Pediatric Neuroimaging for the Pediatrician

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With the application of increasingly complex technologies to pediatric neuroimaging, the task of ordering the appropriate study for specific clinical presentations has become increasingly complex. The pediatrician faced with a neurologic clinical question needs to know not only what question he or she needs answered, but also which tools are available, the strengths and weaknesses of those tools, and the most efficient way to use those tools to reach a diagnosis.

This article describes the terms and tools of pediatric neuroimaging, and discusses specific clinical presentations along with the imaging techniques most appropriate to their workup.

EDUCATIONAL OBJECTIVES

1. Review the major neuroimaging modalities currently available for use in the pediatric population.
2. Determine the relative advantages, disadvantages, costs and limitations of the currently available pediatric neuroimaging modalities.
3. Discuss the selection of appropriate imaging techniques for specific clinical settings.

Modalities and Techniques

There are several modalities relevant to pediatric neuroimaging and many specific techniques within each modality. Some techniques involve the use of ionizing radiation. This poses some risk to the patient, a risk that increases with increasing radiation dose. It is a basic tenet of medical radiation use that dose be kept as low as possible without compromising the diagnostic quality of necessary studies. There are many ways to minimize radiation dose to the patient without compromising the diagnostic quality of studies. These include shielding, selection of proper technique, coning on the area of interest, and limiting the use of radiation-delivering studies to those cases in which the studies will offer significant diagnostic or therapeutic benefit.

Plain Radiographs and Fluoroscopy

In pediatric neuroimaging, plain radiographs are most useful for assessing the location and course of ventricular catheters, assessing skull morphology, detecting and documenting skull fractures in cases of suspected child abuse, assessing the alignment of the spine, and screening the spine for fractures. Although relatively inexpensive and noninvasive, plain radiographs involve radiation and its risks. The radiation dose of a plain radiograph is much lower than that of a computed tomographic (CT) scan.

Fluoroscopy uses continuous x-rays, which pass through the patient to a detector that renders a live, continuously updated image. The technique can be useful for assessing the cervical spine for instability during flexion and extension, as well as for diagnostic and interventional pro-

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cendures. As with plain film radiography, the radiation dose used for fluoroscopy poses some risk to the patient. Fluoroscopy is more expensive than plain radiographs but less expensive than ultrasound or cross-sectional imaging.

**Angiography**

During an angiogram, the radiologist uses catheters and contrast material with fluoroscopy to examine vessels for malformations, aneurysms, aberrant vascular branches, and stenoses and to determine the vascular supply of neoplasms and vascular malformations. Interventional procedures such as embolizations depend on angiography for targeting, treating, and reassessing lesions.

Some lesions are located in regions difficult to access safely using open surgical techniques, and are more safely treated using angiographic techniques. Endovascular techniques such as embolization or angioplasty can be used to treat some lesions, obviating an open surgical procedure. Angiographic images of vascular lesions offer better spatial resolution and are less susceptible to artifacts than CT angiography or magnetic resonance (MR) angiography, which are discussed later (Figs. 1, 2, and 3). Angiographic techniques are expensive, invasive, and can give the patient a large radiation dose.

**Ultrasound**

Sonography uses high frequency sound waves to locate the depth and morphology of structures within soft tissues or fluid. It is useful in the first few months of life in assessing intracranial hemorrhage, ventricular size, extra-axial fluid spaces, periventricular leukomalacia, and spinal abnormalities such as tethered cord or meningocele.

The risk of injury to the patient from sonography is considered extremely low, and the technique is less expensive than other cross-sectional modalities. Generally, it is better tolerated by nonsedated children than CT or magnetic resonance imaging (MRI). However, ultrasound requires an adequate “acoustic window” of tissue through which the sound beam can pass easily. Since sound waves cannot penetrate thick bone, certain regions of the brain and spinal cord may be difficult to evaluate with ultrasound, and ultrasound is less useful as the fontanelles close and the posterior elements of the spine ossify. In general, spinal ultrasound becomes technically limited after the age of 4 months. The timeframe of fontanelle closure is fairly broad, but generally cranial ultrasound is limited by 8 to 12 months of age.

The need for an acoustic window requires that the transducer be held over the fontanelles and angled in order to see off-midline structures. Because there are limits to the angle that can be used, structures and lesions that are sig-
significantly off-midline may be not be visible. This may cause extra-axial fluid collections and masses as well as peripheral intraparenchymal lesions to be missed by ultrasound.

Thin bone can be penetrated by the ultrasound beam: in order to interrogate vascular flow within the Circle of Willis, the operator can penetrate thin portions of the calvarium using a technique known as transcranial doppler (TCD). Passage of the ultrasound beam through even thin bone, however, causes significant attenuation; this degrades resolution to the point that the parenchyma cannot be evaluated in detail.

Ultrasound is susceptible to artifacts caused by the sound beam being reflected off gas or bone, and the quality of the images is highly dependent on the skill of the operator. However, it is less expensive than cross-sectional imaging, uses no ionizing radiation, and can be performed portably at the bedside on patients who are unstable or difficult to transport.

**Computed Axial Tomography**

Computed tomographic scanners generate a narrow x-ray beam that passes through the patient and is projected onto one or more detectors. The beam/detector array is rotated so that multiple angles are used to image a "slice" of patient tissue. A computer uses a reconstruction algorithm to interpret the different values of beam attenuation at each angle and to generate a two-dimensional image that represents the densities of tissues in the slice. High attenuation (i.e., more radio-dense) tissues are represented in white, low attenuation tissues in black, and intermediate attenuation tissues are represented on a gray scale.

Computed tomography is an excellent modality for detecting hemorrhage, hydrocephalus, or mass effect, and for evaluating primary bone lesions, fractures, and craniosynostosis.

Until recently, all CT scanners obtained each slice separately. Newer helical or "spiral" scanners acquire images very rapidly. A helical scanner rotates its beam and detector array continuously while the patient is moved through the scanner on a motorized table. By accounting for the rate of motion of the patient, the machine can calculate and display the location of each tissue density in three dimensions. The resulting image slices look similar to images acquired axially. Whereas an axial scan of the chest, abdomen, and pelvis may take 60 seconds, a helical scan through the same tissue would take 20 seconds. This difference becomes significant when patients are medically unstable, cannot hold still, or when moving structures such as the lungs are being imaged and it is desirable to cover a large anatomic region during a single breath hold. Rapid scanning is also crucial during CT angiography, because the bolus of contrast moves quickly through the vessels being imaged, and the scanner must cover the region of interest before the contrast bolus disappears.

Computed tomographic angiography involves the injection of an intravenous contrast bolus followed immediately by scanning through the region of interest, so that the lumen of the vessels is as bright as possible. Postprocessing is then used to construct a three-dimensional model of the vessels, which can be rotated so that the vessels can be seen in multiple projections. This technique is less susceptible to slow intravascular flow than MR angiography but is not as effective as MR angiography in studying vessels in close proximity to bony structures.

Computed tomography is more expensive than most other modalities. It is prone to artifact from bone, and therefore may be less sensitive in evaluating lesions of the posterior fossa than MRI. Computed tomography is limited to scanning in the axial and coronal planes; therefore, lesions such as Chiari malformations, subtle enhancement of the dura of the floor of the cranial vault, and brainstem lesions are better seen with MRI than with CT (Figs. 4 and 5, page 664).

Computed tomography involves the highest radiation dose of any modality except a prolonged fluoroscopic procedure. The use of CT in children has recently received attention for its potential to cause cancer later in life. However, measures can be taken to decrease the radiation dose to the patient substantially, particularly in the pediatric population, without compromising diagnostic quality. Computed tomography can offer significant diagnostic value in many situations, and when there is an appropriate indication for its use, its potential benefit to the patient far outweighs its risk.
referring clinician and the radiologist is particularly crucial when an MRI is being performed.

Magnetic resonance imaging is capable of generating angiographic data as well. By interrogating tissues containing flowing blood, the scanner can generate two-dimensional images of blood vessels. The computer can then stack these images and generate a three-dimensional model of the vessels, which the operator can rotate on the workstation. Alternatively, the scanner can acquire a three-dimensional volumetric data set directly. These methods can help display the vessels and enhance detection of vascular anomalies, aneurysms, stenoses, malformations, and aberrant vessels.

Magnetic resonance imaging is particularly useful for detecting subtle differences between soft tissue types, based on their compositions. It is therefore the study of choice when looking in the brain parenchyma for neoplasms, inflammatory lesions, and juxtaposed gray and white matter structures. Unlike CT, MRI is impervious to artifact from bone, and therefore is much more sensitive than CT when evaluating structures within the posterior fossa and adjacent to bone.

Magnetic resonance imaging is the most expensive of the cross-sectional imaging modalities. It is also the most prone to motion artifact, because the images are generated over the course of a few minutes, rather than fractions of a second as with plain radiographs and fluoroscopy, or than the few seconds required by CT. In addition to motion artifact, MRI is prone to artifact from metallic implants and dental braces. It also requires that the patient be placed in a long tube, which makes it difficult to monitor the patient visually during the scan. If the patient is on a ventilator or continuous intravenous infusion, special support equipment including long intravenous tubing and electronic monitoring equipment compatible with a strong magnetic field is required.

There is currently no known significant risk from MRI, although the technology is new enough that very long-term follow-up studies to assess potential risk have not yet been possible. However, patients with implanted metallic devices, aneurysm clips, prostheses, cardiac pacemakers, or ocular metallic foreign bodies may be harmed by exposure to the strong mag-
netic field of the MR scanner. Therefore, such patients must be assessed on an individual basis before being placed in the scanner.

**CLINICAL APPLICATIONS**

Following are examples of specific clinical situations in which the pediatrician may want to order imaging examinations, with a brief discussion explaining which modality is most appropriate, and why.

**Premature Infant**

Premature infants are at risk for subependymal, intraventricular, and intraparenchymal hemorrhage as well as the subsequent development of periventricular leukomalacia. Intracranial ultrasound is useful in evaluating premature infants for these conditions. It does not involve radiation, and can be performed portably at the bedside of unstable patients, while clinicians and nurses administer other supportive and therapeutic interventions. This can be extremely important in critically ill infants, who may require serial scans and who cannot safely be transported.

**Birth Trauma: Premature or Term**

In the case of the full-term newborn who has undergone a traumatic vaginal delivery and has a seizure, CT without contrast is the single best test for the identification of intracranial trauma and bony injury. In the child with low Apgar scores after prolonged labor complicated by evidence of fetal distress, MR and MR spectroscopy may provide helpful information regarding the presence or extent of hypoxic-ischemic injury. However, the stress of the environment of the MR suite may be an unjustified risk to the health of these fragile children, and ultrasound at the bedside is more than adequate to exclude a surgically treatable complication.

**Abnormal Head Circumference**

In the child with nonfused cranial sutures, increased head circumference is a good indicator of disturbances in cerebrospinal fluid production and resorption, and can indicate obstructive hydrocephalus (from congenital or acquired causes). In the infant with an increased head circumference, ultrasound can detect increased extra-axial fluid, and enlargement of the ventricles, as well as obstructive lesions. However, despite the advantages of ultrasound, including decreased radiation and decreased cost, in many instances a follow-up CT is indicated regardless of whether the ultrasound exam is positive or negative. For example, an ultrasound may reveal a lesion that would be seen better with CT, because of its location or potential for contrast enhancement. Conversely, if the ultrasound is negative, although this may provide immediate clinical reassurance, there may be a later need to exclude a lesion such as subtle extra-axial hemorrhage in a region difficult to see by ultrasound.

In the setting of head growth at a rate greater than expected, CT is often employed to evaluate the size of the ventricles, extra-axial fluid spaces, and basal cisterns. Both communicating and non-communicating hydrocephalus can be detected.

A circumference measurement less than normal for age can indicate loss of brain parenchyma (from prior injury or a progressive degenerative process). Premature fusion of cranial sutures may result in either an increase or decrease in circumference measurements. When an abnormal head circumference measurement or head shape raises the question of craniosynostosis, CT is generally the study of choice. Although plain films are sensitive in the detection of premature suture fusion, CT protocols can be performed with three-dimensional reconstruction techniques that are extremely helpful to the neurosurgeon in planning reconstructive surgery.

**Seizure**

Whether or not the child presenting with a seizure requires imaging at all has been studied carefully, and specific recommendations have been proposed. In the case of a first nonfebrile seizure, when the seizure itself was the sole indication to obtain a scan, there is a consensus that imaging is not warranted because of the low likelihood of finding a significant underlying abnormality. It has also been suggested that imaging is not warranted in the child aged 6 months to 6 years presenting with an otherwise uncomplicated febrile seizure.45

However, a child of any age exhibiting a postictal focal deficit that does not resolve rapidly, or who does not return to baseline within several hours of
the seizure, deserves emergent neuroimaging. The purpose of imaging in such cases is to detect a serious condition requiring rapid intervention. Such conditions would include acute hemorrhage or the presence of a mass, mass effect, or edema. For this purpose, CT is most appropriate, as it is sensitive to these conditions and can be performed rapidly, usually without sedation, while allowing close clinical monitoring of the patient.4

Nonurgent imaging may be appropriate in any child “with a significant cognitive or motor impairment of unknown etiology, unexplained abnormalities on neurologic examination, a seizure of partial (focal) onset with or without secondary generalization, an electroencephalogram that does not represent a benign partial epilepsy, or in children under 1 year of age.”4 Such imaging is most appropriately performed with MRI. While most imaging studies in children with seizures identify no abnormalities whatsoever, the increased sensitivity of MR in detecting subtle parenchymal abnormalities makes it the modality of choice in the nonurgent imaging of the child with seizures.

The multiplanar capability and capacity to evaluate metabolites with MR spectroscopy further enhance the sensitivity and versatility of MRI in this arena. Magnetic resonance imaging is the best method we have to identify and characterize intracranial tumors, congenital malformations, sequelae of prior injury, metabolic or degenerative diseases, and neurocutaneous syndromes, all of which may present with seizure activity.

Neurologic Abnormalities With Fever

In the clinical setting of a child with signs of infection/inflammation and neurologic abnormalities, imaging is generally indicated for the identification of complications of the infection, rather than as the primary diagnostic tool. Imaging should not be seen as a substitute for any component of the sepsis workup. More specifically, imaging is relatively insensitive for the detection of central nervous system inflammation when compared to cerebrospinal fluid analysis; only the more severe cases of meningitis will be detected by imaging. Generally speaking, MR is the study of choice when imaging the central nervous system for infection/inflammation.

It is much more sensitive and specific than CT in the detection and characterization of encephalitis, meningeal inflammation, and focal abscesses. This sensitivity is even greater when the spinal column is considered. Computed tomography is helpful in the specific evaluation of bony erosion or osteomyelitis.

Developmental Delay

Developmental delay is a term that encompasses a broad range of abnormalities in the neurological development of a child. The breadth of this clinical presentation is beyond the scope of this report, but in the investigation of children with developmental delay MRI is the imaging modality of choice. In addition to screening for congenital anatomic abnormalities including cortical dysplasias, migrational abnormalities, and volume loss, MRI often can detect signal abnormalities in regions of the brain that appear morphologically normal on CT or ultrasound. It is clearly the best modality for evaluation of the status of myelination of white matter tracts, and of gray and white matter volume. Metabolic and neurodegenerative diseases are often best characterized by MR. Magnetic resonance spectroscopy can provide information that would prompt a search for an underlying metabolic abnormality in cases where none was suspected, or to narrow the differential possibilities when a metabolic condition is suspected.

Trauma to the Brain, Skull, and/or Face

One of the most common issues in imaging of traumatic injury to the head is whether and when to obtain plain radiographs of the skull. Plain radiographs are more sensitive than CT images for linear, nondiastatic, nondepressed skull fractures, particularly those oriented in the axial plane. However, skull radiographs are generally not indicated in the workup of acute trauma. If there is soft tissue swelling but no palpable step-off to suggest a depressed skull fracture, the likelihood that there is a fracture requiring treatment is low. Moreover, the identification of a nondepressed skull fracture on radiographs is unlikely to alter clinical management. In the presence of a palpable step-off suggesting a depressed skull fracture, CT is more accurate in determining the degree of step-off. This is important to the neurosurgeon, who will generally
elevate fractures that are depressed by greater than one calvarial thickness. At the same time, CT is more useful than plain films because it can evaluate the adjacent brain parenchyma and extra-axial fluid spaces. Computed tomography can show accompanying parenchymal injuries and intraxial or extra-axial hemorrhage; these are not detectable by plain film.

There is one notable exception to this approach. In the setting of suspected child abuse, the increased sensitivity of radiographs relative to CT becomes germane. Because of the importance of documenting every injury in these instances, plain radiographs of the skull should always be performed as part of the evaluation of the child who may have been abused (Fig. 6).

In the setting of a focal neurologic deficit following head trauma, CT is the study of choice. It can be performed very rapidly and can detect acute intraparenchymal or extra-axial hemorrhage or mass effect. Focal or diffuse edema can be identified by CT, although MR has some increased sensitivity for these lesions. However, CT can be acquired more quickly, and patients are more easily monitored in the CT scanner. Finally, CT may reveal unsuspected fractures, which may help document that trauma did occur if the history is unclear.

Outside of the acute setting, MRI can be very helpful in the evaluation of the child with central nervous system trauma. It is exquisitely sensitive to edema and to hemosiderin deposition, which is associated with hemorrhagic contusion and shear injury. The extent of intracranial injury identified by MR one week after trauma is often much greater than that seen on CT studies (Figs. 7-9).

If facial fractures are suspected, performing plain films as a screening test is generally not indicated. Plain films are far less sensitive than CT for subtle fractures, and in the case of orbital fractures may miss important findings such as entrapment of orbital fat or of extra-ocular muscles, or extension of fractures into the paranasal sinuses. To obtain the most detail and optimize diagnostic accuracy, CT of the facial bones consists of thin sections acquired directly in the axial and coronal planes. That is, the patient is scanned twice: once in the conventional axial plane, usually while supine, and once either supine or prone, with the neck extended and the CT gantry angled to obtain direct coronal images. In the child who cannot be imaged directly in the coronal plane due to cervical spine injury or clinical instability, thin axial sections can be obtained, and coronal reconstructions can be generated from these. The diagnostic quality of these coro-
nal reconstructions is often quite good, although not as good as images scanned directly in the coronal plane.

If a fracture of the temporal bone is suspected, axial and coronal CT thin sections should be obtained, and can provide exquisite detail of the structures of the temporal bone. The precise location of fractures and status of the ossicles, semicircular canals, facial nerve canal, vestibule, internal auditory canal, and carotid and jugular canals can all be determined.

When vascular injury is suspected as a complication of cranial trauma, MR angiography is a useful tool to evaluate for dissection. While conventional angiography may still be indicated in some cases, a good quality magnetic resonance angiography can effectively exclude the presence of a dissection of the major cranial arteries.

### Headache

As with seizures, the key element regarding imaging of children with headaches is whether imaging is indicated at all. The overwhelming majority of children with headaches without an accompanying neurologic deficit have normal imaging studies, regardless of the modality used. Therefore, imaging should be reserved for those children with atypical clinical presentations that could indicate an underlying lesion or the diagnosis of a headache syndrome (migraine, etc.) Because of the risks of ionizing radiation exposure to children, CT in the nonacute setting should be avoided. Its only advantages over MR in the evaluation of chronic headache are increased sensitivity to bony lesions and greater availability and tolerance by patients. It may be justified to perform CT for chronic headaches in a child who would require sedation for an MR study but can tolerate the much quicker CT study without any sedation. In this scenario we generally perform CT with intravenous contrast, which is more sensitive in the detection of neoplastic or vascular lesions than CT without intravenous contrast.

If imaging is indicated clinically in the setting of acute headache, a CT scan without contrast should be performed. This study can be obtained very quickly and is very sensitive in the detection of intracranial hemorrhage, mass lesion, or ventricular enlargement. Positive exams can be followed-up with MR or contrast-enhanced CT, depending on the nature of the disclosed abnormality.

In the setting of hydrocephalus due to obstruction by a Chiari I malformation, although CT may suggest the diagnosis, MRI is much more useful in providing detailed evaluation. Magnetic resonance imaging allows not only imaging in the sagittal plane, which is more useful than axial imaging in this setting, but it also allows direct visualization of the cerebellar tonsils and the cerebrospinal fluid volume surrounding the tonsils in the foramen magnum. The degree of effacement of cerebrospinal fluid is useful for assessing the presence and severity of any obstruction. Magnetic resonance cine images can give even more useful information by providing a "movie" showing whether the normal cerebrospinal fluid flow past the cerebellar tonsils is obstructed (Figures 4 and 5, page 664).

### Acute Onset of Neurologic Deficit

There is a limited differential for the child who presents with the spontaneous acute onset of a neurologic deficit. The possibilities include cerebral infarction, hemorrhage from a vascular malformation, and neoplasm. In these instances MR imaging is generally the single best examination. But the limitations in availability and tolerance may make CT a more attractive choice. Almost any lesion presenting with the acute onset of a neurologic deficit that is amenable to immediate intervention can be detected with CT. The lone exception may be an early ischemic stroke. Centers that are equipped to treat children with acute ischemic stroke aggressively using thrombolytics should have a predetermined imaging protocol that takes into account the sensitivity, specificity, and logistical hurdles presented by both imaging modalities. Magnetic resonance with diffusion imaging is a very sensitive means of detecting the extent, distribution, and severity of brain injury caused by ischemia or infarction. Magnetic resonance imaging can therefore document ischemia or infarct as a cause of new symptoms, and help establish prognosis.

When a vascular lesion is identified or suspected as the source of an acute neurologic deficit, magnetic resonance angiography (MR...
angiography) is an exceedingly helpful tool to detect aneurysms, arterio-venous malformations, arterial dissections, arterial stenoses, and arteriopathies. Magnetic resonance angiography is not prone to artifact from adjacent bone, making it ideal in evaluating vessels in close proximity to bone, such as the petrous segments of the internal carotid arteries. In this manner, catheter angiography can be avoided until catheter-directed or surgical treatment of the lesion can be performed.

Recent advances in CT angiographic techniques have improved the utility and sensitivity of this modality, and there are certain situations in which CT angiography is superior to MR angiography. Unlike MR angiography, which relies on the signal within flowing blood to generate images, CT angiography relies on the presence of intraluminal radiopaque contrast to demonstrate the configuration of blood vessels. It is thus less prone to some of the artifacts that can limit MR angiography, such as slow blood flow through the lesion. In patients with metallic implants precluding MRI scanning, or who need very close clinical monitoring, CT angiography should be considered as an alternative to MR angiography.

**Sensorineural Hearing Loss**

For most conditions affecting the temporal bone, CT is the preferred imaging modality. Thin axial sections are obtained when there is a clinical question of sensorineural hearing loss. These images exquisitely delineate the anatomy of the otic capsule, identifying the subtle dysplasias that can present as sensorineural hearing loss in children. If there are findings on these sections requiring further evaluation, thin coronal sections are obtained. In the setting of conductive hearing loss, trauma, cholesteatoma, or any pathology suspected primarily to involve the middle ear, both axial and coronal images are routinely acquired.

Magnetic resonance imaging of the temporal bone is generally reserved for the evaluation of cranial nerve inflammation, extrinsic compression, or neoplasm. As the availability of MR scanners increases, however, it may replace CT as the primary modality for evaluation of inner ear dysplasias. Magnetic resonance imaging can also be used to evaluate the temporal bone itself for neoplasm or inflammation.

**Spine: Tethered Cord**

The selection of an imaging modality for suspected tethered cord depends on the age of the patient. In infants younger than four months, ultrasound offers excellent images of the cord, including the conus medullaris, filum terminale, and cauda equina. The presence or absence of motion of these structures can be assessed, and the level of the conus can be determined. If there is a skin lesion such as a sacral dimple or hair patch causing clinical concern, the tissue deep to the lesion can be imaged, and abnormalities such as a sinus tract or lipoma sought.

In children older than 4 months, ultrasound generally cannot penetrate the ossified tissues surrounding the cord, and therefore MRI becomes the study of choice. Distal spinal anatomy can be seen clearly with MRI, and sagittal cine images can be obtained which, like ultrasound, show the normal motion of these structures. The subcutaneous tissues are also very well seen on MRI; in fact, MRI can be used to evaluate these tissues when questions about them are raised by an ultrasound examination.

**Spine: Trauma**

Plain radiographs remain the initial study of choice. The alignment and height of the vertebral bodies and posterior elements can be assessed, as can the relationships of the facets. If further evaluation of a bony abnormality is warranted, CT is usually the best modality. Thin axial CT sections can be acquired through the area of concern, and sagittal and coronal reconstructions can be generated from the primary axial data.

Magnetic resonance imaging is more sensitive than CT if the primary clinical question is whether there has been ligamentous or other soft tissue injury or injury to the spinal cord itself. The disadvantages of MRI in this situation are that the patient cannot be as closely monitored during the examination, the examination takes longer to perform, and MRI is much less sensitive for fractures than CT.

**Spine: Abnormal Curvature**

In patients with abnormal curvature of the spine, standing frontal and lateral plain radiographs are excellent tools both for screening and for follow-up. If findings on radiographs suggest
an abnormal vertebral body, spondylolysis, or a focal bone lesion such as an osteoid osteoma, CT focused to the area of interest can be used. When the presentation or progression of spinal curvature abnormalities is atypical, MRI can be useful in the investigation for an underlying spinal cord lesion. Occasionally spinal cord tumors or congenital malformations may present in this manner. Spinal MRI may also be helpful to the orthopedic surgeon in the preoperative evaluation of children with scoliosis, especially in more severe cases.

Spine: Inflammation, Neoplasm

Magnetic resonance imaging is preferable to CT in evaluating inflammatory and neoplastic lesions of the spine due to its superior ability to resolve abnormalities of the paravertebral soft tissues, the intervertebral disks, and abnormalities of bone parenchyma such as edema. Neoplasms containing primarily osseous, chondroid, or calcified elements are an exception to this, as CT can resolve the matrix of such tumors better than can MRI. Also, CT offers better detail regarding the extent of bony destruction in inflammatory and neoplastic lesions than does MRI (Figs. 10 and 11).

When there is clinical suspicion of an inflammatory or neoplastic lesion of the spinal cord, dural sac, or nerve roots, the resolution of these structures and multiplanar capability offered by MRI makes it the preferred imaging modality. This is true both for initial screening evaluations and for follow-up examinations in children with primary spinal neoplasms, spinal metastases, or inflammatory conditions of the spinal cord and surrounding structures.

CONCLUSION

Recent improvements in imaging technology have provided a wide range of tools allowing the pediatric neuroradiologist to answer clinical questions quickly and accurately. However, the first step in imaging is to select the appropriate modality and technique to answer the clinical question at hand. To do this, there must be effective communication between the pediatric neuroradiologist and the pediatrician.

REFERENCES