Correlative Pediatric Imaging

Itzak Garty, Dominique Delbeke, and Martin P. Sandler

Vanderbilt University Medical Center, Department of Radiology, Nashville, Tennessee

Nuclear medicine, ultrasound, and magnetic resonance imaging (MRI) are considered ideal imaging modalities for pediatric patients. The future is even more promising for pediatric imaging with the development of newer and improved radiopharmaceuticals, instrumentation and diagnostic modalities such as positron emission tomography, labeled monoclonal antibodies, and faster dynamic and contrast enhanced MRI methods. However, correlation of more conventional imaging modalities with nuclear medicine, ultrasound and MRI remain essential for optimal patient care.

J Nucl Med 30:15–24, 1989

The recent technological advances in nuclear medicine, the introduction of new short-lived radiopharmaceuticals, and improved detector systems have considerably minimized the radiation exposure to pediatric patients. This has led to the dramatic development of nuclear medicine as a pediatric imaging modality over the last decade.

Magnetic resonance imaging (MRI) in children is a promising modality, due to the lack of radiation exposure, superior anatomic resolution, and exquisite soft-tissue contrast capability. In some disease categories, MRI is complementary to other imaging modalities such as computed tomography (CT), ultrasonography (US) and nuclear medicine (*1,2*). However, MRI is rapidly replacing CT as the study of choice in the evaluation of neurological disease.

The following is a survey of correlative imaging in the pediatric-age group organized by anatomic regions.

BASIC CONSIDERATIONS

The imaging principles of nuclear medicine, US, and CT are well established. In nuclear medicine techniques, the radiolabeled pharmaceutical is designed to localize in the organ of interest allowing assessment of morphology and physiologic function.

Magnetic resonance imaging makes use of magnetic fields and radiofrequency (RF) waves applied in specific pulse sequence to image selected slices in the body with image contrast determined by tissue characterization. Magnetic resonance imaging is considered absolutely safe since no radiation is used. However, this diagnostic modality frequently requires sedation for young children who are not able to be motionless for several minutes.

The MRI technique may be applied in any plane: axial, coronal, and sagittal. An advantage of MRI over CT is that images are constructed from data acquired in the chosen image plane and not reconstructed from data acquired in another plane.

CLINICAL APPLICATIONS

Central Nervous System

With the introduction of cranial CT the role of radionuclide imaging of the central nervous system in children has changed. Radionuclide studies still have an important role over other modalities, for the diagnosis of brain death (*3*), encephalitis (*2,4*), minimal cerebrovascular disease (*5*), arterio-venous malformations (*6*), and assessment of dural sinus patency (*7*). Radionuclide studies in children are especially valuable in critically ill patients because of the mobility of this technique.

Magnetic resonance imaging seems to be advantageous over CT in a wide spectrum of pediatric brain disorders, with the exception of acute head trauma and possibly herpes encephalitis. These advantages include: (a) lack of bone artifact, (b) increased contrast between normal and abnormal brain, (c) ability to choose non-axial planes, (d) good delineation of the posterior fossa where CT is weak, and (e) lack of ionizing radiation. Although the inability to detect calcification is a relative weakness of MRI, it clearly detects more cerebral abnormalities than CT and characterizes them better. In addition, MRI is particularly advantageous for evaluating children, as most childhood brain tumors occur

Received Aug. 23, 1988; revision accepted Sept. 21, 1988.

For reprints contact: Martin P. Sandler, MD, Dept. of Radiology, Vanderbilt University Medical Center, Nashville, TN.

in the posterior fossa and tumors that are sometimes missed by MRI (such as meningioma, acoustic neuroma and pituitary adenoma) are rare in children.

Brain death. The definition of brain death has been a subject of considerable discussion in the literature (*2*). When cardiopulmonary processes are artificially maintained, neurological criteria must be used to assess whether brain function has irrevocably ceased. With the widespread usage of brain metabolic suppressive therapy (e.g., barbiturate coma and hypothermia), cerebral blood flow studies become more accurate for the assessment of irreversible neurological loss than electroencephalography. Conventional and digital arteriography are useful tools for assessment of cerebral flow, but they are invasive and cannot be performed at the bedside. Radionuclide imaging has a threshold advantage over other modalities in the assessment of brain death being noninvasive, portable, and of reliability equal to that of angiography (*3*). Scintigraphic findings diagnostic of brain death include absence of cerebral perfusion and nondelineation of the dural sinuses on radionuclide angiography and the immediate postinjection static study. However, persistent superior sagittal sinus activity in the face of absent arterial flow may be the result of drainage of extradural flow from external carotid distribution and can be seen in brain death.

The MRI findings of brain death include patchy infarction in the anterior, middle, and posterior cerebral territories, as well as extensive venous thrombosis (*2*). However, at present, MRI is not a reliable procedure to assess blood flow and therefore brain death. In addition, its lack of portability makes its routine use unsatisfactory.

Cerebral vascular disorders. Brain scintigraphy is sensitive to detect minimal cerebrovascular diseases in children who have suffered respiratory arrest with diffuse cerebral hypoxia, and neonates with severe respiratory difficulties during delivery (*5*). The recent development of radiopharmaceuticals, such as iodine-123 (^{123}I) iodoamphetamine (IMP), iodine-123 HIPDM and more recently technetium-99m (^{99m}Tc)HM-PAO (*8*) and thallium-201 DDC (*9*), allows one to assess cerebral perfusion with SPECT. The scintigraphic patterns obtained with these agents have paralleled those obtained with PET (*2*).

Intracranial tumors. In children, over 70% of intracranial tumors arise in the posterior fossa. The overall sensitivity of radionuclide brain imaging in detection of posterior fossa tumors is ~80%.

However, the studies of choice in tumors of the brain and skull are CT and MRI (*2,10*). Magnetic resonance imaging is exquisitely sensitive in the detection of intracranial tumors, approaching 100% if quality T2 images are obtained (*10*). Sensitivity is superior to CT but it is not yet clear whether MRI will offer enough specificity to permit a tissue diagnosis (*2*).

Two frequent limitations of CT are the inability to distinguish tumor from adjacent brain edema, and recurrent tumor from postsurgical or radiation changes. Contrast enhanced MRI using gadolinium-diethylenetriaminepentaacetic acid (Gd-DTPA) can distinguish tumor from edema. A weakness in MRI evaluation of tumors is the potential inability to identify cystic components that can be visualized on CT. Enhancement with Gd-DTPA may help MRI resolve these difficulties (*2*). Figure 1 illustrates a case of tuberous sclerosis better visualized on [Gd]DTPA acid images. The ability to perform spectroscopic studies of potassium-31 and/or carbon-13 may allow MRI to become competitive with PET in the functional evaluation of cerebral tumors (*2*).

Recently, several new PET techniques using both fluorine-18 fluorodeoxyglucose and carbon-11 amino acids have been utilized to study gliomas and to differentiate high grade tumors from low grade tumors (*11*). Thallium SPECT imaging of high grade gliomas has been reported as a method to detect and quantitate the volume of residual and recurrent tumor mass (*12*).

Intracranial inflammatory disease. Radionuclide brain imaging is sensitive to detect cerebral abscesses (showing a sensitivity of at least 95% in most series) and will also detect focal pyogenic cerebritis before the evolution of such a lesion into a frank abscess. However, this procedure lacks specificity (*13*).

Viral encephalitis remains a difficult diagnostic challenge without biopsy. Scintigraphic brain imaging remains a very sensitive modality to detect herpes simplex encephalitis (*4*). The most common pattern seen on perfusion and static images is unilateral focal increased uptake of the radiopharmaceutical in the temporal lobe (Fig. 2). This scintigraphic pattern is usually present soon after the onset of neurologic symptoms, when angiography, CT, or MRI may be normal or equivocal (*2,4*). Magnetic resonance imaging can occasionally contribute to the diagnosis of encephalitis. Findings include ill-defined hyperintensity on T1 weighted images in the temporal lobe (*2*).

Magnetic resonance imaging is useful in evaluating chronic subdural hematomas and subdural empyemas (*2*), especially for small collections located high over the convexities, which might be difficult to appreciate on CT.

Hydrocephalus. Computed tomography and MRI have largely replaced radionuclide cisternography as a screening test for hydrocephalus because of their clear delineation of CSF space. Magnetic resonance imaging is more likely to identify a cause for hydrocephalus, such as Arnold-Chiari malformation, aqueductal stenosis or posterior fossa tumor (*2*). Radionuclide cisternography remains a simple and convenient means to distinguish communicating from noncommunicating hydrocephalus in individuals with obviously enlarged

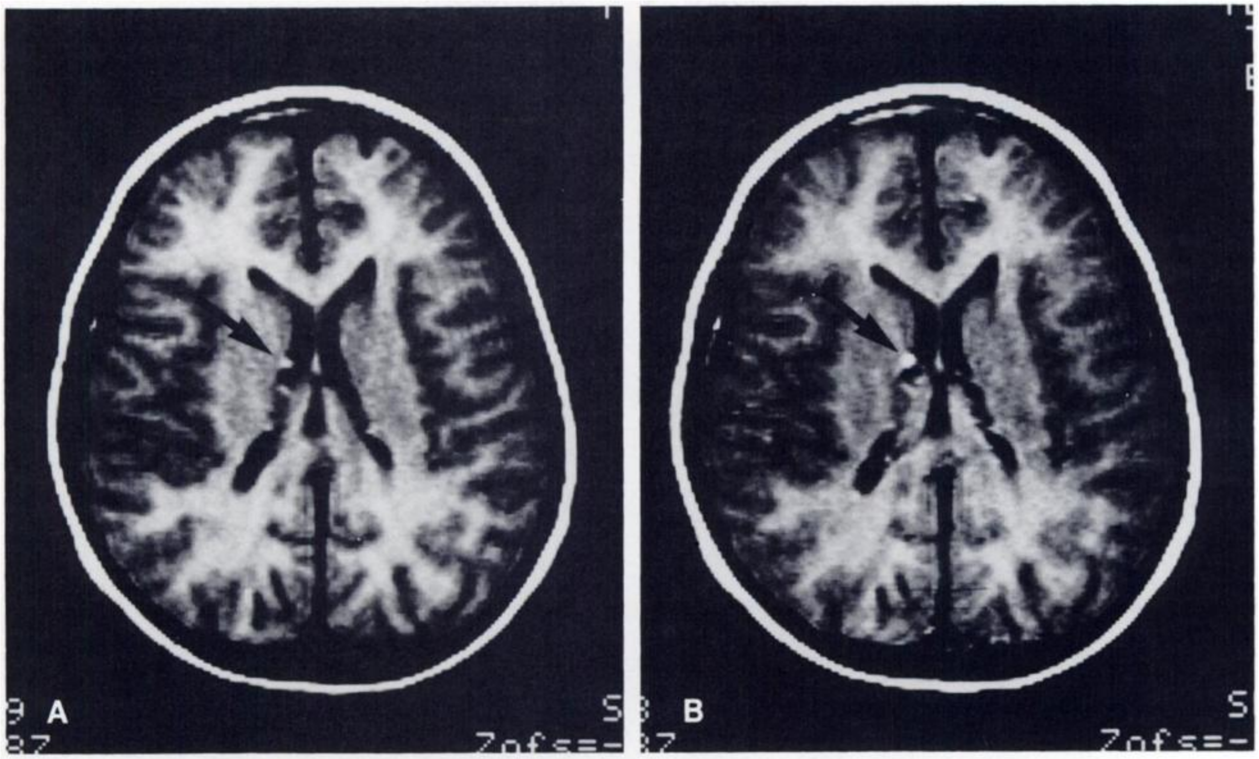

FIGURE 1
Tuberous sclerosis in a 12-yr-old female (A) precontrast and (B) postcontrast head MRI. T_1-weighted axial scans demonstrate several small, subependymal masses projecting into the lateral ventricles (arrows). At least one of these tubers enhances intensely following Gd-DTPA administration. C: Head CT scan demonstrates multiple subependymal punctate calcifications in the location corresponding to the tubers seen on MRI (arrow).

lateral ventricles on CT or MRI (*14*). Scintigraphy remains a highly accurate imaging modality in the detection and localization of cerebrospinal fluid fistula and shunt obstruction.

Congenital malformations. The ability of CT to delineate ventricular size, detect large fluid collections, and document the position of cerebral structures noninvasively has reduced the diagnostic role of radionuclide brain imaging in congenital malformations. However, radionuclide brain imaging is still widely used in the evaluation of arterio-venous malformations (*6*).

Porencephalic and congenital arachnoid cysts will

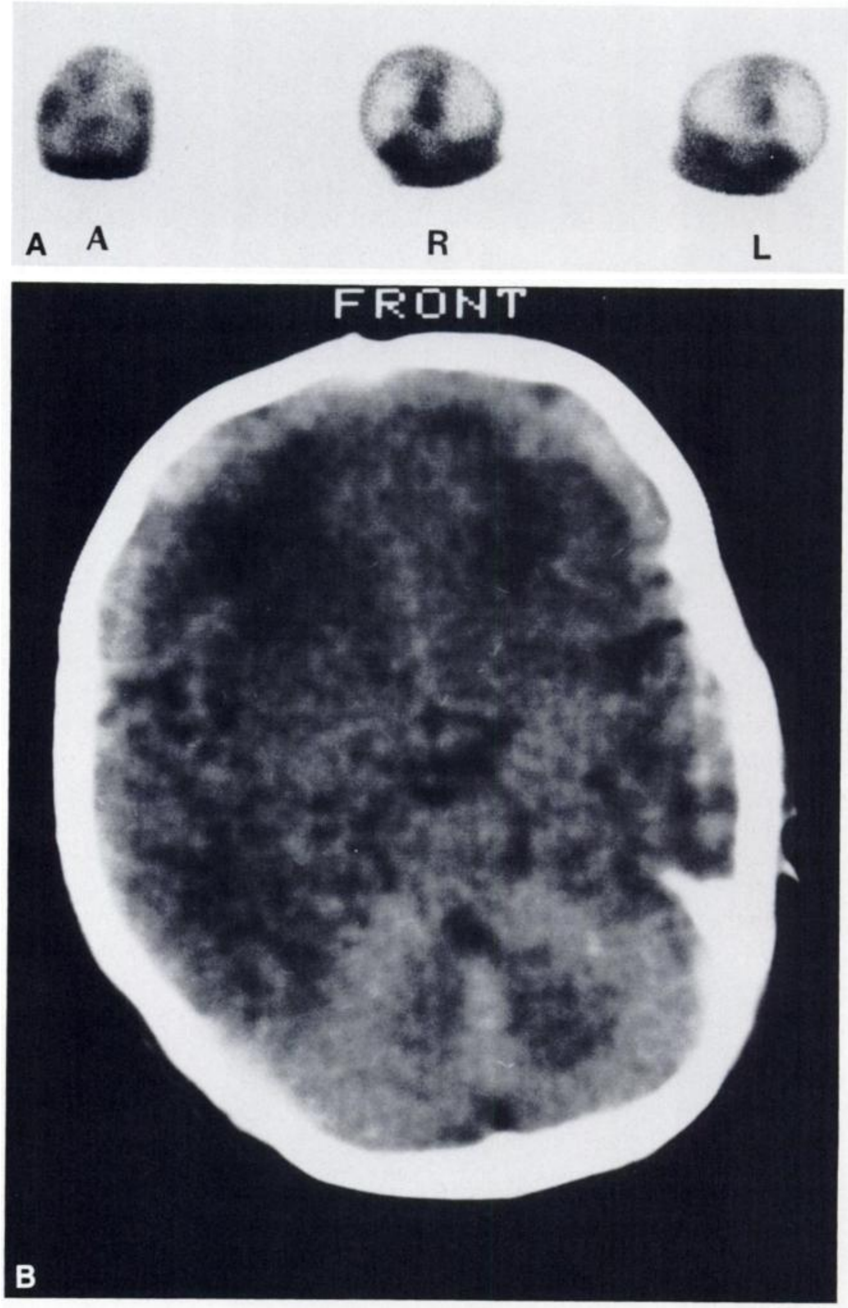

FIGURE 2
Herpes encephalitis in a 2-wk-old baby. A: Cerebral scintigraphy obtained following intravenous injection of 5 mCi of [^{99m}Tc]glucoheptonate, demonstrates increased activity in the parieto-temporal regions bilaterally. A = anterior, R = right lateral, L = left lateral. B: Axial head CT scan demonstrates diffuse swelling and hypodensity mostly throughout the right cerebral hemisphere.

generate MR signals similar to CSF on all pulse sequences and are thus easy to identify. These cysts are usually demonstrated by radionuclide cisternography as well with typical retention of activity long after it has cleared from the rest of the CSF space.

Magnetic resonance imaging is superb for demonstrating Arnold-Chiari, and Dandy-Walker malformations (*2*). Occasionally, scintigraphy can discover an unsuspected Dandy-Walker cyst because of the high primitive position of the transverse sinuses and torcula, which are overlooked clinically or misinterpreted on skull radiographs (*6,15*).

Head trauma. Computed tomography remains the procedure of choice for acute head trauma (*16*) because sedation (often necessary for MRI) is undesirable and life support equipment is difficult to maintain in close proximity of the magnet. With the possible exception of mild cerebral contusion, CT is equal or superior to MRI for all of these.

Dural Sinus Thrombosis

Dural sinus thrombosis remains a very elusive clinical diagnosis, as patients frequently present with a myriad of nonspecific signs and symptoms. Conventional arteriography remains the most sensitive and specific but also most invasive diagnostic procedure. Truncated appearance of activity in the lateral sinus without tapering (stump sign) has been suggested to be pathognomonic of lateral sinus thrombosis with scintigraphic imaging (*7*). Capabilities of CT for diagnosing dural sinus thrombosis are limited due to possible calvarial artifacts and the difficulty to differentiate the sinus from adjacent brain parenchyma (*17*). Magnetic resonance imaging is capable of unambiguously characterizing dural venous thrombosis noninvasively and is the modality of choice for diagnosing this entity. Initially, lack of a flow void is seen. Four to five days after the event, the thrombus appears hyperintense on both T1 and T2 weighted images presumably due to methemoglobin effect. Later, reappearance of flow void occurs as the vessel recanalizes (*18*).

Epilepsy and seizures. Seizures are a common disorder in pediatric patients. The majority are benign, self limited convulsions associated with fever during infancy. Radionuclide procedures may be helpful for the evaluation of seizures if its character suggests a focal abnormality, as in seizures associated with an ischemic episode or with signs of inflammatory brain disease or tumor.

It is now well established that PET examinations of patients with partial seizures demonstrate focal areas of decreased [^{18}F]FDG uptake in the area of the seizure focus in the interictal state in ~70-75% of patients (*19*).

SPECT and MRI appear competitive to PET in the diagnostic workup of epilepsy: SPECT studies with [^{123}I] HIPDM in patients with seizures, present abnormal interictal scans with foci of decreased uptake in 60% of the patients (*2*). Diamox enhanced interictal scans reveal an abnormality in 20% of patients with normal interictal scans. Magnetic resonance imaging examinations detect 83% of structural abnormalities in patients with epilepsy (*2*), including tumors, hematoma, vascular malformations and mesial temporal sclerosis.

No direct comparison of all the above mentioned modalities for evaluating epilepsy has been done, but PET will probably become the technique of choice because of high resolution and greater sensitivity to detect metabolic disorders.

Chest

Lungs. Although lung scintigraphy is not performed with the same frequency in pediatric patients as it is in adults, ventilation/perfusion scanning in children can be helpful in the following situations (*15*):

1. Early recognition of pulmonary disease in cystic fibrosis. Magnetic resonance imaging may have a complementary role in cystic fibrosis where it can distinguish impacted bronchi from normal vessels and detect peribronchial inflammation.
2. Diagnosis of pulmonary embolism which is uncommon in children.
3. Evaluation of the degree of functional pulmonary disturbances in children with structural abnormalities of the thorax.
4. Evaluation of lung function prior to segmental pulmonary resection.
5. Diagnosis of bronchial obstruction secondary to extrinsic compression or to foreign body aspiration, especially when the aspirate is small and missed by chest radiography and/or fluoroscopy.
6. Diagnosis of pulmonary sequestrations.

Magnetic resonance imaging and CT are roughly equal in overall sensitivity for detecting intrapulmonary masses. Computed tomography is superior for small masses close to the pleura or nodules close to each other because of increased spacial resolution, but MRI is superior for nodules near blood vessels (*20*). The inability of MRI to detect calcification is a definite disadvantage in pulmonary imaging. Both CT and [^{99m}Tc] phosphonates are sensitive for the demonstration of intra and extra pulmonary structures which tend to calcify.

Mediastinum. Magnetic resonance imaging and CT are considered much more sensitive and specific than radionuclide scintigraphy for diagnosing mediastinal tumors. However, nuclear scintigraphy remains the technique of choice to evaluate retrosternal thyroid masses and tumors which tend to calcify and/or necrotize as in mediastinal neuroblastoma (*21*).

In the mediastinum, MRI offers an advantage over CT in that the major blood vessels are easily identified and the thymus is clearly delineated over nondisplaced mediastinal structures. This can be contrasted to the appearance of lymphoma which has a lumpy appearance and tends to displace adjacent mediastinal structures (*2*).

Heart. Radionuclide angiography (RNA) can be a valuable imaging modality in pediatric cardiac patients for delineation of abnormal flow patterns, cardiac shunt quantitation and assessment of ventricular function (*2*, *22*). The newer development of ^{81}Rb-^{81m}Kr generator has made available an ultrashort half-life radionuclide suitable for intravenous injection, with consequent possible use of much higher radiation doses in children and lower radiation exposure. This method was proved to be especially efficient for the assessment of right ventricular function (*23*).

Echocardiography is an excellent modality for assessment of intracardiac anatomy and left ventricular function in children (*24*). It is less useful for evaluation of extracardiac vascular structures and quantitative functional evaluation of the right ventricle where radionuclide angiography serves an important role.

Magnetic resonance imaging provides natural inherent contrast between flowing blood, myocardium, epicardium and pericardial fat (*2*). Gating of MRI with the beating heart reduces, if not totally eliminates, motion artifacts (*25*) and allows delineation of congenital cardiovascular abnormalities in a noninvasive manner without requiring contrast medium or ionizing radiation (*2*) (Fig. 3).

Paramagnetic substances such as manganese ion may ultimately provide a basis for myocardial perfusion imaging. Tissue characterization, noninvasive blood flow measurements and even myocardial metabolism assessment are future potentials for MRI that await clinical evaluation (*2*). However, it is unlikely that MRI will replace echocardiography as the simplest and most definitive method of establishing a noninvasive diagnosis in young patients with congenital cardiac malformations. Magnetic resonance imaging is a complementary noninvasive imaging procedure to answer some questions left in doubt by echocardiography (mainly extracardiac artery and vein assessments) or radionuclide angiography.

Cardiac catheterization will remain necessary in many patients to provide vital physiological data, i.e., chamber pressures, shunt volumes, oxygen saturations, and pulmonary vascular resistance.

Abdomen

Gastrointestinal tract. Gastroesophageal scintigraphy is the most sensitive examination that can be used as a screening procedure to evaluate gastroesophageal reflux and aspiration. Quantification of reflux and monitoring response to medical and/or surgical therapy are possible (*26*).

In general, the use of MRI in bowel diseases is hampered by peristaltic motion and abundant interfering bright T2 signal from fat. Oral iron containing material such as Geritol or iron rich vitamins has been suggested as a bowel contrast agent, but the effect on relaxation time is unpredictable (*1*). Intravenous glucagon may be used to decrease bowel motion artifacts (*2*). Magnetic resonance imaging can detect choledochal cyst, anal atresia and bowel inflammation and may eventually become useful for diagnosis of Crohn's disease and ulcerative-colitis (*2*).

FIGURE 3
Congenital malformations of the heart in a 5-yr-old male. T_1-weighted gated coronal MRI of the chest demonstrates a single ventricle and atrial septal defect.

Liver and spleen. Liver spleen scintigraphy is a simple method providing information on shape, size, position, focal and/or diffuse abnormalities of these organs. However, newer imaging modalities including CT, US and MRI are challenging the diagnostic role of scintigraphy in hepatic disorders as well as the potential to characterize the nature of the abnormality seen on scintigraphy. Magnetic resonance imaging is at least as sensitive but so far not more specific than CT for detecting hepatic mass lesions (*27*). Both liver scintigraphy and MRI have the potential to specifically diagnose Budd-Chiari Syndrome.

Scintigraphic splenic imaging, using [^{99m}Tc]-labeled heat damaged red blood cells, provides a very sensitive and specific technique to diagnose splenosis and/or accessory spleens, and is frequently performed in children presenting with spleen trauma (*28*).

Intra-abdominal tumors and abscesses. Bone-seeking radiopharmaceuticals can accumulate in abdominal tumors, especially those that tend to calcify or necrotize. Neuroblastoma can be detected with a sensitivity of up to 93% using a combination of gallium-67(^{67}Ga)citrate and iodine-123 metaiodobenzylguanidine([^{123}I]MIBG) (*29*). Gallium-67 citrate imaging is considered highly reliable in excluding abdominal abscesses. However, because of difficulties in interpretation caused by bowel activity, imaging with indium-111(^{111}In)WBC is generally preferred. The sensitivity and specificity of [^{111}In] WBC scintigraphy are, respectively, 85% and 95%, compared to sensitivity of 82% and specificity of 95% for US and sensitivity of 98% and specificity of 95% for CT (*30*). Ideally, nuclear medicine studies should direct the use of CT, US or MRI to further localize and characterize the lesion.

Bone and Locomotor System

Primary bone tumors. The most frequent primary malignant bone tumors in the pediatric age group are osteosarcoma and Ewing's sarcoma. Nuclear medicine studies are 100% sensitive for detecting primary malignant bone tumors in children, although the specificity is obviously very low. The primary role of radionuclide studies is to evaluate skeletal metastases in patients with a solitary bone tumor, or to evaluate the skeletal system when radiographs are normal or equivocal.

Conventional radiography is still considered the best method in predicting the nature of the primary bone tumor, while CT and MRI are effective for the assessment of soft-tissue involvement (*31*). Computed tomography has the advantage of being able to identify matrix calcification to suggest a cartilaginous tumor, while MRI is unreliable for this purpose. Furthermore, osteomyelitis can simulate bone malignancy on MRI which cannot reliably distinguish benign from malignant tumors (*32*). However, MRI has an important role in evaluating the extent of bone marrow, soft-tissue and joint involvement in lesions that appear malignant on plain films. In fact, MRI was found to be as good or better than CT for demonstrating extent of marrow involvement in 98% and of soft-tissue involvement in 100% of a wide variety of bone tumors.

Osteoid osteoma. Bone scintigraphy plays an important role in detection of osteoid osteoma since radiography may be normal, especially in the vertebrae, femoral neck and small bones of the feet. However, bone radiography is still considered the best and most cost-effective method for diagnosing osteoid osteoma of long bones. The role of MRI in evaluating osteoid osteoma has not yet been fully defined (*2*).

Metastatic bone disease. Bone scintigraphy is the most sensitive method for detecting bone metastases, identifying metastases not visualized by conventional radiographs in more than 30% of patients (*33*). However, rapidly destructive metastases, such as in newborns with neuroblastoma, may cause a photopenic defect or have a normal appearance on bone scan. In addition, symmetrical metaphyseal lesions of the long bones may not be recognized because of the normal prominence of epiphyseal activity in children.

Magnetic resonance imaging and CT seem to be complementary to radionuclide studies in differentiating metastases from other lesions in the bone and may demonstrate epidural metastases and paravertebral extension of the tumor. Magnetic resonance imaging is sensitive to detect leukemic infiltrations which appear as areas of decreased signal intensity on T1 weighted images (*2*).

Avascular necrosis. In the early phase of avascular necrosis of the femoral head, bone radiographs are frequently normal. Bone scintigraphy has a sensitivity of 98% and a specificity of 95% in diagnosing Legg-Perthes disease, and can demonstrate the onset of revascularization and healing process a few months before the initial radiographic signs of new bone formation (*34*). Recent studies show that MRI may be more sensitive and specific than CT and bone scintigraphy for the early detection of avascular necrosis and suggest MRI as the procedure of choice for diagnosing Legg-Perthes disease in children (*2,35*) (Fig. 4).

Bone Trauma. Stress fractures and epiphyseal fractures are common in children and may be difficult to diagnose radiographically. Bone scintigraphy is a highly sensitive modality to detect fractures and other forms of bone trauma such as periosteal injuries. Within hours of a fracture, radionuclide bone scintigraphy becomes abnormal (*15*).

Bone scintigraphy can help to evaluate child abuse, particularly in infants who present with multiple and symmetrical lesions. However, complementary radiographs are essential since bone scintigraphy tends to misinterpret minimal symmetrical metaphyseal injuries, and cannot determine the healing stage of the fracture, nor completely detect healing fractures (*15*).

Musculoskeletal infections. Bone scintigraphy is extremely sensitive in the detection of early osteomyelitis (*30*). The specificity is augmented by the triple phase technique which allows differentiation of osteomyelitis from cellulitis in the absence of underlying pathology. However, difficulties may occur in the presence underlying bone disease, and false positive studies may be seen in various conditions, such as primary or metastatic bone tumor, metabolic bone disease, trauma or surgery.

If the bone scan is normal but there is a high index of clinical suspicion of osteomyelitis, ^{67}Ga scintigraphy is indicated as it may become abnormal earlier than the bone scan. Moreover, ^{67}Ga imaging is of greater value than conventional radionuclide bone imaging in assessing the response of osteomyelitis to therapy. Sequential bone and ^{67}Ga scanning are useful in the differential diagnosis between osteomyelitis and bone infarction in sickle cell disease (*36*).

Indium-111 WBC can be used as an alternative to ^{67}Ga scintigraphy with a sensitivity of 100% and specificity of 96%. However, [^{111}In]WBC scintigraphy is less satisfactory for chronic osteomyelitis with a sensitivity of only 60% (*30*).

Sequential bone and ^{67}Ga scintigraphy and MRI have a similar sensitivity and specificity for disc space infection with an accuracy of 94% compared to 23% for plain films (*2*). However, the situation is less clear in the long bones (*37*).

Urinary Tract

Renal scintigraphy and US are frequently used for evaluation of renal disorders in children (*38–40*). The following are the most common pediatric renal diseases which may be evaluated using this imaging combination with additional correlative imaging studies when indicated.

Congenital anomalies. Ultrasonography is considered the method of choice in the evaluation of congenital renal anomalies, particularly those associated with number, position or fusion (*38*). Nuclear medicine studies are widely used to demonstrate ectopic or hypoplastic kidneys not visualized on intravenous urog-

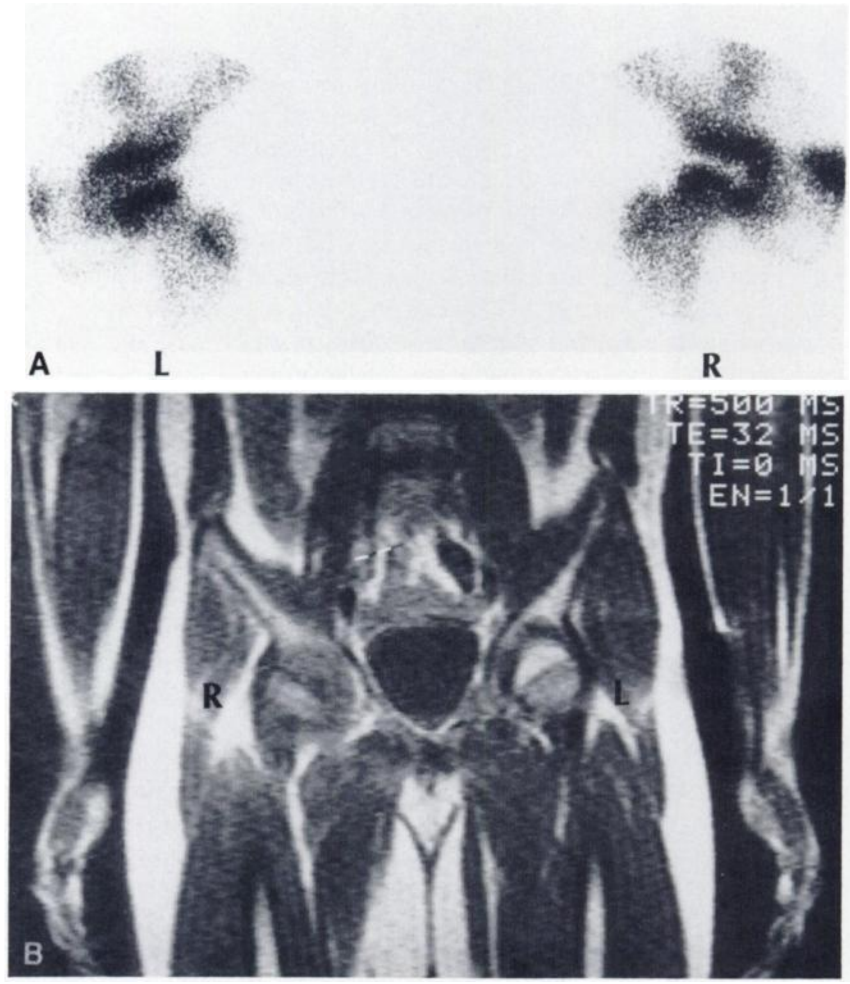

FIGURE 4
Legg-Perthes disease in a 10-yr-old male. A: Bone scintigraphy (pinhole of the hips obtained following intravenous injection of 14 mCi of $[^{99m}Tc]$ HDP) demonstrates a photopenic defect in the right femoral head consistent with avascular necrosis. L = left, R = right. B: T_1-weighted coronal MRI scan of the pelvis demonstrates decreased signal intensity from the epiphysis and distal end of the right femoral head.

raphy, and to assess renal function in a variety of renal congenital anomalies (*38*).

Renal vein thrombosis. The imaging modalities of choice in the evaluation of renal vein thrombosis as a cause of abdominal mass in the flank region include the combined use of renal scintigraphy and Doppler US.

Scintigraphic findings include decreased perfusion and delayed accumulation of $[^{131}I]$hippuran. The sonographic features in the acute phase include: generalized renal enlargement, increased echogenicity and altered renal architecture. Correlation with duplex doppler ultrasonography demonstrating arterial flow, but no venous flow, is diagnostic of renal vein thrombosis.

Vesico-ureteric reflux and urinary tract infections. Direct radionuclide cystography is more sensitive for detecting vesicoureteric reflux than the traditional conventional roentgenographic procedures. The method enables a quantitative estimation of the amount of reflux and the rate of ureteral drainage. In addition radionuclide cystography give minimal radiation exposure compared to the voiding cysto-urethrogram (VCUG).

Ultrasonography is the modality of choice in the evaluation of children with urinary tract infections. The renal sonogram combined with the VCUG attempts to differentiate upper from lower urinary tract involvement. In girls, radionuclide cystography can replace the more traditional VCUG. However in boys where evaluation of the urethra may be important, the VCUG retains its place (*39–40*).

Renal neoplasm. Renal scintigraphy is occasionally used for distinguishing Wilms' tumor from other rare mesoblastic nephroma in newborn and young infants. Failure of a renal mass to accumulate tracer beyond the perfusion phase is considered typical of renal neoplasm. However, most neoplastic renal masses are readily diagnosed by urography, CT, US, and MRI.

Ultrasound is considered much more sensitive than renal scintigraphy for differentiation of renal from extrarenal solid masses in the pediatric population. In addition, US evaluation of the inferior vena cava and right atrium is extremely helpful in the pre-operative assessment of patients with Wilms' tumor.

Magnetic resonance imaging is extremely helpful for evaluating Wilms' tumor and differentiating it from neuroblastoma and for determining the extent of vascular invasion and involvement of adjacent organs (*2*).

Urinary tract obstruction and hydronephrosis. Ultrasound is now considered the modality of choice for the diagnosis and follow-up of pediatric patients with hydronephrosis. The effect of pelvic masses on the kidneys is also easily visualized using this method. Diuretic renoscintigraphy is useful for differentiating mechanical obstruction from functional dilatation of the urinary tract (*41*).

Sympatho-Adrenal System

Iodine-131 MIBG structurally similar to norepinephrine has been developed to image catecholamine secreting tissues and tumors (*42*). The radiopharmaceutical has identified undiagnosed childhood tumors as being neuroblastoma prior to biopsy, with a sensitivity of 85% and a specificity of 95%. In addition, [^{131}I]MIBG has a potential role in the treatment of neuroblastoma by delivering therapeutic doses of ^{131}I radiation to tumors that are otherwise poorly responsive (*42*).

Iodine-131 MIBG detects pheochromocytoma with a sensitivity of 85% and a specificity close to 100% (*42*). The use of SPECT techniques and ^{123}I-MIBG may further increase the sensitivity of this technique. This method can elucidate the nature of extra-adrenal pheochromocytoma for example in the mediastinum. The superior contrast resolution of MRI as compared with CT, may be beneficial in detecting and localizing pheochromocytoma in complex cases (*43*).

The adrenal cortex can be imaged with NP-59 and dexamethasone suppression-NP-59 scintigraphy can be performed to evaluate patients with adrenal virilization (*42*). In congenital adrenal hyperplasia there is usually gross adrenal enlargement that is easily detected on MRI. In early childhood MRI or US might be preferable to CT to exclude a possible adrenal tumor, especially in children with very little perinephric fat (*2*).

REFERENCES

1. Cohen MD. Pediatric magnetic resonance imaging. Philadelphia: W. B. Saunders Company, 1986.
2. Partain CL, ed. Magnetic resonance imaging, ed 2. Philadelphia, W. B. Saunders Company, 1988.
3. Pjura GA, Kim EE: Radionuclide evaluation of brain death. In Freeman MF, Weissmann HS, eds. *Nuclear medicine annual.* New York: Raven Press, 1987, pp 269–293.
4. Kim EE, DeLand FH, Montebello T: Sensitivity of radionuclide brain scan and computed tomography in early detection of viral meningoencephalitis. *Radiology* 1979; 132:425–429.
5. Savage TP, Gilday DL, Ash TM. Cerebrovascular disease in children. *Radiology* 1977; 123:385–391.
6. Gates GF, Fishman LS, Segal HD. Scintigraphic detection of congenital intracranial vascular malformations. *J Nucl Med* 1978; 19:235–244.
7. Barnes BD, Winestock DP. Dynamic radionuclide scanning in the diagnosis of thrombosis of the superior sagittal sinus. *Neurology* 1977; 27:656–667.
8. Sharp BF, Smith FW, Gemmell HG, et al. Technetium-99m-HMPAO stereoisomeres as potential agents for imaging regional cerebral blood flow: human volunteer studies. *J Nucl Med* 1986; 27:171–177.
9. Van Royer EA, Debruine JF, Hill TC, et al. Cerebral blood flow imaging with thallium-201 diethyldithio carbamate SPECT. *J Nucl Med* 1987; 28:178–183.
10. Packer RJ, Bathnitzky S, Cohen ME. Magnetic resonance imaging in evaluation of intracranial tumors of childhood. *Cancer* 1985; 56:1767.
11. Patronas NJ, DiChiro G, Kufta C, et al. Prediction of survival in glioma patients by means of positron emission tomography. *J Neurosurg* 1985; 62:816–822.
12. Kaplan WD, Takvarian T, Morris JH, et al. Thallium-201 brain tumor imaging: a comparative study with pathologic correlation. *J Nucl Med* 1987; 28:47–52.
13. Crocker EF, McLaughlin AF, Morris JG, et al. Technetium brain scanning in the diagnosis and management of cerebral abscess. *Am J Med* 1974; 56:192–201.
14. Harbert JC, McCullough DC, Schellinger D. Computed cranial tomography and radionuclide cisternography in hydrocephalus. *Semin Nucl Med* 1977; 7:197–200.
15. Sty JR, Starshak RJ, Miller JH, eds. Pediatric nuclear medicine. Norwalk: Appleton-Century-Crofts, 1983.
16. Harrigan WC, Wright SM, Wright RM. Clinical utility of magnetic resonance imaging in pediatric neurosurgical patients. *Pediatrics* 1986; 103:522–529.
17. Kim KS, Walczak TS. Computed tomography of deep cerebral venous thrombosis. *J Comput Assist Tomogr* 1986; 10:386–380.
18. Erdman WA, Weinreb JC, Cohen JM, et al. Venous thrombosis: clinical and experimental MR imaging. *Radiology* 1986; 161:233–238.
19. Latack J, Abon-Khalil BW, Siegel GJ, et al. Patients with partial seizures: evaluation of MR, CT and PET imaging. *Radiology* 1986; 159:159–163.
20. Muller NL, Gamsu G, Webb WR. Pulmonary nodules: detection using magnetic resonance and computed tomography. *Radiology* 1985; 155:687–697.
21. Garty I, Koren A, Moguilner G, et al. Nearly total absence of pulmonary perfusion with corresponding technetium-99m MDP and gallium-67 uptake in a patient with mediastinal neuroblastoma. *Clin Nucl Med* 1985; 8:579–682.
22. Parrish MD, Graham TP. Radionuclide angiography in children. *J Pediatr* 1984; 104:165–172.
23. Ham HR, Piepsz A, Vandevivere J, et al. The evaluation of right ventricular performance using krypton-81m. *Clin Nucl Med* 1983; 8:257–260.
24. Tajik AS, Sevard JB, Hagler DT, et al. Two dimensional realtime ultrasonic imaging of the heart and great vessels: technique imaging orientation structure identification and validation. *Mayo Clin Proc* 1978; 53:271–303.
25. Lanzer P, Botvinick EH, Schiler NB, et al. Cardiac imaging using gated magnetic resonance. *Radiology* 1984; 150:121–127.
26. Arasn TS, Wyllie R, Fitzgerald JF, et al. Gastroesophageal reflux in infants and children: comparative accuracy of diagnostic methods. *J Pediatr* 1980; 96:798–803.
27. Weinreb JC, Cohen JM, Armstrong E, et al. Imaging the pediatric liver: MRI and CT. *Am J Roentgenol* 1986; 147:785–790.
28. Zwas ST, Samra D, Samra Y, et al. Scintigraphic assessment of ectopic splenic tissue localization and

function following splenectomy for trauma. *Eur J Nucl Med* 1986; 12:125.
29. Garty I, Kedar A, Sandler M. The role of I-131-MIBG, Tc-99m MDP and Ga-67 citrate in the evaluation and follow-up of neuroblastoma [Abstract 38]. *J Nucl Med* 1988; 29:750.
30. Alazraki N. Infection imaging. In: Silverstein EB, ed: *New directions in nuclear medicine.* Southeast Chapter of the Society of Nuclear Medicine, IX, 1987, 1–18.
31. Levin E, Lee KR, Neff R JR, et al. Comparison of computed tomography and other imaging modalities in the evaluation of musculoskeletal tumors. *Radiology* 1979; 131:431–437.
32. Zimmer WD, Berquist TH, McLoan RA, et al. Bone tumors: magnetic resonance imaging versus computed tomography. *Radiology* 1985; 155:709–718.
33. Brady LW. The role of bone scanning in cancer patients. *Skel Radiol* 1979; 3:217–222.
34. Sutherland AD, Lavage JP, Paterson DC, et al. The nuclide bone scan in the diagnosis and management of Perthes' disease. *J Bone Joint Surg* 1980; 62b:300–306.
35. Mitchell MD, Kundel HL, Steinbey ME, et al. Avascular necrosis of the hip: comparison of MR, CT, and scintigraphy. *Am J Roentgenol* 1986; 147:67–71.
36. Koren A, Garty I. Bone infarction in children with sickle cell disease: early diagnosis and differentiation from osteomyelitis. *Eur J Ped* 1987; 142:93.
37. Sandler MP. Nuclear magnetic resonance and scintigraphic imaging of the skeletal, endocrine and cardiovascular system. In: Silberstein EB, ed. *New directions in nuclear medicine.* Southeastern Chapter of the Society of Nuclear Medicine. XIX, 1987, pp 1–16.
38. Conway JJ, Relalis PP, King LR, et al. Radionuclides in clinical pediatric urology. Philadelphia: W. B. Saunders Company, 1976: 60–76.
39. Sty JR, Starshak RJ. Sonography of pediatric urinary tract abnormalities. *Semin Ultrasound* 1981; 2:71–87.
40. Sanders RC, Menon S, Sanders AD, et al. The complementary role of nuclear medicine and ultrasound in the kidney. *J Urol* 1978; 120:521–527.
41. O'Reilly PH. Current status of diuretic renography. In Freeman LM, Weissmann HS, eds. *Nuclear medicine annual.* New York: Raven Press, 1987: 173–192.
42. Shapiro B, Gross MD, Sandler MP. Adrenal scintigraphy revised: a current status report on radiotracers, clinical utility and correlative imaging. In: Freeman LM, Weissmann HS, eds. *Nuclear medicine annual.* New York: Raven Press, 1987: 193–231.
43. Schultz V, Haag A JR, Fletcher BD, et al. Magnetic resonance imaging of the adrenal gland. A comparison with CT. *Am J Roentgenol* 1984; 143:1235–1240.