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Review Articles

Recent Advances on Paediatric Body Imaging for Clinical Diagnosis

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Abstract There is a revolutionary contribution of modern technology to overall ease in diagnosis. However, among the non-radiologists, they may not have caught up with the new advances in radiology. They may not be aware of the development of new applications as well as risks of the recent advances in imaging. This article is to introduce some recent advances in the application of paediatric imaging.

Key words CT; MR; Paediatric; Paediatric imaging; Recent advances; Ultrasound

Introduction

The revolutionary changes in modern technology helped shorten morbidity, reduced mortality and improved quality of life. The ability to 'see' inside the body represents one of the most potent diagnostic tools of modern medicine. Ultrasound imaging is particularly attractive owing to the portability of imaging machines and inherent safety of low-power acoustic interrogation of tissue.

The introduction of helical, or spiral, single and multi-detector CT scanners markedly increased the clinical indications for CT. As a result there had been a considerable increase in number of CT examinations performed and in the average scanned volume obtained per examination. Studies in the United States and the United Kingdom had shown an approximately twofolds increase in the number of CT performed between the late 1980s and the late 1990s. CT became a standard modality in assessing a variety of disorders.

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MRI established itself as the choice of imaging modality for neurological disorders. Its application to paediatric body imaging was gaining acceptance. Technological advances with ultrafast pulse sequences and artefact suppression facilitated its utilisation in cardiac and body imaging.

Recent Advances in Ultrasound Imaging

Due to its lack of radiation and non-invasiveness, ultrasound (US) had been used extensively in children and was usually the first line of imaging choice. The usefulness of US in children had been well documented and would not be discussed in details. Diagnostic ultrasound contrast agents had been developed for enhancing the echogenicity of blood and for delineating other structures of the body. Approved agents were suspensions of gas bodies (stabilised microbubbles), which had been designed for persistence in the circulation and strong echo return for imaging. The use US contrast in children was not as common as in adult. There was increasing number of papers advocating contrast-enhanced US voiding cystography (VUS) as a screening examination for vesicoureteral reflux.[1,2] Radmayr et al[1] used echo enhancing US contrast (inside the bladder) to look for reflux of microbubbles in ureter or renal pelvis. They correlated with traditional voiding cystogram and showed that the specificity and sensitivity of the contrast reflux US were significantly higher than that of traditional voiding cystogram. VUS detected higher grade reflux than traditional voiding cystogram. However, VUS imaged one body part at a time and thus could not provide an anatomical overview as in traditional voiding cystogram. The urethra was not well demonstrated. The examination time would be lengthened and VUS was highly operator dependant. Wang et al[3] used US contrast (IV contrast) to image a child with intra-abdominal desmoplastic small cell tumour.

While the use of US contrast agent was promising, one should be aware of its adverse effect. The interaction of US pulses with these gas bodies is a form of acoustic cavitation. This interaction produces bioeffects on nearby cells or tissues.[4] In vivo study, IV contrast agent with US mechanical index (MI) values greater than 0.4 had produced microvascular leakage petechiae, cardiomyocyte death, inflammatory cell infiltration and premature ventricular contractions. Bioeffects for MIs of 1.9 or less had been reported in skeletal muscles, fat, myocardium, kidneys, liver and intestine. Therefore, in order to avoid adverse bioeffects, the US setting and MI had to adjust accordingly.

In the application of contrast US voiding cystogram, as the contrast was introduced into the bladder instead of blood vessels, the bioeffects might not be as great as intravenous injection. No animal study had been done on the potential effect of insonation of the urothelium in the presence of microbubbles with the different MI settings. In the small number of VUS studied children, no adverse events directly related to ultrasound contrast agent had been reported.[2] The osmolarity of US contrast agent such as Levovist was five times higher than that of previously used ionic radiographic contrast. However, the amount of US contrast agent used was small and was diluted in urine. Although no detail studies regarding any possible interaction with urine and the urosystem had been done, no adverse events had been reported regarding to the osmolarity of US contrast agent. The other drawback of US contrast was its expensiveness and availability.

Recent Advance in CT and MR Imaging

Cardiac and Vessels Imaging

Multislice CT (MSCT) provided high accuracy for non-invasive assessment of coronary artery disease (CAD). The introduction of latest 16-256 slices CT allowed comprehensive evaluation of various aspects of CAD, including coronary stenosis, bypass patency, and myocardial function. The main paediatric application of coronary CT was in patients with history of Kawasaki's disease. CT was useful for the assessment of coronary calcification, coronary aneurysm or stenosis, and bypass patency (Figures 1-3).[5]

However, a number of technical issues had to be considered for optimal image acquisition and interpretation. Patients had to be prepared and instructed for breath holding prior to the CT examination. For very small children and infants that cannot held their breath, images would be degraded by respiratory or movement artifacts. A relative low and stable heart rate during breath holding was a need for optimal imaging results. Various schedules for oral and/or intravenous administration of beta-blockers had been proposed. The rapid heart rate in small children and infants was a problem and might degrade the imaging results. A bolus of contrast material with a relative high iodine concentration would be injected through the antecubital vein at a flow rate of 4-5 ml/second in adult patient. The relatively smaller size of the vein in children limited the flow rate of contrast and might also degrade the imaging results. Therefore, this examination was more suitable for children at older age. It was advised that a venous block with at least 20-22G is to be set up at the antecubital vein in children.

Radiation exposure of patients was generally expressed as the effective radiation dose. The effective dose of current 64-slice coronary MSCT varied between 8-21 mSv. The radiation dose in selective coronary angiography (CAG) varied from 2-10 mSv. The radiation dose of a chest radiograph was about 0.1-0.3 mSv. Radiation dose was a concern in infant and children. However, the advantage of coronary CT was its relatively short examination time. An examination usually takes less than 15 mins and the child does not have to undergo general anaesthesia.

In addition to coronary artery, MSCT allowed CT angiogram and venogram of the whole body. CT could also assess the right (RV) and left (LV) ventricular function of heart. Because of the lack of radiation exposure, the use of MR angiogram was more common than CT angiogram in paediatric application. Cine MR is now generally recognised as the most accurate and reproducible technique for assessing global ventricular function. It was ideally for serial assessments of RV and LV function that had undergone therapeutic interventions. The main paediatric application was in patients with congenital heart disease. Their RV and LV function could be assessed.[6,7] MR could also calculate the pulmonary flow and assess the severity of pulmonary regurgitation (Figure 4). MR was useful for the assessment of pre and post-operative changes of coarctation of aorta and pulmonary artery anatomy (Figures 5-7). The measurement of collateral flows in descending

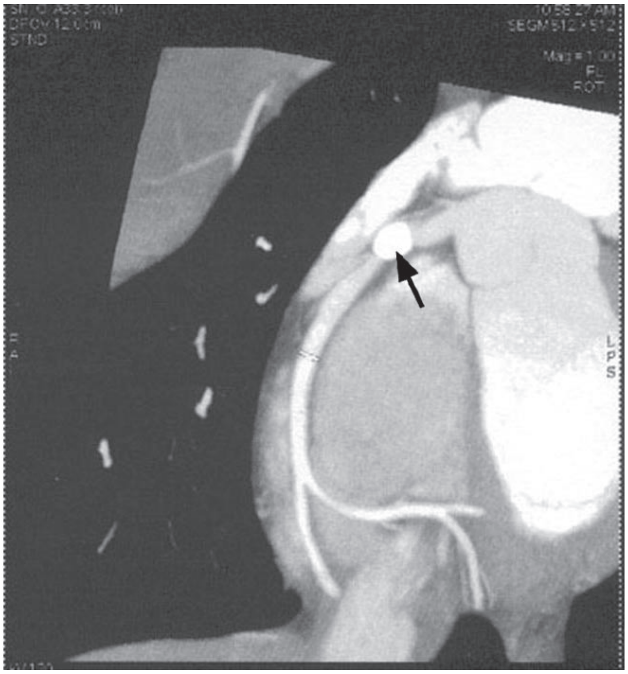

Figure 1 CT coronary angiogram (CTA) in a case of Kawasaki disease showing calcification and focal dilatation at its proximal region of right coronary artery (arrow).

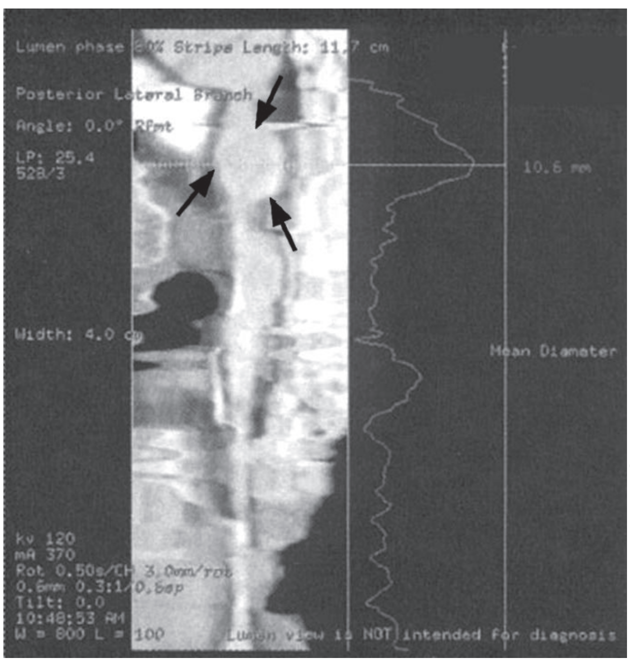

Figure 2 CTA of another case of Kawasaki disease showing aneurysms at right coronary artery (arrows).

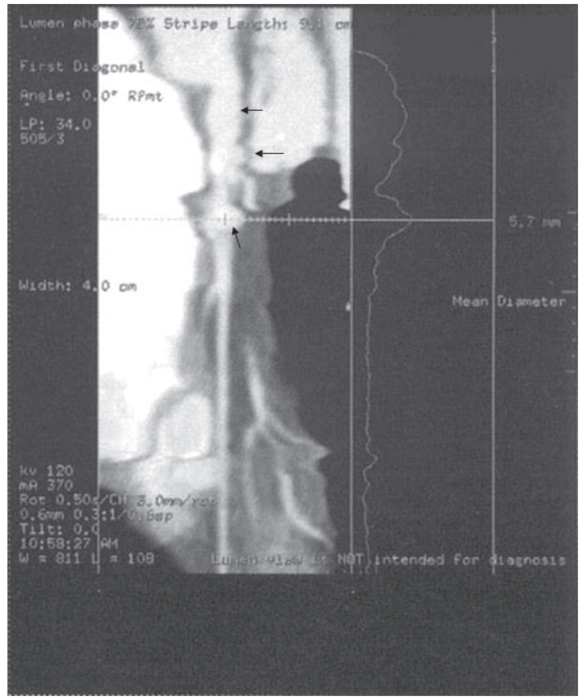

Figure 3 CTA in a case of Kawasaki disease showing aneurysm at left coronary artery (arrows).

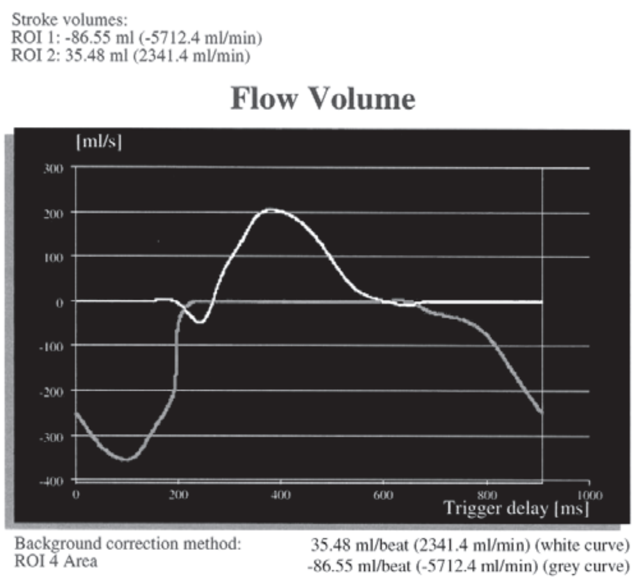

Figure 4 MR functional analysis of pulmonary regurgitation fraction in a post-operative case of Tetralogy of Fallot. White and grey curves were forwards and backwards flow respectively.

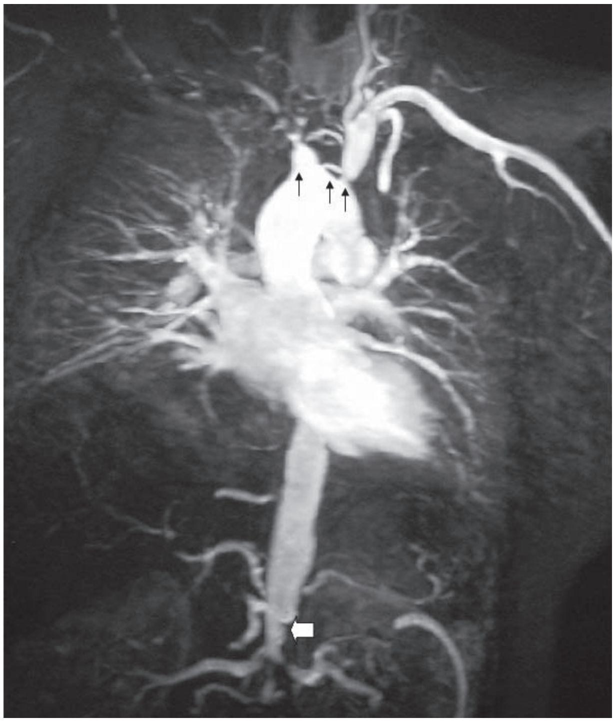

Figure 5 MR angiogram in a case of Takayasu's disease showing stenotic descending aorta, Rt innominate, Lt common carotid arteries (arrows); and complete stenosis of aorta below superior mesenteric artery (thick arrow).

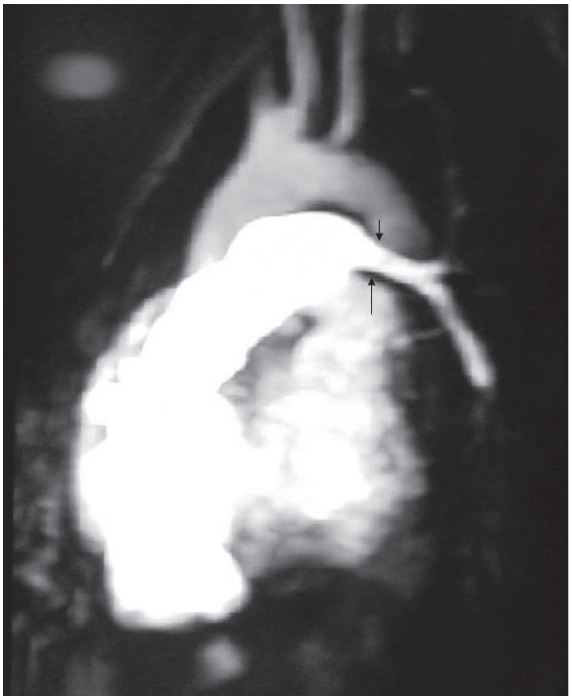

Figure 6 MR angiogram showing hypoplastic left pulmonary artery (arrows).

Figure 7 MR angiogram in a post-operative case of Coarctation of aorta showing residual aneurysmal dilatation (arrow).

aorta could also give an estimation of severity of the residual coarctation of aorta after operation. Late Gd-enhanced MR could also be used to assess the transmural fibrosis in RV and LV in post-operative cases of congenital heart disease.[8]

The disadvantage of MR compared to CT was its relatively long imaging acquisition time and the need of longer sedation in infant and small children. Breath holding was required in cardiac imaging. The spatial resolution of MR angiogram was inferior to CT angiogram, and CT was superior to MR in coronary artery imaging. However, MR cardiac imaging was less dependent on the heart rate compared to CT.

Airway Imaging

Three-dimensional (3D) CT and virtual bronchoscopy enabled us accurately locate the site of fistula and assess the length of gap between upper and lower esophageal pouches in esophageal atresia.[9] It could give a 3D overview of the trachea and branches in tracheal stenosis. The site of stenosis and its abnormal branches were located. Virtual bronchoscopy and 3D CT provided both endoluminal and extraluminal information (Figures 8 & 9) on any viewing direction. It had the advantage of going beyond a stenosed

(a) (b)

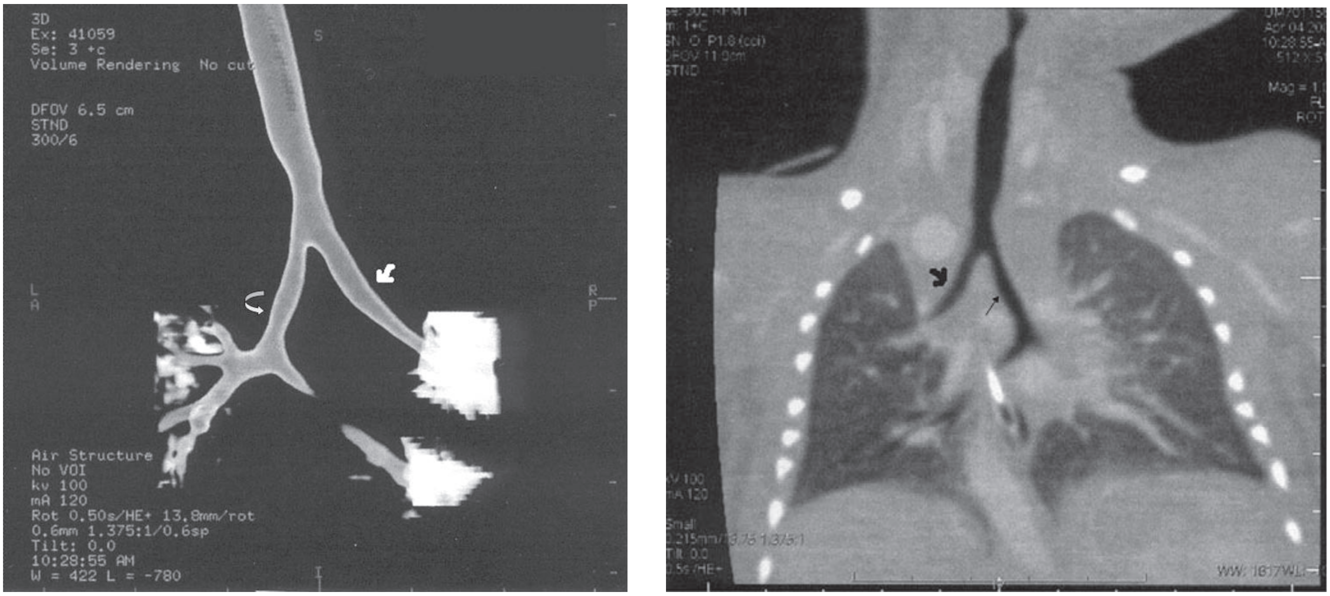

Figure 8 (a) 3D and (b) reformat images of the airway showing right main bronchus arising from the main trachea (tracheal bronchus) (arrow), and the stenosis at lower 1/3 of the main trachea (curve & small arrow).

airway, whereas bronchoscopy did not have this capability. It was less invasive than flexible bronchoscopy and could be performed under simple sedation without general anaesthesia. The pitfalls were radiation exposure and respiratory artefacts in infants and small children.

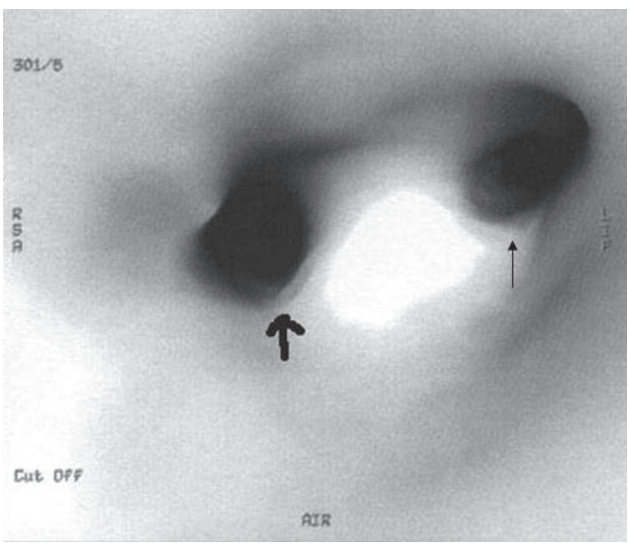

Figure 9 Virtual bronchoscopy of the same patient showing (a) right tracheal bronchus (arrow) and main bronchus, (b) stenosis at lower 1/3 of the main trachea (small arrow).

Recent Advance in Tumour Imaging

After the tissue diagnosis of a tumour or lymphoma, consideration might turn to the determination of the extent of disease and staging, as this would have a direct impact on the management of the disease and the patient's prognosis. The most significant dividing line was between those patients who were candidates for surgical resection and those who were inoperable but would benefit from chemotherapy or radiation therapy. Currently, fluorine-18 deoxyglucose (FDG) positron emission tomography (PET) was in wide use as a whole-body screening tool in routine clinical practice because of its high diagnostic accuracy. Recently, whole-body MR imaging had been proposed as an alternative technique for this purpose.

According to a study in adult,[10] for assessment of head and neck metastases, including brain metastases, the accuracy and sensitivity of whole-body MR imaging (sensitivity: 84.6%, accuracy: 95%) was significantly better than FDG-PET (sensitivity: 15.4%, accuracy: 89.1%). Some investigators had suggested that FDG-PET was not suited for the detection of brain metastases.[10,11] The sensitivity of FDG-PET for detection of brain lesions was low when compared to that of standard imaging techniques. This was the result of the extremely high level of physiological tissue accumulation of FDG in the cerebral cortex, which made it difficult to visualise metastatic disease in brain. For routine clinical practice, therefore, CT and/or MR imaging had remained the standard imaging tests for this purpose.[11,12] However, one should be aware that the marked increased in number of CT examinations performed would increase the radiation dose significantly. This was especially true for oncology patients who would undergo repeated examinations. One should consider carefully about the indications of repeated examinations.

For assessment of thoracic metastases, whole-body MR imaging was not significantly different from that of FDG-PET.[10] Based on a lesion-by-lesion analysis, sensitivities of whole-body MR imaging and FDG-PET were 23.1% and 15.4% respectively. Due to limited spatial resolution in MR and PET, they were not suitable as the initial screening tool for identification of metastatic nodules of the lung. Currently, CT is still the most sensitive screening tool for detection of small pulmonary nodules. The diagnostic capability for assessment of abdominal and pelvic metastases of whole-body MR imaging (sensitivity: 63.6%, accuracy: 93.8%) was not significantly different from that of FDG-PET (sensitivity: 81.8%, accuracy: 93%).[10] Studies had shown that there were false-negative small liver and adrenal gland metastases in FDG-PET imaging, because of the faint uptake of FDG. It was probably due to low metabolic activity and spatial resolution of FDG-PET.[12,13] On the other hand, a colon cancer and a rectal cancer, which were missed by whole-body MR, were detected by FDG-PET only.[12,13]

For the assessment of bone metastases, whole-body MR imaging (sensitivity: 88%, specificity: 96.1%, accuracy: 94.8%) was significantly better than that of FDG-PET (sensitivity: 88%, specificity: 88.3%, accuracy: 88.2%) (Figure 10).[10] In a study of 39 children who had Ewing's sarcoma, osteosarcoma, lymphoma, rhabdomyosarcoma, melanoma, and Langerhans' cell Histiocytosis, the sensitivity of bone and bone marrow lesions diagnosed with FDG-PET, whole body MR and skeletal scintigraphy were 90%, 82% and 71% respectively.[14] Most false-positive lesions were diagnosed using FDG-PET. The results suggested that whole-body MR constituted a significantly specific and accurate screening tool in the assessment of bone marrow metastases. It played an important role in the assessment of haematological malignancies such as lymphoma, especially in the assessment of early treatment response.

The advantage of MR was its complete lack of irradiation, rendering it more suitable for infants and children. One of the significant drawbacks of whole-body MR was the time-consumed with higher number of images per patient than FDG-PET, therefore it took even longer time for image acquisition. This was a challenge to the requirement of sedation technique in infants and children, as well as to older children by asking them to stay still for a long time during the whole imaging process. PET-CT is now a new functional and anatomical tool in the assessment of malignancies. So far there was no comparison between PET-CT with whole-body MR. Its drawback was the same as PET and CT, the radiation dose to children.

Summary

In paediatric imaging, US is still the first line of imaging and mainly used for screening. The experience of new US contrast agent is still very limited. The technique of VUS may be more popular in the future with further improvement of the US contrast safety, and

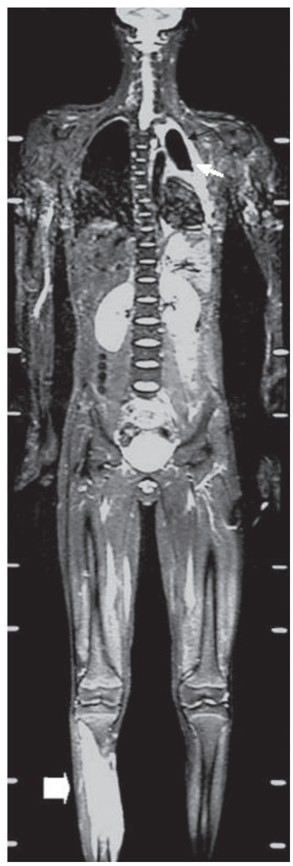

Figure 10 Whole body MR in a case of Ewing's sarcoma showing metastases to Rt calf (thick arrow) and Lt thorax (arrow) as hyperintense signals on STIR images.

with a lower price. In CT imaging, further advances are expected in hardware and scanning protocols in MSCT. Recently, a dual-source CT and 256 slices low dose CT were introduced. It is expected that with further improvements in CT hardware and acquisition protocols, significant reductions in radiation dose are attainable. The appropriateness of the use of MSCT is constantly evolving in concert with the clinical requirements and technical possibilities.

The acquisition of MR images is still time-consuming and the patient throughput with MR is substantially lower compared to MSCT. Further advances in hardware and scanning protocols in MR may help to solve the problem in the future. However, the limited availability of MR imagers still limits the use of MR on a day-to-day basis.

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