PAEDIATRIC RADIOLOGY: WHAT'S HOT AND WHAT'S NOT

Unnecessary imaging should not be happening in paediatric practice.

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Gerrit Dekker was a GP for 15 years in a rural practice in the Western Cape before returning to his alma mater as a registrar in radiology. During his time as a GP he did several locums in Canada, obtained the Canadian LMCC and completed MFamMed at the University of Stellenbosch. Under the guidance of Professor Andronikou, he has, like many registrars in this department, an interest in paediatric radiology.

The days of excessive radiation from unnecessary or non-informative radiographs should well and truly be over. These seem to persist in practice, however, in the form of comparative views, sinus X-rays and skull X-rays for trauma. In South Africa, where there are limited resources, we must preserve what we have and use what is available only if it is genuinely useful. This review will highlight some changing concepts in current paediatric radiology practice and indicate where there is validity in continuing procedures which may be dated, but relevant in a particular social and economic background. Responsibility lies both with the radiologist in offering an appropriate and affordable service, while keeping radiation to a minimum, as well as with the referring clinician who should be modern, educated and cautious of radiation exposure in his/her imaging referrals for children.

Comparative views (Fig. 1 a and b)

These are not indicated. Radiologists should be educated on the appearances of epiphyses and comparative views should only be performed on request for subtle or confusing appearances. Orthopaedic surgeons may need to measure the carrying angle on the normal side when dealing with a supracondylar fracture and a comparison view may be performed on request. Skeletal surveys, by definition, include both sides.

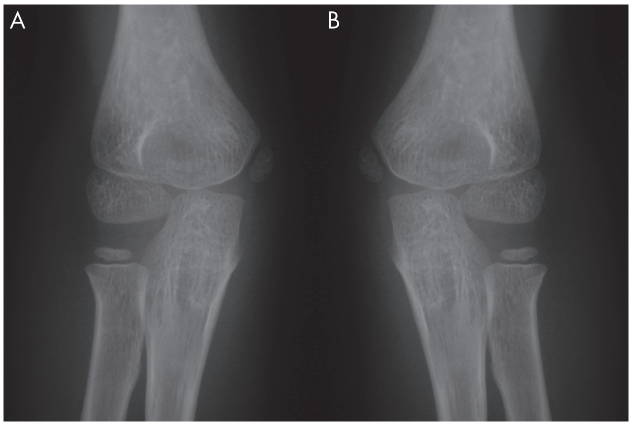

Fig. 1 a and b. Comparative views of the right elbow. The ossification centres have a 'predictable' age at which they appear, with the capitellum appearing first.

Skull X-rays (SXR) and alternative imaging (Fig. 2 a - e)

SXR should not be performed as a routine for trauma. An indication for SXR in the trauma setting is when there is a mild head injury in a child (normal Glasgow Coma Scale) when **CT would not be considered** but there are no facilities for patient monitoring. SXR may be used as a screening test for detecting skull fractures in these patients, the identification of which should prompt a CT to show any intracranial involvement.

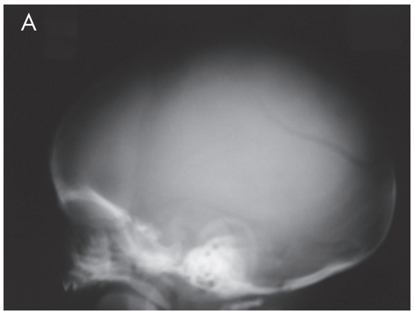

*Fig. 2 a. A patient with **no** loss of consciousness or neurological signs after a head injury in a rural setting demonstrates a skull fracture on a skull radiograph. He was referred for CT based on this finding and showed a drainable subdural haemorrhage.*

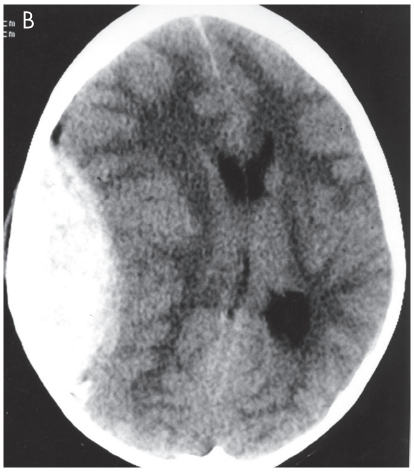

Fig. 2 b. Axial non-contrast cranial CT demonstrates a high-density extradural haemorrhage with associated midline displacement after head injury.

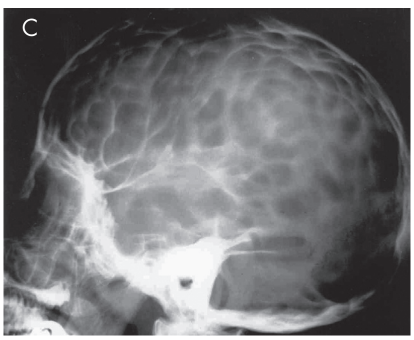

Fig. 2 c. Exaggerated convolutional markings of the calvarium on plain skull radiograph give the appearance termed a 'copper beaten skull' due to early sutural closure.

Fig. 2 d. 3D reformatting of axial CT scans of the head is a far more elegant and useful way of evaluating early sutural closure. In this patient there is partial fusion of the coronal sutures which are only patent near the fontanelle.

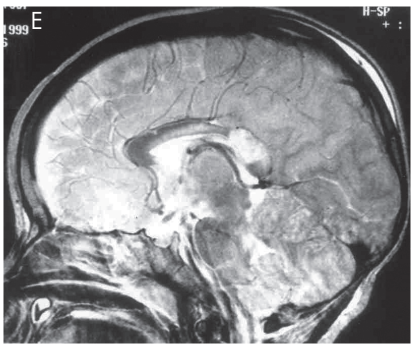

Fig. 2 e. Sagittal T2-weighted MRI shows involvement of the corpus callosum at the splenium which was not appreciated on axial CT images.

If there is any clinical indication for imaging the head in the trauma setting, it should be performed with non-contrast CT scanning. SXR should be reserved for suspected non-accidental injury, craniosynostosis and calvarial lesions. Multidetector CT with 3D reconstruction is also useful for evaluating the sutures and skull shape. MRI scans are rarely used in the trauma setting but are useful in demonstrating the cytotoxic oedema in diffuse axonal injury especially in areas seen best in the sagittal or coronal planes.

Sinus radiographs (Fig. 3)

The value of sinus radiographs in children is limited for diagnosis, detection of complications and planning treatment. Children with sinus complaints should be treated empirically without imaging except when there are features of a complication. If there is repeated sinusitis and endoscopic sinus surgery (ESSS) is contemplated, then limited 'coronal' CT should be performed (this is actually performed axially and reconstructed coronally on current multidetector CT scanners). This has a 9/10 diagnostic accuracy and is excellent for planning ESSS. This study should be offered routinely as an alternative to sinus X-rays, which have almost no value. The Radiological Society of South Africa recommends reduced rates for this investigation aimed at matching plain radiographs. The radiation dose from CT when performed at optimised paediatric settings on modern equipment is comparable to that of standard radiography.

Fig. 3. Coronal reformatting of axial CT of the sinuses demonstrates the anatomy of the maxillary sinus infundibulum and central nasal passage, and also shows mucosal thickening.

X-rays of orbits, optic canal, mastoids, petrous bones and pituitary fossa (Fig. 4 a - c)

These examinations are of little use. When no abnormality is shown, pathology cannot be excluded. When an abnormality is shown, it requires further characterisation. CT or MRI is indicated in all cases, and should be requested in the first instance. Beware of referrals aimed at 'saving the patient the expense' or not being 'convinced clinically to warrant CT or

MRI'. If CT or MRI is not warranted, then no investigation should take place to save unnecessary radiation or the false sense of security offered by a plain radiograph.

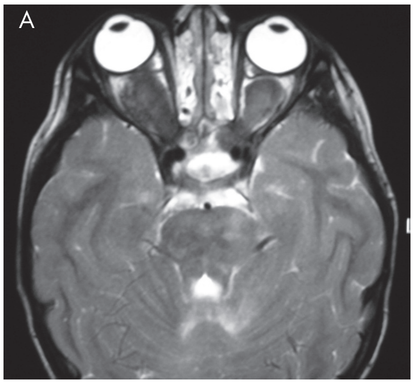

Fig. 4 a. Axial T2-weighted MRI demonstrates bilateral optic nerve gliomas in a patient with neurofibromatosis I.

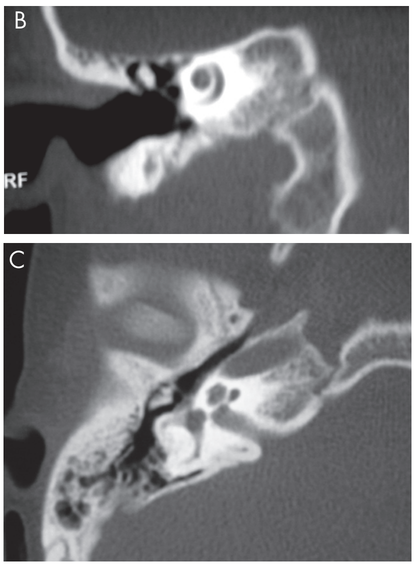

Fig. 4 b and c. Coronal and axial high-resolution images of the middle ear demonstrate the ossicles, cochlea and vestibular apparatus in excellent detail.

Cervical spine X-rays (Fig. 5a and b)

Neck trauma in children < 8 years of age should initially be imaged with a lateral C-spine X-ray only. Odontoid, frontal and oblique views are of limited value and not only increase the radiation burden, but also confuse the findings. The lateral view offers appreciation of soft-tissue swelling, alignment, fracture detection and evaluation for odontoid fractures, which occur through the odontoid synchondrosis. When a fracture is seen, when there is doubt or when C7/T1 cannot be demonstrated, a CT is indicated. In the situation where the C-spine X-ray is normal, but neurology suggests a cord injury, an MRI is indicated to determine prognosis in a case of spinal cord injury without radiographic abnormality (SCIWORA).

Fig. 5 a. Lateral plain radiograph of the cervical spine demonstrates a distraction injury at the C6/7 interspace.

Fig. 5 b. Sagittal reformatting of an axial multidetector CT scan of the cervical spine demonstrates the relationship of C1/C2 and the base of skull to great advantage and also offers the ability to assess alignment and soft-tissue thickness without moving the patient.

Vertebral column in general (Fig. 6 a - d)

There is still a significant role for plain radiographs in imaging the spinal column, particularly in South Africa. Scoliosis evaluation and diagnosis of congenital anomalies (block and butterfly vertebra, Klippel Feil anomaly, evaluation of kyphosis), primary vertebral tumours (haemangioma, lymphoma, eosinophilic granuloma), metastases (neuroblastoma) and initial diagnosis of (TB) spondylitis are all possible with plain radiographs. Often MRI may be indicated on review of plain films, as may be the case in TB spondylitis. There is a limited role for plain X-ray in bone element assessment in dysraphic states. In this regard, the bony 'spina bifida' is of secondary importance to the cord tethering, which is demonstrated with ultrasound (< 6 months of age) or in older children with MRI.

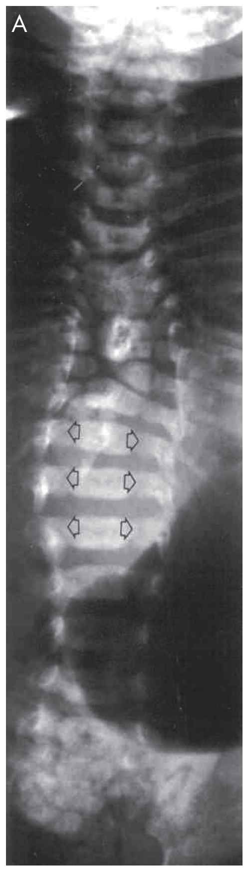

Fig. 6 a. Plain radiograph of the vertebral column demonstrates numerous thoracic vertebral anomalies including hemivertebrae, block vertebrae and widening of the spinal canal.

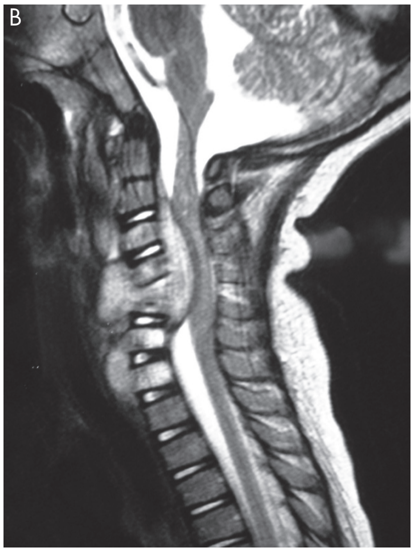

Fig. 6 b. T2-weighted MRI of the cervical spine demonstrates contiguous vertebral body destruction and kyphosis, soft-tissue masses, subligamentous spread of disease and compression of the spinal cord all on one study.

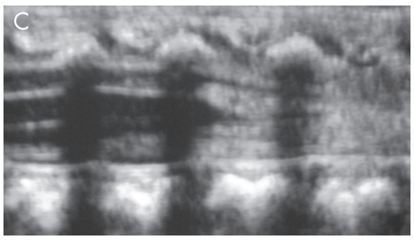

Fig. 6 c. Ultrasound of the spinal cord in an infant demonstrates normal position and tapering of the conus medullaris and allows real-time evaluation of pulsatility and dependency.

Fig. 6 d. Sagittal T1-weighted MRI of the spinal cord demonstrates non-tapering and low position of the cord inserting into a terminal lipoma which is in continuity with a subcutaneous fatty mass.

Pelvic X-rays (Fig. 7 a - c)

X-rays of the pelvis are not very useful for assessing developmental dysplasia of the hip in children prior to ossification of the femoral heads. Ultrasound of the hips, however, especially in neonates, is an excellent way of obtaining both static and dynamic images. An irritable hip can be assessed with ultrasound when looking for a hip effusion, even in an older child. Plain X-rays have a place in detecting and defining bone lesions, detecting Perthe's disease and slipped upper femoral capital epiphysis (SUFE) in older children. MRI scanning is, in the end, a far more elegant and sensitive investigation that is almost a one-stop shop for detecting effusions, picking up Perthe's disease early on and problem solving in cases of suspected SUFE. It also demonstrates marrow oedema and bone lesions with higher sensitivity.

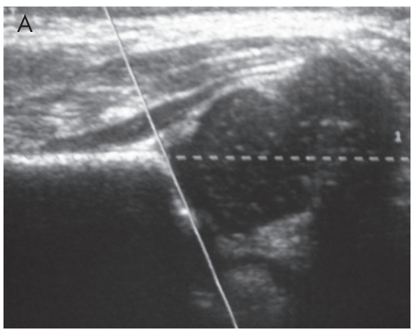

Fig. 7 a. Coronal ultrasound of the hip for developmental dysplasia in a neonate allows measurement of the alpha angle which indicates whether the hip joint is shallow. The cartilaginous head of the femur is well located and well covered at a normal acetabulum in this patient.

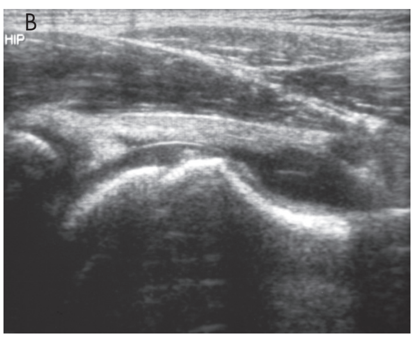

Fig. 7 b. Sagittal ultrasound of the hip demonstrating an effusion which is bulging out the fibrous capsule.

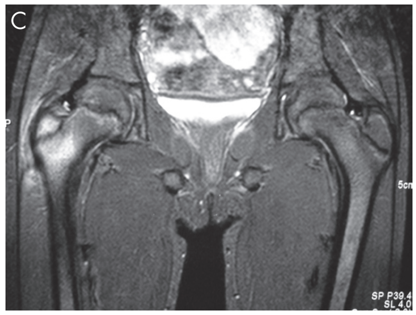

Fig. 7 c. STIR MRI of the pelvis suppresses the signal from the marrow fat and demonstrates the oedema involving the proximal portion of the right femur.

Lateral chest radiographs (Fig. 8)

Even though the lateral chest radiograph is not in routine use in the UK, it is still considered valuable for detecting TB lymphadenopathy and is currently used extensively in South Africa. Plain radiographs including the lateral view have been shown to be insensitive for the diagnosis of lymphadenopathy in children. However, it is currently not feasible to perform CT on every child with suspected TB for the detection of lymphadenopathy in South Africa or any other country where this disease is endemic.

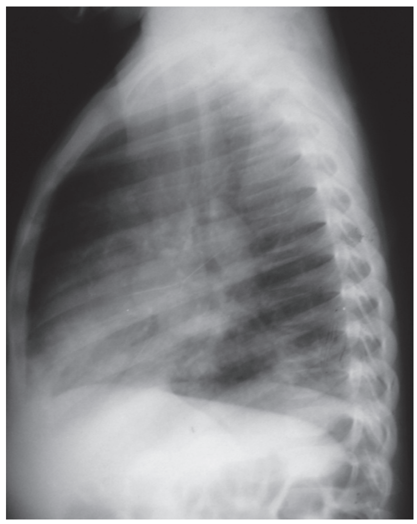

Fig. 8. Lateral chest radiograph demonstrates the 'doughnut'-shaped density around the hilum representing lymphadenopathy.

Fluoroscopy (Fig. 9a and b)

Fig. 9 a. Voiding during an MCUG with the catheter in situ. *Note the granularity of the image which has been 'stored' directly from the pulsed fluoroscopy, avoiding the radiation dose from a full exposure.*

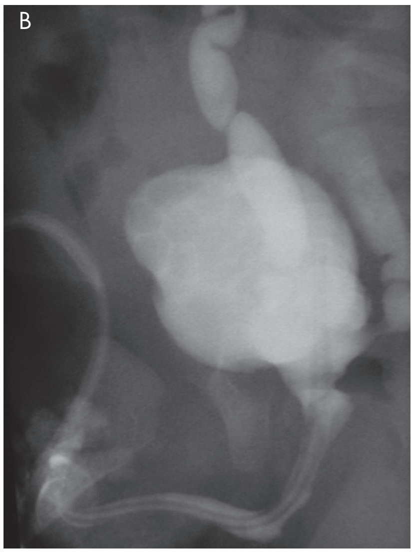

Fig. 9 b. An MCUG during voiding shows bilateral vesico-ureteric reflux into mega-ureters. This has been acquired unnecessarily as a full exposure, and demonstrates the high quality of the image (compared with Fig. 9 a) at the expense of a significantly higher radiation dose.

There have been major advances in this technique, which has become a digital process that allows storing of images or cine-loops directly, without exposing the patient to a 'full' X-ray and without needing to time the capturing of an event. Furthermore, new units offer pulsed fluoroscopy, with massive reduction in radiation and minimal compromise in diagnostic capability. Dedicated paediatric radiologists limit fluoroscopy time and full exposure to a minimum and use an intermittent screening technique with narrow collimation while performing directed investigations.

Oblique exposures of the pelvis to determine minor grades of vesico-ureteric reflux are considered unnecessary. Repeat fluoroscopy to evaluate voiding after removal of the catheter in boys is no longer considered necessary for diagnosing posterior urethral valves and control films have all but been eliminated.

In short, referral to a radiology practice that does not own or know how to utilise a pulsed fluoroscopy unit with the 'image grab' facilities is unacceptable. Moreover, performance of fluoroscopy without using the pulsed fluoroscopy option and image grab facilities should be considered negligent. More importantly, the use of rapid exposure to capture swallows and duodenal C-loop in children should be considered criminal.

Intussusception diagnosis and treatment (reduction) (Fig. 10 a - c)

Diagnosis should be made confidently on ultrasound; where there is doubt or when an intussusception is demonstrated, the procedure of choice is air reduction under fluoroscopic control. More advanced departments perform saline reduction under ultrasound guidance. Repeated attempts at reduction have been shown to improve outcome. Contrast or fluid reduction increases morbidity in the

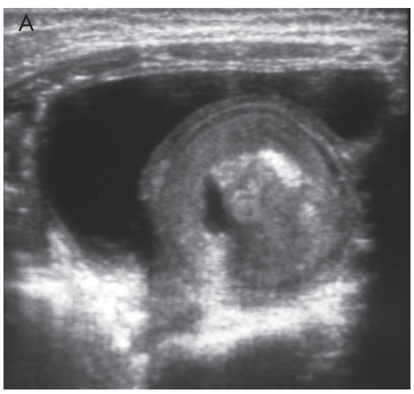

Fig. 10 a.

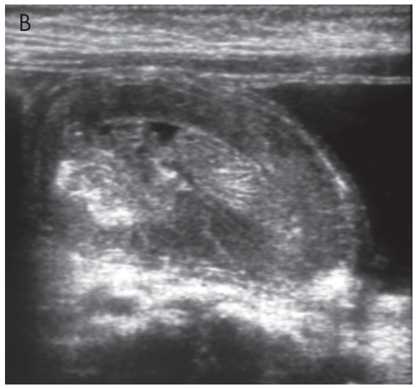

Fig. 10 a and b. The 'Swiss-roll' and 'pseudokidney' signs of intussusception as diagnosed on ultrasound.

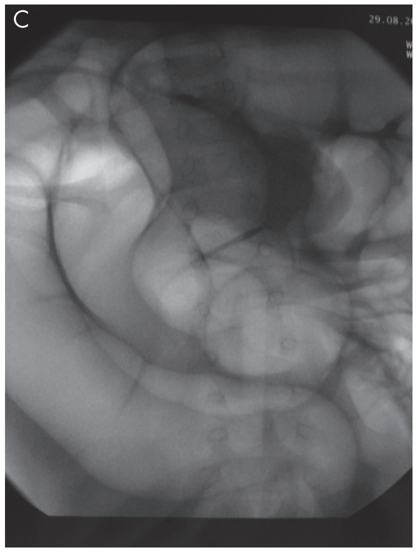

Fig. 10 c. Air reduction technique demonstrates the position of the intussusceptum at the transverse colon.

event of perforation, and diagnosis using a contrast enema is outdated. Pulsed fluoroscopy is considered a standard requirement.

Hypertrophic pyloric obstruction/stenosis (Fig. 11 a - c)

Ultrasound should be the diagnostic method of choice because there is no need to wait for the stomach to empty, there is no radiation, the examination is rapid and the accuracy of this investigation approaches 100%. Upper GIT contrast examination is reserved for the very few cases where there is diagnostic confusion. Radiologists who are unfamiliar with this ultrasound technique should not accept referrals.

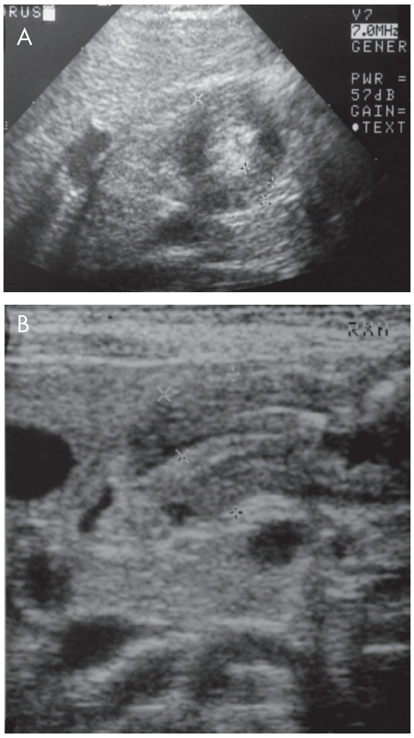

Fig. 11 a and b. Ultrasound features of hypertrophic pyloric stenosis allowing measurement of diameter, muscle wall thickness and length.

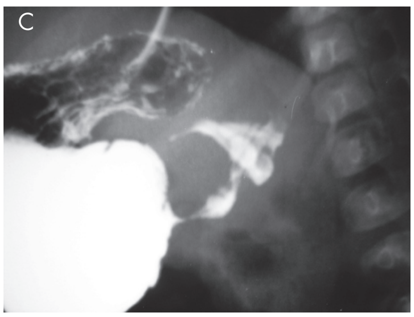

Fig. 11 c. The outdated traditional method of diagnosing hypertrophic pyloric stenosis by oral contrast fluoroscopy.

Intravenous urography/ pyelography (IVU/IVP) (Fig. 12)

This examination is avoided by paediatric radiologists worldwide as it delivers a high radiation dose. Indications include the need to view calyces or ectopic ureteric insertions (e.g. in duplex kidneys with enuresis). There are alternative imaging modalities such as MRU without contrast (heavily T2-weighted turbo spine echo/'HASTE' sequences) or post gadolinium and furosemide MR urography. Non-contrast CT scanning is acceptable for diagnosing ureteric calculi when low-dose settings are employed, but focused ultrasound should be the first imaging modality for detecting renal calculi.

Fig. 12. Intravenous urogram/pyelogram (IVU) remains useful for imaging calyceal abnormalities and ureteric anomalies as in this patient with bilateral duplex kidneys and abnormal ureteric insertions. There is no place for ***routine*** *use of IVU in UTI imaging.*

Urinary tract infection (Fig. 13 a - e)

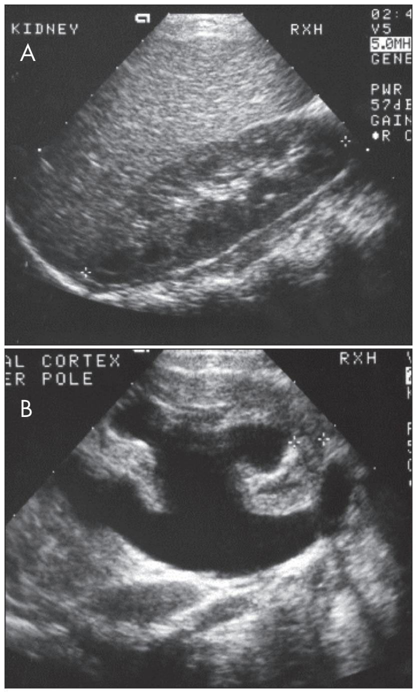

Fig. 13 a and b. A normal kidney (a) is shown in comparison to a hydronephrotic kidney (b) as demonstrated very elegantly by ultrasound.

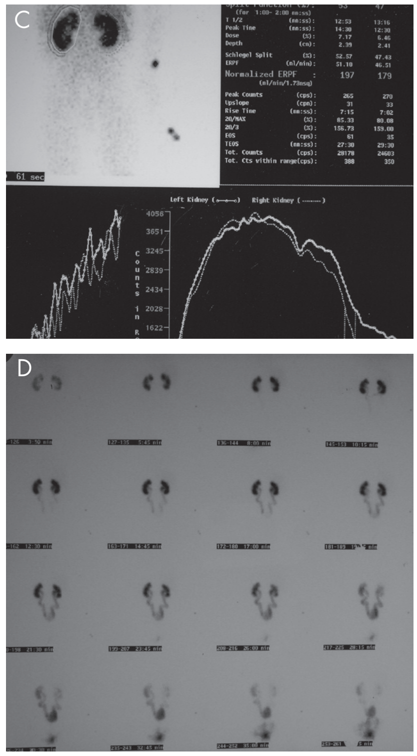

Fig. 13 c and d. A MAG 3 isotope study demonstrates uptake and excretion from the kidney both graphically (c) and as a series of images (d). If children are able to void on command, then MAG 3 is also useful for demonstrating vesico-ureteric reflux at the end of the same study (not shown here).

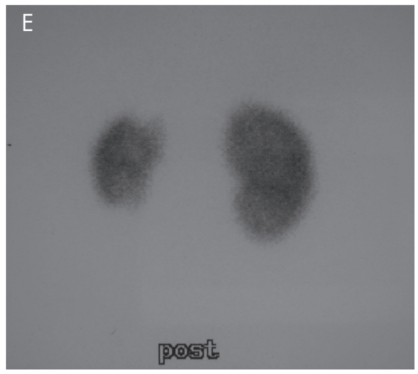

Fig. 13 e. DMSA isotope scan demonstrates defects in the upper and lower poles of the left kidney (note that this is a posterior view) in keeping with renal scars or current infection. This imaging should be performed 3 - 6 months after the infection has cleared to differentiate between the 2 possible causes.

There have been many advances in the imaging of UTI for children but there has also been a major change in attitude recently. IVU no longer falls within the arsenal for the imaging of UTI. However, ultrasound should be performed in all cases to determine if there is hydronephrosis, calculus or anomaly. Hydronephrosis should be investigated with Mag 3 renography, which imparts a low dose and shows the presence and level of any obstruction. In boys, micturating cystourethrography (MCUG) is indicated (using pulsed fluoroscopy) to exclude posterior urethral valves, but in girls an MCUG may not be the least invasive way of looking for vesico-ureteric reflux. The latest feeling from the paediatric radiology community is that low grades of reflux are relatively unimportant with regard to the need for surgical treatment. More important is the rapid recognition and management of UTI. Dimercaptosuccinic acid (DMSA) scans are still the method of choice for demonstrating renal scarring (even though there is some doubt as to whether these are linked with vesico-ureteric reflux). This investigation should be performed at least 6 months after an infection so as not to confuse defects on the scan from scars with those due to infection.

CT sanning (Fig. 14 a - d)

CT became the pariah of paediatric radiology over the past few years, because of the high radiation dose. Now with multislice technology (which delivers an even higher dose) it is back in vogue and used extensively in paediatric practice. Why?

Radiologists have reduced dose delivery by lowering mAs (milliamperage) and increasing pitch (table speed) on the scanner. This was done on a case-by-case basis for a while, which left the danger that an uninformed radiologist/radiographer may not employ such measures. More recently, especially on new multidetector scanners, these parameters are preset into the machines for paediatric studies. Multidetector technology also offers other advantages for reducing radiation dose. CT angiography can be performed at a far lower dose than conventional angiography. So-called 'combi' scans of the chest offer both

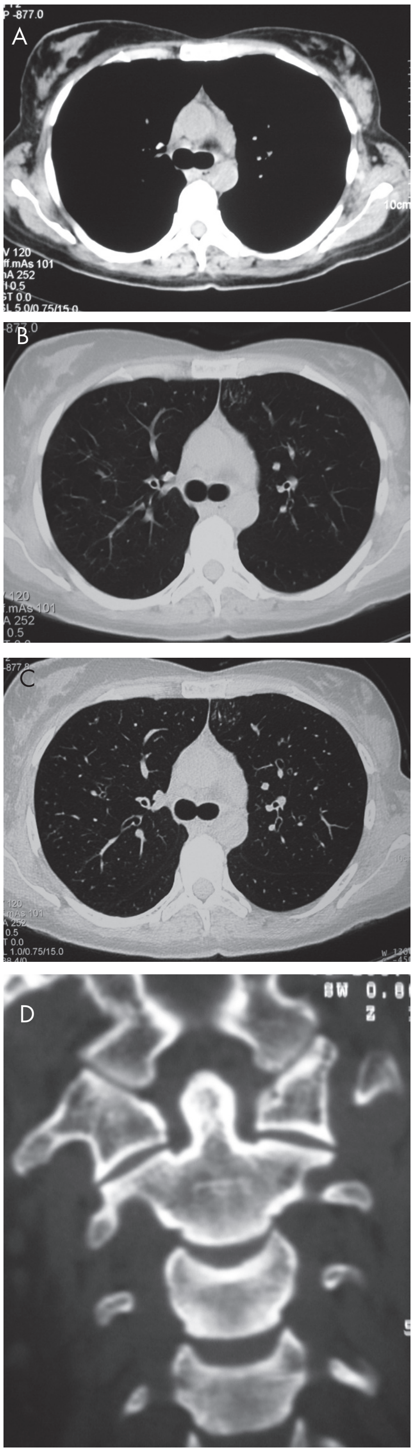

Fig. 14 a - d. The components of a ***single*** *'combi' scan of the chest using multi-detector CT technology. (a) Post-contrast CT demonstrating the mediastinal soft tissue and central vessels. (b) Contiguous 5 mm thick slices on lung window to demonstrate the 'air space' of the lung. (c) High-resolution 1 mm thick slices with interslice gaps for assessing the interstitium and evaluating for the presence of bronchiectasis. (d) Coronal reconstruction of axial CT images using multidetector technology allows demonstration of the atlanto-occipital and atlanto-axial articulations as well as evaluation of the odontoid process without having to move the patient in the trauma setting.*

soft-tissue contiguous slice evaluation of medistinal soft tissues and vessels, as well as HRCT evaluation of the interstitium, as a result of a single study. This required 2 individual studies through the chest tissue on traditional scanners. The exceptional multiplanar and 3D reconstructions offer such advances in diagnosis that the higher dose imparted is considered worthwhile and indicated. New volume rendering techniques offer enhanced evaluation of air-filled structures and virtual bronchoscopy allows evaluation of the airway but their place in routine image reconstruction is under development.

Position emission tomography CT

A combination of CT for anatomical localisation and fluorodeoxyglucose (FDG) positron emission tomography (PET) allows for accurate determination of tumour response to therapy and sites of metabolic activity for biopsy in oncology. The success is unprecedented, but the first PET CT scanners in South Africa are still being installed in the private sector at the time of writing.

Magnetic resonance imaging (Fig. 15 a - e)

MRI should be the panacea for all imaging requirements in children. It offers excellent contrast resolution (even in the absence of excessive fat planes, as needed for good CT images) **without any radiation**. MRI is used extensively for imaging central nervous system conditions, particularly structural anomalies, grey-matter seizure disorders and white-matter toxic and metabolic conditions. It also has excellent value for imaging muskuloskeletal diseases, especially of the joints and marrow and it is a major problem solver for slipped upper femoral epiphysis, Perthe's disease, septic joint effusions, primary bone tumours and physeal (growth plate) analysis. Whole-body STIR imaging for lymphoma, neuroblastoma metastases and other marrow disease is an excellent and simple technique.

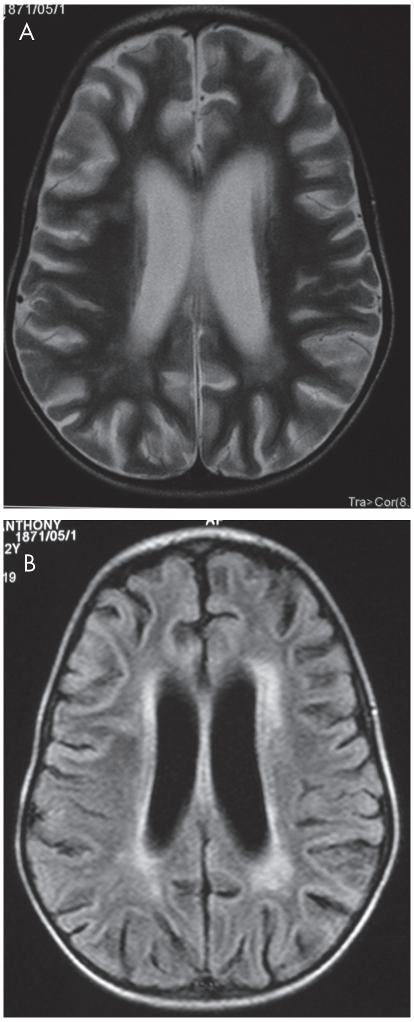

Fig. 15 a and b. Axial T2-weighted (a) and FLAIR (b) images are the mainstay for detecting pathology as a high signal abnormality using MRI. FLAIR adds the advantage of suppressing normal intraventricular CSF to reveal periventricular white-matter abnormality.

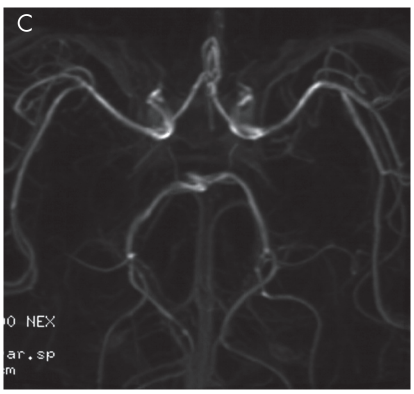

Fig. 15 c. 'Time of flight' MR angiography is performed non-invasively ***without*** *the use of IVI contrast medium and without exposure to radiation. In children this is highly desirable and MRA is considered adequate for initial assessment of the cerebral vessels.*

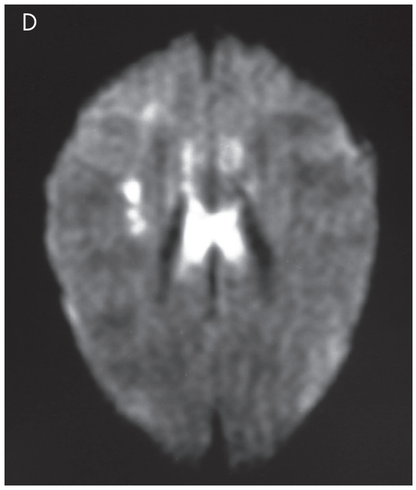

Fig. 15 d. This diffusion weighted image is ideal for demonstrating ischaemic areas in stroke as it demonstrates areas with cytotoxic oedema. It may also be used to demonstrate the extent of diffuse axonal injury, as in this patient with abnormality of the corpus callosum after a motor vehicle accident.

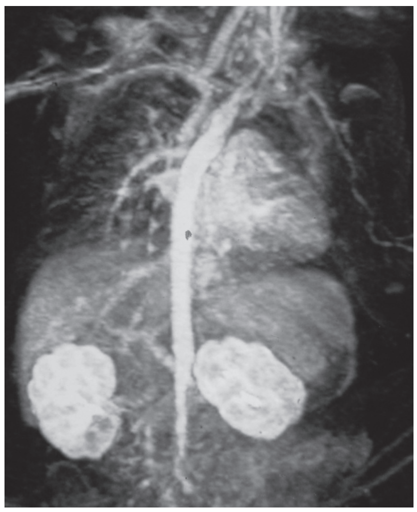

Fig. 15 e. This peripheral MR angiogram is performed with intravenous 'gadolinium' and has varying degrees of success in small children.

Cardiac MRI is advancing rapidly and MR angiography (MRA) is overtaking conventional angiography in paediatric practice, except when interventional procedures (embolisation, ballooning or stenting) are indicated. New technologies such as 'diffusion imaging' for infarction, 'MR spectroscopy' for tissue characterisation and functional MRI in psychological analysis are advancing rapidly and are available locally.

What is the trade-off that has kept MRI from becoming a 'one-stop shop' without any radiation concerns?

MRI still requires the patient to lie still for long periods of time and diagnostic quality depends on this. Sedation in children is dangerous, especially in the MRI suite where monitoring is difficult. Many institutions have therefore resorted to general anaesthesia for MRI in children younger than 6 years of age – this requires specialised and expensive equipment and anaesthetics expertise, and causes a burden on speed and cost of the service. The risks of anaesthesia now need to be weighed against the benefit of MRI and against the diagnostic capabilities and radiation dose imparted by other modalities.

CONCLUSION

Paediatric radiology has advanced as rapidly as the radiology technology has allowed it to. Unique aspects to paediatric imaging include justifying the radiation dose of the imaging technique to its diagnostic yield based on the severity of the disease presentation. Old imaging concepts have to be abandoned where new techniques offer an advantage, sometimes at the expense of an increased radiation burden. Clinicians and radiologists must be aware of current evidence-based evaluation of imaging techniques and must not rely on anecdotal information from their own experience. Uncooperative children may need general anaesthesia, as is the case for MRI. This modality continues to be restricted by the risks of general anaesthesia, where it would be a first-choice procedure because of its diagnostic capability and zero radiation risk.

Responsibility lies with clinicians to refer patients to radiology practices which have modern dedicated equipment and the radiologists who know how to use it. For radiologists there is a responsibility to re-train, re-skill or turn away referrals that fall outside their expertise. There is no excuse for charging high prices for procedures which are not only performed poorly, but may be harming children unnecessarily. There are numerous trained paediatric radiologists in the academic setting who teach and train people daily and are happy to advise at no charge. Perhaps radiologists intending to continue investigations in children should invest some time in modernising their practices.

Further reading

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IN A NUTSHELL

Comparative X-ray views are rarely indicated.

Skull X-ray should not be performed as a routine for trauma.

If there is any clinical indication for imaging the head in the trauma setting, it should be performed with non-contrast CT scanning.

The value of sinus radiographs in children is limited for diagnosis, detection of complications and planning treatment.

Children with sinus complaints should be treated empirically without imaging except when there are features of a complication.

X-rays of orbits, optic canal, mastoids, petrous bones and pituitary fossa are of little use. When an abnormality is shown, it requires further characterisation. CT or MRI is indicated in all cases, and should be requested in the first instance.

Neck trauma in children < 8 years of age should initially be imaged with a lateral C-spine X-ray only. Odontoid, frontal and oblique views are of limited value and not only increase the radiation burden, but also confuse the findings.

There is still a significant role for plain radiographs in imaging the spinal column, particularly in South Africa.

X-rays of the pelvis are not very useful for assessing developmental dysplasia of the hip in children prior to ossification of the femoral heads. Ultrasound of the hips, however, especially in neonates, is an excellent way of obtaining both static and dynamic images.

Even though the lateral chest radiograph is not in routine use in the UK, it is still considered valuable for detecting TB lymphadenopathy and is currently used extensively in South Africa.

Repeat fluoroscopy to evaluate voiding after removal of the catheter in boys is no longer considered necessary for diagnosing posterior urethral valves and control films have all but been eliminated.

Diagnosis of intussusception should be made on ultrasound.

Ultrasound should be the diagnostic method of choice for hypertrophic pyloric obstruction.

Intravenous urography/pyelography is avoided by paediatric radiologists worldwide as it delivers a high radiation dose. Indications include the need to view calyces or ectopic ureteric insertions (e.g. in duplex kidneys with enuresis).

IVU no longer falls within the arsenal for the imaging of UTI. However, ultrasound should be performed in all cases to determine if there is hydronephrosis, calculus or anomaly.

Multislice CT is now commonly used in paediatric practice.

A combination of CT for anatomical localisation and FDG positron emission tomography (PET) is allowing for accurate determination of tumour response to therapy and sites of metabolic activity for biopsy in oncology.

MRI should be the panacea for all imaging requirements in children. It offers excellent contrast resolution (even in the absence of excessive fat planes, as needed for good CT images) without any radiation.