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Personal Practice

Body MRI: Its Application in Paediatrics

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Abstract As magnetic resonance imaging (MRI) establishes itself as the choice imaging modality for neurological disorders, its application to paediatric body imaging is also gaining acceptance. Technological advances with ultrafast pulse sequences and artefact suppression facilitate MRI utilization for different body parts. Choice of appropriate sedation and imaging techniques contribute towards better quality images. Body MRI provides morphologic display in multiple planes for the anatomy and pathology of the thorax, abdomen and pelvis, especially applicable to tumour staging and treatment follow-up. It has also come into use in target areas of the cardiovascular system and gastrointestinal tract. For the musculoskeletal system the inherent superior contrast resolution permits MRI visualization of structures and processes previously not readily imaged. It is expected MRI with its exploding advancement of techniques and instrumentation will soon achieve wide application in paediatric body imaging, although accessibility is still a problem.

Key words MRI, body; Paediatric imaging

Introduction

With its safety and versatility, magnetic resonance imaging (MRI) should be an ideal modality for body imaging in children. However, its use is not as universal as expected. Most MRI equipment manufacturers have not committed adequate resources to produce hardware and software that are specifically designed to meet the needs of children. Another problem is the necessity to sedate the uncooperative young children and infants, often demanding deep sedation or formal general anaesthesia. In the recent few years, major technical advancements especially the development of ultrafast imaging techniques and artefact suppression methods, have led to improvement of image quality and wider applicability. MRI has become accepted as an important extra-cranial cross-sectional technique for children in many areas of body imaging, rivaling or superceding computed tomography (CT) which utilizes ionizing radiation.

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Body MRI: General and Technical Aspects

The advantages of MRI include multiplanar and volume imaging capacity, excellent soft tissue contrast, improving spatial resolution, lack of ionizing radiation and the ability to use a non-iodinated intravenous contrast agent for enhanced scanning. MRI is thus assuming a greater role in the imaging of paediatric thorax, abdomen, pelvis and musculoskeletal system.[1]

MR scanners have different magnetic field strength ranging from 0.02 to 4 tesla (T). Systems operating below 0.5T with longer scanning time can produce images with diagnostic quality comparable to systems operating at 1.0 and 1.5T. Reduced motion and chemical shift artefacts and increased soft tissue contrast are attributes of mid-field systems (0.3 to 1.0T). High speed and high strength gradient MR systems can yield high-resolution images by using volume acquisitions either with fast gradient echo (GE) or fast spin echo (FSE) sequences in reasonably short imaging times for even a young, unsedated child. High field imaging however incurs marked lack of T1 contrast in young children and infants who have paucity of retroperitoneal fat, often resulting in inferior images.

Appropriate choice of coils depends on the body part under investigation and should be the smallest possible to increase spatial resolution. It is also important to position the body part in the isocenter of the magnetic field. Large children and teenagers are usually imaged in the body coil.

With most infants a head coil is used to improve signal and resolution. Older children can be imaged in one of the newer phase array torso coils. A surface coil is used to image small parts.

Basic pulse sequences include T1-weighted and T2-weighted spin-echo (SE) sequences. T1-weighted sequence provides excellent anatomic details, permits evaluation of contour abnormalities, demonstrates fat or hemorrhage within a lesion and aids in characterizing the extension of tumour into normal fatty tissue and bone marrow. For T1-weighted SE images, the repetition time (TR) is short typically ranging between 300 and 500ms and the echo time (TE) is also short, ranging between 8 and 15ms. The short scanning time provides an effective means of artefact reduction.

In T2-weighted SE sequence, the TR varies between 2000 and 3000ms and the TE between 80 and 120ms. It provides excellent contrast differentiation especially between normal and abnormal soft tissues, and an improved sensitivity for lesion detection. Extension of soft tissue mass into muscle or neurovascular bundle is readily assessed. This is most useful in the staging of disease. It can provide information about lesion homogeneity, margination, signal intensity, peritumoral edema and bone involvement. The required longer imaging times however are often susceptible to motion-related artefacts. Fast (or turbo) spin echo (FSE) sequences and spatial presaturation are effective methods to reduce such artefacts on T2-weighted images. Faster imaging sequences markedly decrease respiratory artefacts such as ghosting and blurring, but with a trade-off of lesion conspicuity owing to lower contrast to noise ratio. It is less sensitive to susceptibility artefacts and thus is not good for the detection of haemosiderin. On the other hand, it is good for body imaging in the presence of metallic prosthesis or device.

In GE imaging, both TR and TE are shortened, with reduced scan times. Contrast is determined by TR, TE and the flip angle of the initial exciting pulse. For T1-weighted GE images, the TE is short, typically 8 to 10ms, the TR ranges between 25 and 40ms, and the flip angle is greater than or equal to 40 degrees. True T2-weighted images are not possible with GE techniques, but T2*-weighted images can be obtained using longer TE and small flip angles. Gradient echo images show high signal in flowing blood and are useful to assess patency of vessels. Because GE techniques require very short scan times, they also afford the ability to monitor contrast enhancement following a rapid bolus of gadolinium contrast (Gd-DTPA).

Fat suppression sequences are usually applied with T2-weighted images to improve lesion to adjacent tissue contrast. These techniques, such as short T1 inversion recovery (STIR) fat saturation, result in enhanced signal intensity in water-containing tissues and increased lesion conspicuity. Chemical shift imaging is another method that is helpful to detect and characterize lesions suspected of fat content. This technique exploits the difference in relaxation times of fat and water. One example is GE in-phase (TE 4.2ms, flip angle 70 degrees) and out-phase (TE 2.1 or 6.3ms, flip angle 70 degrees). Fat will be increased in signal on in-phase GE images and decreased in signal on out-phase GE images.

Other fast sequences include inversion-recovery prepared FSE (FSEIR) images for fat suppression, fast GE images with or without spoiling (SPGR or MPGR). Fast GE sequences are used as rapid localizer, typically requiring 1 second of scan time per image. On occasion, fast GE sequences can be helpful to avoid gross motion artefacts. This is especially useful in an uncooperative child. 3-D SPGR sequence is used in Gd-DTPA infusion MR angiogram (MRA). Single shot fast spin echo (SSFSE) is a technique utilizing 0.5 number of excitations to permit slice acquisition in less than 1 sec. It offers fast motion-resistant imaging for uncooperative paediatric patients. It is ideal for imaging of fluid-filled structures in MR urogram and MR cholangiography.

The use of Gd-DTPA does not increase sensitivity or specificity in tumour detection. It differentiates focal masses as cystic/solid and vascular/avascular. It is useful in the characterization of viable tissue in a large soft tissue mass, which may be important in biopsy site planning. It is also applied to obtain contrast-enhanced MRA. There have been no reports on severe adverse reactions after the administration of Gd-DTPA in children and infants. An occasional problem is nausea and vomiting after injection.

Sedation for MRI

Sedation is usually needed for children younger than 6 years old, and on occasion older ones. In the absence of adequate sedation, movement results in signal misregistration and image degradation, especially at the onset of a pulse sequence, thus obscuring important diagnostic information. Other criteria for sedation include the need for analgesia during the procedure and claustrophobia in the older child. Sedation may be administered by many routes: oral, rectal, intramuscular or intravenous. The recommendation of the American Academy of Pediatrics is that infants are kept nil per ora (NPO) for at least 4 hours prior to deep sedation; older children NPO for 6 hours.[2] Sleep deprivation before the procedure is a good practice. Intravenous line is required to be set up before sedation. In our hospital, oral choral hydrate (initial dose of 50mg/kg) is used as first line drug. If oral sedation fails, intravenous midazolam (Dormican,

0.2mg/kg) is used as second line drug.

The American Academy of Pediatrics and the American Society of Anesthesiologists recommend that the following parameters be monitored in all sedated infants and children: heart and respiratory rates, blood pressure and arterial oxygen saturation.

Thoracic MRI

This is one of the more difficult areas of the body to image because of physiological motion artefacts. The principal sources of artefacts are cardiac pulsation, respiratory motion, and fully magnetized flowing blood. Axial images are particularly affected by the predominant diaphragmatic respiration in sedated and anaesthetised children. Optimization of thoracic MRI requires cardiac gating for nearly all examinations as well as attention to the usual technical parameters. Respiratory motion artefacts are minimized with compensation techniques by using a respiratory sensing belt placed on the chest. Saturation bands decrease ghost images and intravascular signal on spin-echo images.

Most thoracic MRI examinations include gated axial T1-weighted and GE images. Axial T2-weighted images are obtained for evaluation of a mediastinal mass. Additional pulse sequences in other planes may be obtained including coronal, sagittal and oblique images; sagittal or coronal views for evaluation the paraspinal and supraclavicular areas, oblique views for aortic arch. Except for examinations tailored to the soft tissue structures of the chest wall, FSE pulse sequences are not effective in evaluating the chest because they cannot be used with respiratory compensation techniques. Gradient echo sequences enable evaluation of blood flow and are used to assess thrombosis and intravascular tumour extension. Gradient echo images can also be acquired at a single level during consecutive phases of the cardiac cycle. Displayed as a continuous cine loop, these images are useful for detecting turbulent flow in stenotic vessels. Gd-DTPA has a limited role in the evaluation of thoracic pathology with the exception of tumour invasion.

Indications for MR include assessment of mediastinal invasion by tumour, posterior mediastinal mass for intraspinal extension (Figure 1), chest wall invasion by tumour, separation of tumour and fibrosis, selected pleuroparenchymal disease such as sequestrated lung and pulmonary haemosiderosis, and assessment of vascular disorders of the lungs including arteriovenous malformation and pulmonary varices. The sagittal images permit evaluation of structures that lie along the longitudinal axis of the body, for instance the trachea, and extension of mediastinal lesion in relation to the trachea, aorta and spine. The sagittal and coronal images are also most sensitive for spinal metastases.

Cardiovascular MRI

MRI complements echocardiography and cineangiography in imaging patients with congenital heart disease. Echocardiography is favoured by its lower cost, ready availability and portability. MRI is non-invasive, without ionizing radiation, capable of multiplanar imaging and displaying a large field of view. It is useful in the evaluation of great vessels such as pulmonary arteries and veins, vascular rings, coarctation of aorta and aneurysm of aorta.[3]

Its role in the assessment of cardiac morphology is limited. Essentially all congenital heart lesions have been imaged by MRI; most of which are visualized equally well using echocardiography. In complex congenital heart lesions, MR can be used to complement echocardiography and cineangiography.[4]

MRI provides sectional pictures in arbitrary planes to allow direct demonstration of regional morphologic and functional abnormalities. Currently, MR evaluation of ventricular function and valvular dysfunction is lengthy and labour intensive, thus not a routine in clinical practice. Cine MRI provides both qualitative as well as accurate quantitative assessment of regurgitant volume and regurgitant fractions.[5,6]

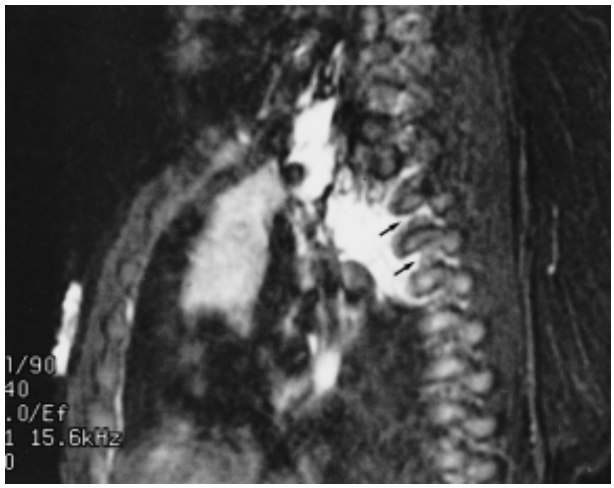

Figure 1 Neurogenic tumour. M/7M. Contrast-enhanced sagittal scan of the thorax showing an enhancing tumour in the posterior mediastinum with tumour infiltration into intervertebral foramina (arrows). (Illustration is provided courtesy of Princess Margaret Hospital.)

Basic techniques include SE and cine GE techniques. Segmented k-space acquisition (Fastcard) and Gd-enhanced angiography have been recently developed. The advantages of segmented k-space acquisition include the ability to image several phases of the cardiac cycle in a relatively short time, absence of intraluminal signal artefact, excellent differentiation of vascular from non-vascular structures, rapid scanning capability in multiple planes and ability to visualize turbulent flow. The disadvantages include susceptibility artefacts and inability to visualize vessel walls or the airway. Gd-enhanced MR visualizes the contour of blood vessels well, and has the ability to orient the imaging volume to ensure optimal coverage of vessels[3,7] (Figure 2). It can demonstrate the preferential enhancement of arteries and has multiplanar capabilities. The method can be applied to show the morphology and extent of anomalies of the aorta, large aortic branches and pulmonary arteries. Used in conjunction with MRI it can demonstrate the stenosis and mural thickness in aortitis.

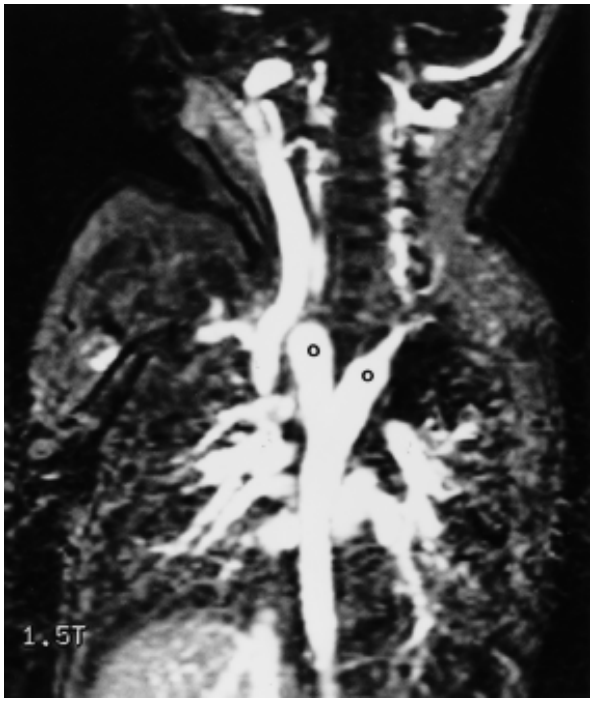

Figure 2 Double aortic arch. F/3Y. Post-contrast MR angiogram showing a double aortic arch (0) with common descending aorta.

Abdominal MRI

In imaging of liver, the useful sequences include T1- and T2-weighted SE sequences, T1-weighted GE imaging, and dynamic scanning with Gd-DTPA injection. Optional techniques include fat suppression sequences and chemical shift imaging. CT has superior spatial resolution compared to MRI, but MRI offers better soft tissue contrast and is more reliable in determining the extent of tumour and venous invasion. Indications include benign and malignant neoplasm in the liver, cirrhosis and fatty infiltration of liver. Compared with CT, MRI in the evluation of hepatoblastoma and hepatocellular carcinoma better delineates the diffuse infiltration and venous involvement. MRI is useful in hemochromatosis. With marked increase in iron deposit in the liver, spleen and pancreas, the T1-, T2-weighted and GE images will lose signal. MR imaging can provide important information when the portal vein is not visualized on sonography or CT and can readily display periportal collateral vessels. Evaluation of portal vein can be done by 2-D time of flight imaging, phase-contrast imaging and dynamic Gd-DTPA infusion MRA. MR cholangiopancreatography using heavily T2-weighted SE sequences can visualize the biliary tree with reasonable quality. It is useful in biliary obstruction and choledochal cyst (Figure 3), and is the modality when endoscopic retrograde cholangiopancreatography is contraindicated or not feasible.

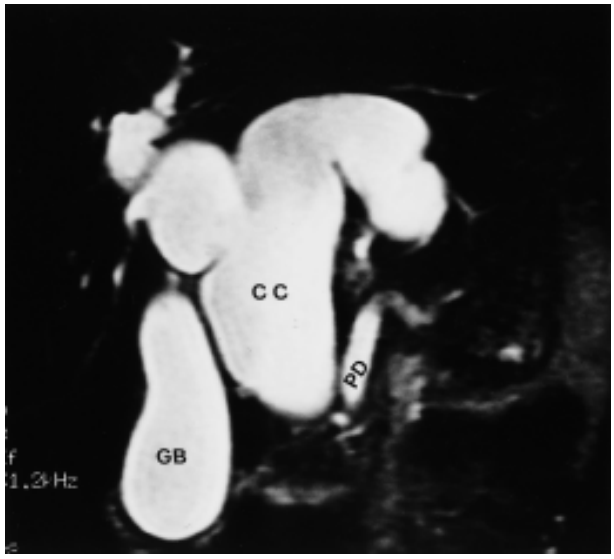

Figure 3 Choledochal cyst. M/9Y. MR cholangiogram showing the choledochal cyst (CC), gallbladder (GB) and pancreatic duct (PD).

Other indications in the abdomen include imaging of adrenal glands in adrenal haemorrhage, myelolipoma and pheochromocytoma; and oncologic staging of neuroblastoma, Wilms' tumour (Figure 4) and lymphoma.[8-11] MRI has the advantage over CT in demonstrating vascular anatomy and vascular involvement without intravenous contrast injection, and spinal canal extension without the use of intrathecal contrast. MR is superior to sonography in determining the orgin of tumour and local extent of tumour. In vascular extension, MR is

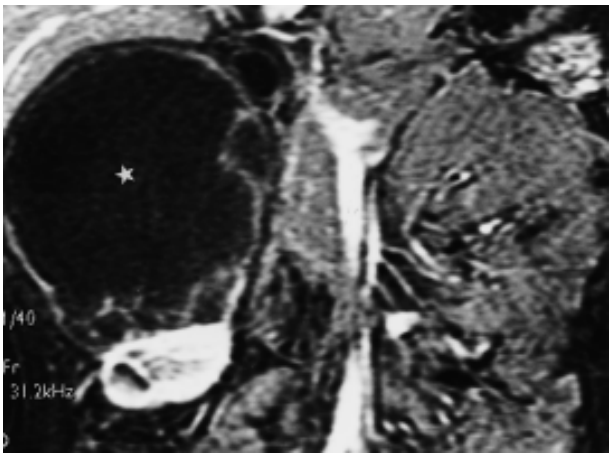

Figure 4 Wilm's tumour. F/10Y. Post-contrast axial scan showing a cystic lesion (white star) with rim enhancement at superior aspect of the right kidney.

superior to CT for demonstrating the presence of tumour thrombus. MR is however inferior to CT in the detection of calcification. The role of MRI in lymphoma still remains controversial when compared with CT. It is also used for assessment of the extent of cystic disease of the liver and kidneys. In inflammatory bowel disease, MRI shows the extent of bowel involvement, fistula and extraluminal disease (Figure 5). The T2 hyperintensity and contrast-enhancement often indicate activity of the bowel inflammation.

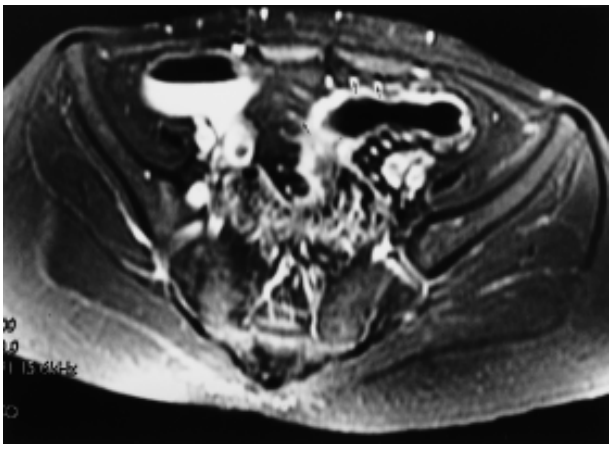

Figure 5 Crohn's disease. F/12Y. Post-contrast axial scan showing marked enhancement at the wall of a loop of small bowel with deep ulcers (arrows).

The common indications for pelvic MRI are evaluation of congenital abnormalities of the female pelvis, such as uterine agenesis and bicornuate uterus; and the study of pelvic soft tissue mass. It is particularly useful in the staging of pelvic malignancies such as germ cell tumour (sacrococcygeal tumour) and skeletal tumours related to the sacrum. MRI is also applied in the detection of undescended testis, and in the detection of the uterus and ovaries in cases of ambiguous genitalia or cloacal malformation. In imperforate anus, MR can be used to locate the level of the rectum, the position and size of levator sling and the relationship of the neorectum to the sling. MR venogram of the testis using Gd-DTPA infusion is useful in the detection of undescended testis when plain MRI fails to detect the lesion.[12]

Musculoskeletal and Soft Tissue MRI

MRI has facilitated the study of paediatric injuries by demonstrating the extraosseous and cartilaginous component of these lesions.[13] In injuries to the epiphysis and epiphyseal cartilage, osteochondral injuries and avulsion injuries, the cartilaginous component is usually the most important part of the lesion. Stress fractures and other injuries to the marrow can also be demonstrated. MRI is valuable in demonstrating the extent of injuries to radiographically occult areas. It is able to exclude epiphyseal cartilage involvement of a fracture and avoid an operation. Changes resulting from ischaemic injury to the growth plate can also be seen. MRI is rarely used in the initial evaluation of acute infectious process (Figure 6), but it is ideal for evaluating chronic inflammatory joint processes by demonstrating the nature, extent and distribution of synovial abnormalities, joint fluid, epiphyseal and articular cartilages, and various intra-articular structures such as ligaments and menisci. Indications include septic arthritis, juvenile rheumatoid arthritis, haemophilic arthropathy and pigmented villonodular synovitis.

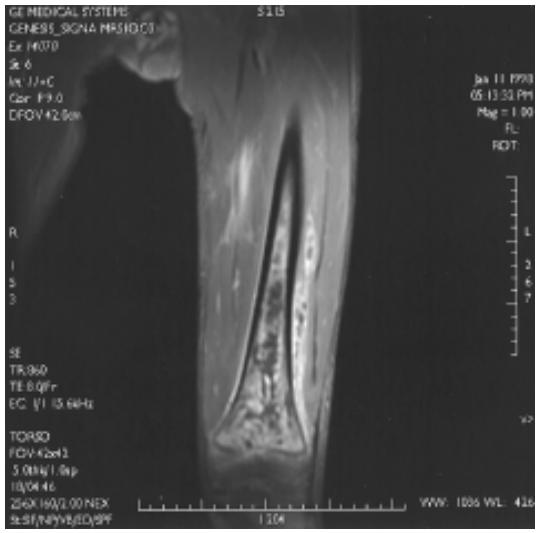

Figure 6 Osteomyelitis. M/15Y. Post-contrast coronal scan showing heterogeneous enhancement at lower end of the femur with adjacent soft tissue involvement.

Soft tissue tumours should be imaged in at least two orthogonal planes. T1-weighted and T2-weighted fat-saturation sequences are useful. The role of MRI in tissue characterization however has been somewhat disappointing. MRI differentiation of benign from malignant soft tissue mass is a controversial area. Biopsy remains the only definitive procedure to diagnose the pathology of soft tissue mass. In general, many soft tissue mass can be confidently diagnosed with MRI (Figure 7). The following specific lesion has a typical appearance of a benign lesion: lipoma, haemangioma/lymphangioma, periarticular cyst, hematoma, giant cell tumour of tendon sheath, benign neural tumour and subcutaneous fat necrosis, although not all of them will show characteristic MR features. In general, MRI cannot definitely distinguish a benign from a malignant nerve sheath tumour. Some malignant mass presents benign MR appearance, and biopsy is mandatory in case of doubt.

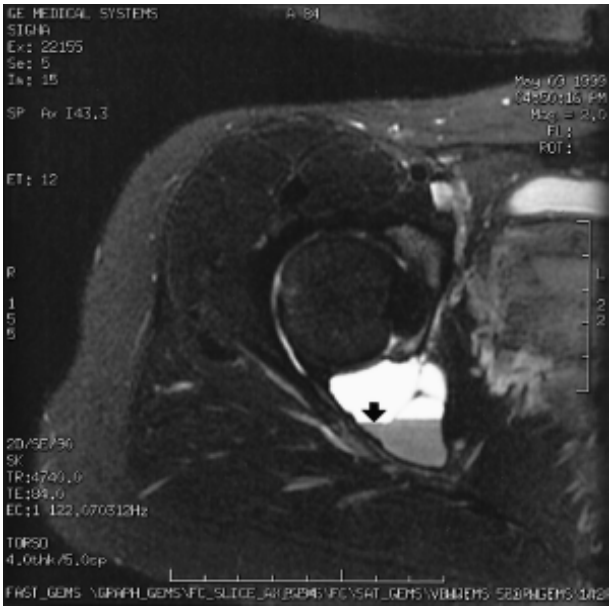

Figure 7 Aneurysm bone cyst. F/13Y. T2W-weighted axial scan of the right hip showing a hyperintense cystic lesion with fluid-fluid level and septation at posterior acetabulum. (Illustration is provided courtesy of Pamela Youde Nethersole Eastern Hospital.)

MR is recommended as a problem solving tool to further evaluate tumour-like lesions detected by other examinations. For evaluation of bone tumour, large field of views are used to accommodate the entire length of the affected bone on longitudinal T1-weighted and STIR images. The indications include benign bone lesions such as bone cysts, aneurysmal bone cyst, fibrous dysplasia, osteomyelitis, soft tissue infection, stress fracture, trauma, haematoma and muscle injury. For paediatric neoplasms, few MRI findings are specific. On MRI, the margin of bone lesion often reflects the amount of perilesional inflammation. Certain benign neoplasms, such as osteoid osteoma, chondroblastoma, and Langerhans cell histiocytosis, often exhibit a severe inflammatory response and thus very indistinct margins. This may lead to overestimation of the size of the tumour or misdiagnosis. In contrast, rapidly growing tumours such as Ewing sarcoma, primitive neuroectodermal tumour and metastastic neuroblastoma can have very distinct margin on T1-weighted images and yet have permeative radiographic margins.

T1-weighted MR images are useful for the determination of the extent of neoplasm. This sequence best depicts the intramedullary extent of the tumour, detects skip metastases if present, and serves as a localizer for prescription of subsequent sequences. Tumours usually can be differentiated from haematopoietic marrow, particularly on T2-weighted images, because marrow has an intermediate rather than high signal intensity. STIR images can provide supplementary information regarding the extent of marrow abnormality and help in the differentiation between haematopoietic marrow from tumoral invasion. On conventional MR images, it is not possible to reliably distinguish tumor from reactive changes in the adjacent marrow and soft tissues. Extension of tumour through the cortex, into the subperiosteal space and the soft tissue is seen best with axial T2-weighted or proton density images. For skeletal malignancies after chemotherapy, enhancement on SE T1-weighted images is a sensitive but nonspecific indicator of residual tumour. Determination of the rate of enhancement can increase the specificity of MRI.

MRI is a highly sensitive non-invasive technique to evaluate bone marrow lesions. It allows quantitative analysis of the major marrow components, fat and water. MR appearance of the bone marrow is highly dependent on the pulse sequence used and the relative amounts of fat and water within the marrow. SE sequences are currently the method most widely utilized for bone marrow imaging. Fat suppressed sequences such as STIR are useful to increase contrast between normal and pathological marrow as well as between red and yellow marrow. Indications for MRI include reconversion marrow disorders (e.g. sickle cell disease), replacement disorders (e.g. leukaemia and lymphoma), depletion disorder (e.g. depletion from infection, drugs, chemotherapy) and myelofibrosis (resulting from therapy, Gaucher's disease, etc.).

Conclusion

MRI has been widely used as the imaging modality for evaluating paediatric neurologic diseases. With the development of new fast imaging techniques and artefact suppression methods, MRI has become an important and more commonly utilized imaging technique in nearly every part of the body. The superior soft tissue contrast and ability to detect flowing blood have rendered MRI significant advantages in the assessment of tissue characteristics, lesion extent and vascular pathologic conditions. In particular, MRI has replaced CT as the primary study to evaluate soft tissue and paraspinal masses, and joint abnormalites. In the oncologic management of abdominal neoplasm, while CT remains the primary modality after ultrasound survey, in view of its accessibility and very fast scanning. MRI has gradually taken up its role in staging and follow up of these patients, especially for retroperitoneal tumours, because of better delineation of tumour involvement of adjacent soft tissue and vascular structures, and possibility to differentiate recurrence from fibrosis in some cases. MRI is going to be the imaging investigation complementing ultrasonography in the study of cardiac and vascular disorders in the children. With further advent in ultrafast imaging and ventilatory contrast agents it is expected that MRI may step into hitherto unexplored imaging fields like disorders of the small airways.

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