embolization are small, the procedure is limited by the ability to reach the tumor's arterial supply by a microcatheter. It is recommended that surgery be performed within 24 to 48 hours from the time of embolization.

Angiography can also be used to evaluate collateral blood flow in cases where the neurosurgeon is considering vessel sacrifice. An example would include a complex skull-based tumor that may surround one of the major vessels. In

such cases, complete resection may require the neurosurgeon to sacrifice such a vessel and rely on collateral circulation. A balloon occlusion test of the targeted vessel for at least 20 minutes with induced hypotension should precede any consideration for permanent occlusion of that vessel. The balloon occlusion test allows the neurosurgeon to determine the risk of stroke subsequent to sacrificing a vessel and whether the patient would benefit from a revascularization procedure before tumor resection.

Other Imaging Modalities

Nuclear medicine in neurosurgery consists primarily of bone scan and positron emission tomography (PET). The bone scan looks at the entire body and is useful in identifying the bony lesions of the skull seen in neoplastic processes, such as multiple myeloma or metastases. PET scans are used mostly for postoperative/radiation therapy evaluation. From the uptake of radioisotope in an area of interest, tumor recurrence and radiation necrosis can be differentiated. In contrast, ultrasound is mostly used for intraoperative evaluation of tumor. Although image guidance is usually helpful in resecting tumors, it has its own limitations. This may result from brain relaxation after craniotomy or other variables, for example, registration of reference points. In such cases, portable ultrasound can be used to help localize a tumor. Ultrasound imaging is also very helpful for cystic lesions. Finally, with the advent of modern imaging technology, myelography is rarely used for intracranial lesion but still has a limited role in evaluating spinal-based tumors.

IMAGING FOR SKULL-BASED TUMORS

Magnetic resonance imaging is invaluable to the skull base surgeon to define the 3-D relationships of the tumor and the skull base and vessels and nerves surrounding it. The MRI information needs to be supplemented by CT findings. Fusion of CT and MRI data sets, when the data sets are imported to an image-guided surgery platform, is extremely helpful in the selection and execution of surgical approach. Specifically, the fusion of CT and MR images on an image-guided platform helps the neurosurgeon when the petrous bone is drilled, from a posterior, lateral, or anterior direction. This fusion is also advantageous when performing complex anterior approach to the skull base.

Moreover, MRI may be invaluable at times in defining the intradural versus extradural location of the pathology. This information is important in selecting the appropriate surgical approach. For example, an extradural petrous apex lesion, such as an epidermoid or a petrous apex granuloma, may be well approached using a subtemporal extradural route, whereas an intradural petrous apex lesion, such as a meningioma, may require a pterional or a 1½ intradural approach. In addition to MRI and CT, angiography retains a place in planning and execution of skull base surgery. For example, measurements of pressure in the transverse-sigmoid junction once the sigmoid is temporarily occluded may help the skull base surgeon to decide whether the sinus may be safely sacrificed. Also, preoperative embolization of vascular skull base tumors, such as meningioma and hemangiopericytoma, may significantly decrease the intraoperative blood loss, making surgery safer.

IMAGING FOR SPINAL COLUMN TUMORS

The imaging modalities for spinal tumors are similar to those for intracranial tumors, aiming for localization, detection of extent of involvement, lesion characterization, treatment planning, and assessment of therapeutic response and outcome. They include x-ray, CT scan, MRI, angiography, nuclear medicine, ultrasonography, and myelography. These modalities have different limitations for spinal tumors than intracranial tumors.

Again, the modality of choice for spinal tumors is MRI. Based upon anatomical compartment, spinal tumors can be subdivided into 3 categories: intramedullary (cord), intradural extramedullary (cerebrospinal fluid space), and extradural lesions. It is possible, but rare, to have a lesion invade all 3 spaces. Other imaging modalities also play a role in the evaluation of the 3 subtypes of spinal tumors. Intramedullary tumors in adults usually correspond to astrocytoma and ependymoma. Metastatic lesions are rarely intramedullary. Also, intramedullary lesions that can mimic a tumor include demyelination, inflammation, or infectious process. A meningioma and schwannoma are examples of intradural extramedullary tumors. In all of these examples, it is important for the neurosurgeon to understand this differentiation to safely plan for surgery and be able to discuss the risks with the patient. Extradural lesions usually involve the vertebral bodies and mostly result from metastatic disease. Involvement of bony structure

is important to the neurosurgeon in determining the stability of the spine. In addition, metastatic lesions, such as renal cell carcinoma, can be extremely vascular and may be amenable to spinal angiography with embolization. Finally, determining the level and extent of the lesion is the most important aspect of spinal tumor imaging, especially when the thoracic spine is involved. There are occasions when the reading of the lesion's level varies by one vertebral body, depending on whether the level is determined by counting from the top or the bottom. The placement of markers during preoperative imaging can be extremely helpful in such cases.

Plain X-ray Film, CT, and Myelography

Plain x-ray film has its greatest role in clarifying extradural lesions involving bony structure, as in primary bone tumors, such as giant cell tumors or metastatic lesions (breast, prostate, lung, and kidney). In combination with myelography or use of intravenous contrast agents, plain x-ray can be of value for intradural extramedullary lesions and intramedullary lesions. As stated previously, plain x-rays are quick and easy to obtain. They can show osseous abnormalities in the vertebrae, and with the addition of intrathecal contrast agent (myelography), they can show obstruction, canal compromise, or enlargement of spinal cord associated with tumors. However, plain x-ray film technology has been set aside with the advent of CT reconstruction and CT myelography. Computed tomography technology provides much more detail to the neurosurgeon for planning a surgical approach, particularly with regard to the bony anatomy. With reconstruction images, CT provides axial, sagittal, and coronal view of the spine, which enables better visualization of the pathology. The 3-D reconstruction CT images further improve the delineation of the lesion and its anatomical relationship to the surrounding bony structure in a non-orthogonal fashion. All of these features are important in evaluating the extent of bony involvement and allow the neurosurgeon to determine how aggressive resection can be based on whether the patient can tolerate complex instrumentation, if needed. Noncontrast CT is most efficacious in evaluating destructive bony lesions.

The use of intrathecal or intravascular contrast agent in CT can help in evaluating intrathecal or intramedullary lesions. However, MRI has mostly replaced contrast CT for evaluating intramedullary and intrathecal lesions. Nevertheless, lesions, like intrathecal meningioma or intramedullary hemangioblastoma, do show enhancement on contrast CT study. Because the lesion to the background ratio or lesion contrast to the normal background is much higher on the contrast MR study as compared with that demonstrated on contrast CT study, computed tomography myelography is occasionally used for the evaluation of spinal tumors, including intradural extramedullary lesions, such as meningioma or extradural metastases. Further, it is helpful to look at spinal canal compromise or nerve root compression caused by the lesions. For intramedullary lesion, particularly for patients unable to obtain an MR study, CT myelography may show enlargement of the spinal cord at the level of the lesion.

Magnetic Resonance Imaging

Magnetic resonance imaging is the study of choice for all subtypes of spinal tumors. The most common primary intramedullary tumors of the spinal cord, astrocytoma and ependymoma, can cause a long segment of circumferential enlargement of the spinal cord that is associated frequently with the syrinx and occasionally with drop metastasis at the time of diagnosis. Astrocytomas are more prevalent in the cervical or thoracic spine and are hyperintense on T2W images and hypointense on T1W images. They may or may not display contrast enhancement. Ependymomas (myxopapillary type) occur more frequently in the conus medullaris or filum terminale and tend to enhance significantly. Hemangioblastoma is an example of an intramedullary vascular tumor, usually associated with von Hippel-Lindau disease, which has intense contrast enhancement. T2-weighted images can show serpiginous flow voids associated with feeding vessels to the hemangioblastoma. Although rare, intramedullary metastasis can occur, which can be differentiated from primary cord tumor as a focal enlargement of spinal cord with intense nodular enhancement and extensive edema extending many levels cranially and caudally.

Common intradural extramedullary tumors are meningiomas, nerve root tumors, and drop metastases. Similarly to cranial meningioma, spinal meningioma may show diffuse enhancement with dural tail and may erode into adjacent bony structure. Edema of the spinal cord is secondary to the mass effect of the lesion. Nerve root tumors include schwannomas and neurofibromas. Both have similar findings on MRI, and both enhance. One key feature of nerve root tumors is that they may extend extradurally, producing a dumbbell-shaped lesion. It may also cause remodeling of the neural foramina, which can be seen on CT. Drop metastases are usually best seen on contrast-enhanced T1W images and show up as either linear enhancement of the surface of the spinal cord (Lükenschädel) or dura. They may also present as nodular lesions involving the spinal cord, nerve root, or cauda equina. In children, ependymomas and medulloblastomas can have drop metastases. Workup of patients having these lesions usually includes complete MRI of the neuroaxis.

Metastatic lesions are much more common than primary bone tumor when it comes to extradural tumors. Extradural tumors can extend from the adjacent vertebral body into the spinal canal and compress the spinal cord. The most common metastatic lesions involve breast, prostate, lung, and kidney cancer. Although CT can show involvement of the bony structure, MRI permits visualization of dural extension of a tumor as well as any compromise of the spinal cord. Epidural extension is best seen on contrast-enhanced T1W images. Magnetic resonance imaging allows for visualization of vertebral body tumor because the fatty marrow is replaced by tumor cells, which have higher water content. Metastases appear with low intensity signal on T1W images and are hyperintense on T2W images. Primary bone tumors, such as osteoid osteoma, osteoblastoma, and vertebral hemangioma, can also be evaluated with MRI. Epidural hemangioma may be of nonosseous origin

(extremely rare)⁵ or, more commonly, be an extension of a vertebral hemangioma. They enhance brightly with gadolinium secondary to their extreme vascularity and may contain flow voids on T2W images.

Other Imaging Modalities

Nuclear medicine in spinal tumors is limited to bone scan, which provides excellent screening for the extent of metastatic disease of the spine and the rest of the body's bony structures. As in intracranial tumors, the role of ultrasonography is limited to intraoperative use for localization of intradural or intramedullary tumors. It is used more frequently for spinal tumors than intracranial tumors. The use of angiography in spinal tumors is usually limited to vascular lesions, such as hemangioblastoma, hemangioma, and renal cell carcinoma. Preoperative angiography defines the vascular anatomy of these lesions and determines which vessels are safe for embolization. Embolization reduces blood loss and helps the neurosurgeon during surgical resection of these tumors. Finally, knowledge of the location of the Adamkiewicz' artery location is critical to the neurosurgeon before any tumor resection that could affect the vessel.

CONCLUSIONS

Whether dealing with spinal or intracranial tumors, the goal of neuroimaging for a neurosurgeon is the ability to build a 3-D model of the tumor and awareness of surrounding tissue or vasculature so that tumor can be safely biopsied or removed. Tumor mimicking pathological processes needs to be excluded. For the imaging of intracranial tumor (MR frequently the study of choice), the imaging protocol should include all 3 orthogonal imaging planes with and without contrast agent to define tumor location as of either intra- or extra-axial origin and assess its extent of involvement. Similar to the imaging of brain lesions, imaging of spinal tumors must help to precisely define level of involvement, generate differential diagnosis, and define anatomical location (intradural, intramedullary, and extradural). The advances in imaging coregistration methodologies that fuse all modern imaging modalities, including MR, CT, and PET, further enhance the neurosurgeon's ability to manage CNS tumors and improve treatment outcome.

REFERENCES

1. Alper MG. Three pioneers in the early history of neuroradiology: the Snyder lecture. *Doc Ophthalmol.* 1999;98:29-49.
2. Pilling JR, Hawkins TD. Distribution of calcification within the pineal gland. *Br J Radiol.* 1977;50:796-798.
3. Enochs WS, Harsh G, Hochberg F, et al. Improved delineation of human brain tumors on MR images using a long-circulating, superparamagnetic iron oxide agent. *J Magn Reson Imaging.* 1999;9:228-232.
4. Kircher MF, Mahmood U, King RS, et al. A multimodal nanoparticle for preoperative magnetic resonance imaging and intraoperative optical brain tumor delineation. *Cancer Res.* 2003;63:8122-8125.
5. Baig MN, Syed S, Caragine LP Jr. Spinal epidural hemangioma: utility of intraoperative sodium tetradeceyl sulfate. Paper presented at: 2006 Congress of Neurological Surgeons Annual Meeting; October 7-12, 2006; Chicago, IL.