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PICTORIAL ESSAY

Institutional Experience of Magnetic Resonance Urography in Children: a Pictorial Essay with Literature Review

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ABSTRACT

Conventional imaging studies such as ultrasonography, intravenous urography, micturating cystourethrography, and radionuclide scintigraphy are the basic investigations used in daily clinical practice for the diagnosis and monitoring of obstructive uropathy in children. Magnetic resonance urography imaging has emerged during the last 10 years, owing to its potential and success as a means of solving problems related to various pathological conditions. The purpose of this paper was to present an institutional experience on magnetic resonance urography in children. The techniques involved and their indications together with a review of literature are discussed.

Key Words: *Child; Magnetic resonance imaging; Urethral obstruction; Urography; Urologic diseases*

中文摘要

一所機構對小兒磁力共振尿路成像的經驗：圖片及文獻回顧

DD Rasalkar、朱昭穎

傳統的影像學例如超聲波、靜脈泌路造影、排尿性膀胱尿路造影及放射性核素顯像是日常用作診斷及檢測小兒阻塞性尿路病變的基本方法。由於磁力共振尿路成像可以有效地檢測不同病況，此技術最近十年間漸漸普及。本文探討一所機構對小兒磁力共振尿路成像的經驗，並討論涉及的技術及指證，並作文獻回顧。

INTRODUCTION

Magnetic resonance (MR) urography has emerged as an imaging method in the last 10 years due to its potential and successful implications when it comes to solving problems associated with various pathological conditions.[1-5] MR urography has been in clinical practice since 1986, soon after the discovery of heavily T2-weighted sequences by Hennig et al.[6] With the emergence of new ultrashort sequences and contrast-enhanced imaging, major developments in MR urography ensued in subsequent years. The advantages of MR urography include the avoidance of ionising radiation and the need to administer iodinated contrast media. Intravenous contrast-enhanced T1-weighted MR urography as well as non-enhanced T2-weighted techniques are usually used in an integrated fashion and complement each other in assessing both the morphology and function of congenital urinary tract anomalies.[7-9] The latter sequence can be used alone to delineate the morphology of obstructed urinary tracts, with poor excretory function, while the role of other contrast studies is limited.[7-9] MR urography is

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currently used in both adults and children for various indications.[1,7,10,11] In this study, examples of MR urography in the evaluation of uropathy in children are illustrated and discussed.

MAGNETIC RESONANCE UROGRAPHIC TECHNIQUES

Two MR urographic techniques are in common use: (a) static-fluid MR urography (also known as static MR urography, T2-weighted MR urography, or MR hydrography); and (b) excretory MR urography (also known as T1-weighted MR urography).[2,5,12]

Static-fluid Magnetic Resonance Urography

T2 sequences using long T2 relaxation time for urine are the key for static-fluid MR urography. They depict a static column of fluid in the urinary tract. In our institution, a respiration-triggered, heavily T2-weighted fat-suppressed inversion recovery sequence (TR/TE/TI 3600/600/25) is used to assess the renal morphology. Three-dimensional volume images using a maximum intensity projection algorithm are reconstructed. A 'vector of interest' editing technique is further used to remove superimposing structures containing static fluid. Static-fluid MR urography resembles conventional intravenous urography (IVU) and is useful for identifying the level of urinary tract obstruction. There is no need to inject contrast; this technique is therefore particularly useful for demonstrating the collecting system of a significantly obstructed and poorly excreting kidney. Additional sequences, however, are needed for evaluating the cause of obstruction.[13] In static-fluid MR urography, sequences can be achieved with single-shot fast spin-echo techniques within 1 to 2 seconds, thereby reducing motion artefacts.[14] The image series should be acquired with 5-10–second intervening intervals, in order to prevent radiofrequency saturation of the tissues that lead to false-positive signal loss along the urinary tract.[14] Cine MR urography is useful in confirming the existence of urinary tract stenosis.[14] Supplementary manoeuvres such as hydration, diuretics, and compression can be used to enhance image quality in patients with non-dilated systems.[15] In our institution, fluid loading is given intravenously rather than orally, so as to avoid the presence of fluid-filled bowel loops that may interfere with image quality, as T2-weighted techniques are not specific for visualising fluid within the urinary system. Diuretics are routinely given just before static MR urography. Contra-indications to furosemide administration include anuria and hypersensitivity to the drug, electrolyte imbalance, or hypotension (which should be corrected before administration).

Excretory Magnetic Resonance Urography and Image Processing

This is also known as dynamic gadolinium-enhanced MR urography, and is analogous to computed tomographic (CT) urography and conventional IVU. A gadolinium-based contrast agent is administered intravenously, and the collecting systems are imaged during the excretory phase. Gadolinium shortens the T1 relaxation time for the urine, allowing urine to appear bright on initial T1-weighted images.

Vivier et al[16] have described acquisition techniques with total acquisition times of 30 min or less that entail use of low-dose gadolinium-based contrast (0.05-0.1 mmol/kg). No general anaesthesia or bladder catheterization is needed. A flip angle (FA) of 10° is chosen for optimum signal-to-noise ratio (SNR), as well as contrast between the enhanced tissues and the linearity of the gadolinium signal to concentration relationship. Sometimes, use of a low FA (8-25°) is adapted to the low dose of contrast agent (≤0.5 mmol/kg), which can provide a high SNR and satisfactory contrast between enhanced tissues.[16-19] This has the advantage of minimising the gadolinium concentration, making it clinically more acceptable without compromising the required SNR.[20,21]

Complex post-processing of MR urography functional analysis has become a limiting factor for its widespread / routine implementation, for 2 major reasons. First there is the inherent complexity of the program (an array of parameters including calculation of functional curves, plots, and maps requiring commercially available complex programs like Analyze [Rochester, MN]).[22] Second, its handling also needs specialised non-medical or non-paramedical personnel.[22]

Two dedicated paediatric MR urography functional analysis programs are available at no charge, but are not routinely applied.[16] In order to solve this problem, Khrichenko and Darge[18] have recently introduced a new user-friendly, fast, easily operated software termed "CHOP-fMRU". This enables comprehensive automated functional analysis and is freely downloadable at www.chop-fmru.com. A copy of the IDL Virtual Machine required for the installation can also be obtained free at www.ittvis.com. On the other hand, Vivier et al[16] share their experience with the V5 MR urography plug in program, which is freely downloadable at the National

Institutes of Health website (http://rsb.info.nih.gov/ij/) and can run on any personal computer equipped with Windows (98, 2000, NT, Millenium, 2003, 2008, Vista; Microsoft Corp, Redmond WA). These new methods enable calculation of split renal function, based on the right-left renal parenchyma volume ratio. Alternatively, dynamic contrast-enhanced T1-weighted sequences by the Rutland-Patlak method can be used. A region of interest encompassing the entire kidney, including parenchyma and the collecting system, can be drawn. The resulting time-intensity curve is called the excretory renogram. The various patterns of diuresis renogram curves were categorised by O'Reilly et al.[23] Other features include creation of movies from the dynamic sequence in AVI (Audio Video Interleave) format. This software requires 15 min and 45 min for entire MR urography processing per examination. The most time-consuming process is kidney segmentation, which is particularly true if a manual segmentation is performed, especially with severe hydronephrosis. A user's guide is available online (http://rsbweb.nih.gov/ij/plugins/mru/mru.html).

Although recently there have been a series of articles trying to standardise and promote specific methods on functional analysis of MR urography, a final set of criteria is yet to be defined according to Avni and Riccabona.[24] Thus, further discussion on how the paediatric radiology community could or should use MR urography is needed. According to Avni and Riccabona,[24] additional research and development is necessary before MR urography can be routinely implemented as a standard, easily performed technique for general use. These considerations should also influence companies to produce integrated post-processing program software for their various workstations and viewing programs.

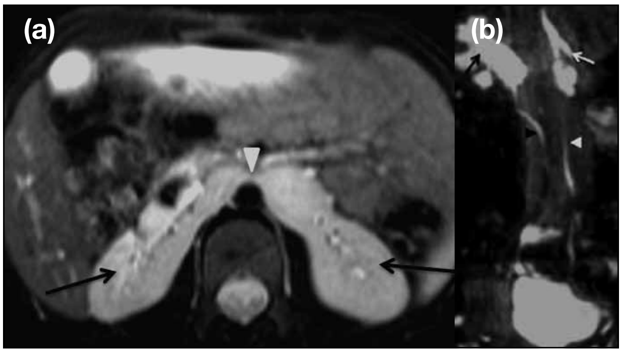

Figure 1. An 8-year-old boy with congenital heart disease and a known horseshoe kidney: (a) T2-weighted axial image showing horseshoe kidneys with fusion of the lower pole of right and left renal parenchyma (black arrows) forming a parenchymal isthmus (white arrowhead) that passes anterior to the aorta, and caudal to the inferior mesenteric artery. (b) T2-weighted maximum intensity projection coronal view: the bilateral excretory systems are not dilated (black arrow and arrowhead showing right pelvicalyceal system and ureter; and white arrow and arrowhead showing left pelvicalyceal system and ureter respectively).

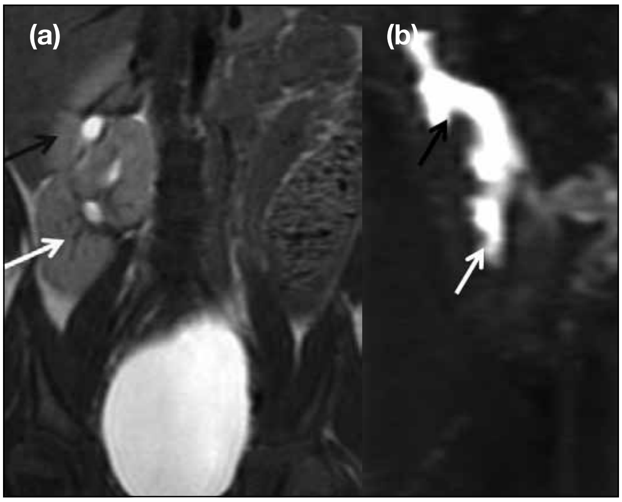

Figure 2. A 1-year-old boy with an ectopic left kidney in the right iliac fossa: (a) T2-weighted and (b) coronal maximum intensity projection images showing the right kidney (black arrows) with a normal position and morphology. The left kidney (white arrow) is ectopic just antero-inferior to the right kidney. The tissue plane between the two kidneys can be delineated. No definite evidence of fusion is seen. Both ureters are not dilated, and there was normal insertion into the bladder (not shown).

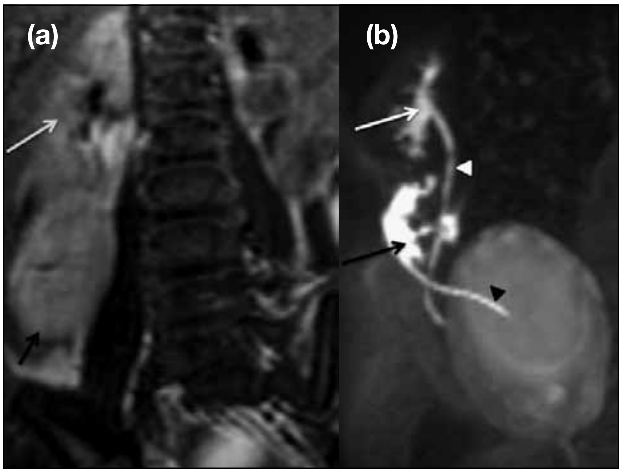

Figure 3. A 2.5-year-old boy with multiple anomalies and crossed fused renal ectopia: post-contrast (a) T1-weighted image showing a crossed ectopic left kidney (black arrow) fused to the lower pole of the right kidney (white arrow), and (b) T2-weighted maximum intensity projection coronal image. Note the prominent left pelvicalyceal system (black arrow) but the normal calibre of the left ureter (black arrowhead). The right pelvicalyceal system (white arrow) and right ureter (white arrowhead) are not dilated.

To achieve adequate spatial resolution in patients with a limited capacity to hold their breath, the urinary tract can also be studied in segments.[25] Imaging the urinary tract in segments with a smaller field of view and thinner sections also allows acquisition of highly detailed images of the collecting systems, although the amount of details obtainable is limited by the SNR.[25] A commonly encountered problem in excretory MR urography is poor visualisation of the course and insertion of ureter, when the urinary system is significantly obstructed or there is poor renal function. This limitation can be overcome by supplementary static-fluid MR urography.[1,10]

Figure 4. A 4-month-old girl with a right cystic dysplastic kidney: post-contrast T1-weighted (a) coronal and (b) axial images showing a right non-functional cystic dysplastic kidney (white arrows). The left kidney is normal in configuration but shows mild hydronephrosis (black arrows).

CLINICAL APPLICATIONS

Congenital Malformations

Inherent excellent anatomic tissue resolution and multi-planner images are keys to depicting congenital renal anomalies related to kidney position and rotation.[26] Horseshoe and ectopic kidneys can be easily separated from the background and overlying tissues (Figures 1-3).[26] On MR urography, renal hypoplasia associated with ureteric ectopia and supernumerary kidneys can usually be demonstrated even in patients with minimal renal function.[26] Although the diagnosis of renal dysplasia is based on histological identification of undifferentiated mesenchyme such as cartilage and immature tubules, there are suggestive features on MR urography. The various forms of renal dysplasia (multicystic dysplastic kidney [Figure 4], cystic obstructive dysplasia, hypodysplasia, and solid renal dysplasias), anomalous calyceal development and ureteroceles can be demonstrated by MR urography.[27] The identification of maldeveloped calyces associated with hypoplasia supports the diagnosis of renal hypodyplasia secondary to abnormal interactions between the metanephros and the ureteric bud, all of which can affect the entire urinary tract.[26] Furthermore T2 HASTE (half-fourier acquisition single-shot turbo spin-echo) sequences also help delineate associated genial and spinal anomalies as in one of our cases (Figure 5).

Evaluation of Hydronephrosis

Hydronephrosis is the most common indication for MR urography in the paediatric population.[26] Dilatations of the urinary system in the paediatric age-group are generally attributed to urethropelvic strictures, vesicoureteral reflux, and posterior urethral valves.[28] The common causes for obstructive uropathy in children are due to ureteropelvic junction anomalies (Figure 6), or megaureters. Vesicoureteric junction obstruction can also be well delineated (Figure 7). Obstructive uropathy can trigger an intricate interaction via release of vasoactive factors and cytokines,[28,29] causing derangement in the glomerular haemodynamics and tubular function. Clinical management of these conditions is determined by both anatomical and functional criteria; the ultimate goal being the relief of obstruction and the preservation of renal function.[26] MR urography not only reveals anatomical details but also provides functional information. Currently, conservative management with close follow-up is indicated in infants with hydronephrosis.[26] Surgery is reserved for patients

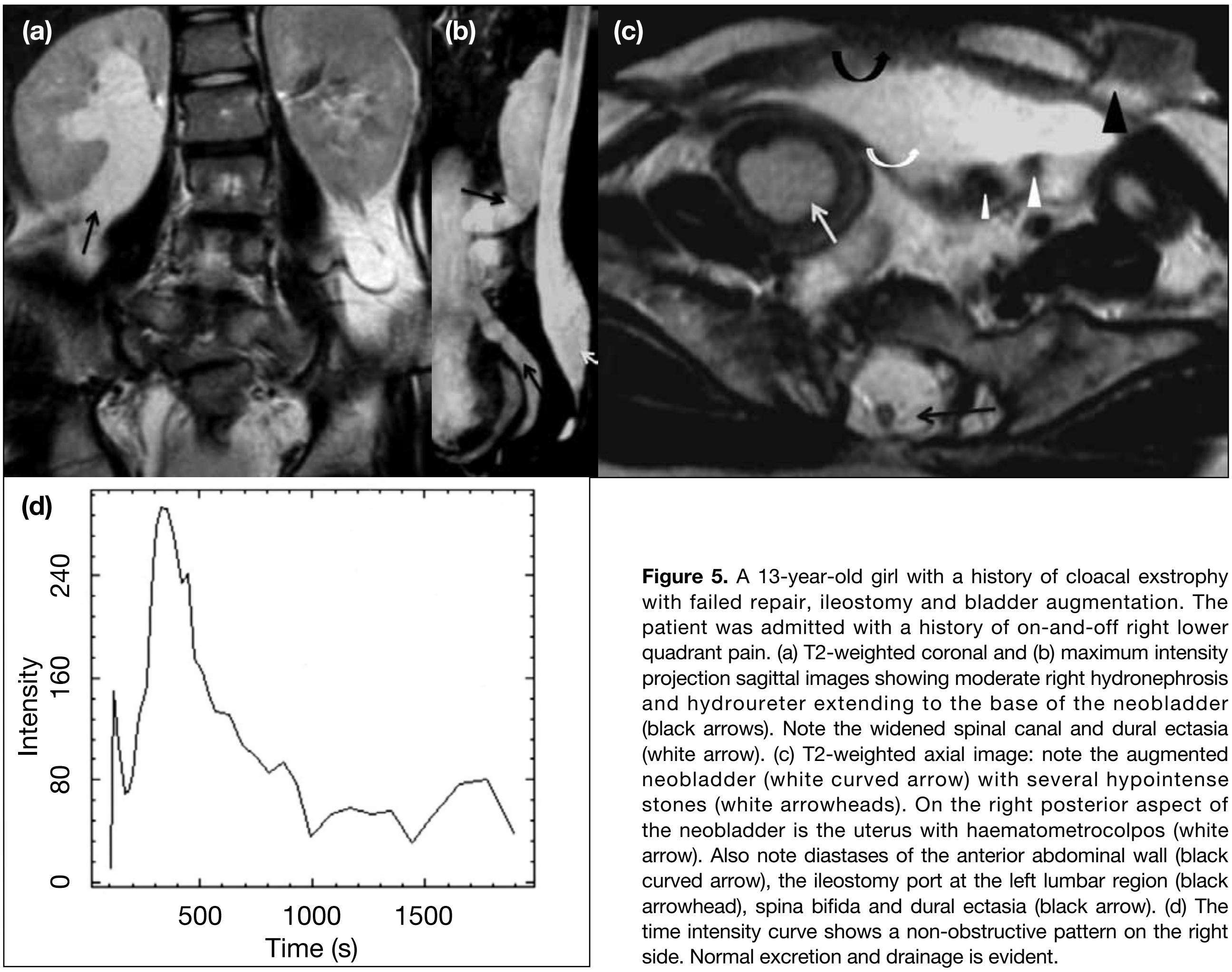

Figure 5. A 13-year-old girl with a history of cloacal exstrophy with failed repair, ileostomy and bladder augmentation. The patient was admitted with a history of on-and-off right lower quadrant pain. (a) T2-weighted coronal and (b) maximum intensity projection sagittal images showing moderate right hydronephrosis and hydroureter extending to the base of the neobladder (black arrows). Note the widened spinal canal and dural ectasia (white arrow). (c) T2-weighted axial image: note the augmented neobladder (white curved arrow) with several hypointense stones (white arrowheads). On the right posterior aspect of the neobladder is the uterus with haematometrocolpos (white arrow). Also note diastases of the anterior abdominal wall (black curved arrow), the ileostomy port at the left lumbar region (black arrowhead), spina bifida and dural ectasia (black arrow). (d) The time intensity curve shows a non-obstructive pattern on the right side. Normal excretion and drainage is evident.

with impaired renal function.[30,31]

In our institution, dynamic sequence / excretory urography is sometimes used for further evaluation of obstructive uropathy in subjects with indeterminate results from radioisotope urography. In addition, the arterial phase of the contrast agent in the dynamic study can be used to construct a MR angiogram of the aorta and renal arteries. Crossing vessels can be accurately identified in both obstructed and unobstructed systems. The ability to delineate the ureteric anatomy is an additional advantage over ultrasonography (US) or renal scintigraphy. Ectopic ureteric insertion either in single systems or in association with duplex systems can usually be displayed on the delayed post-contrast images or on the T2-weighted images for both non-dilated and markedly dilated / poorly functioning systems. MR urography can also demonstrate both simple and ectopic ureteroceles (Figures 8-12).

PROS AND CONS OF DIFFERENT IMAGING MODALITIES

In current clinical practice, various conventional imaging techniques are used for screening of the paediatric urinary system. These are often important for making accurate diagnoses and thereby help in early management.

(1) US remains the initial method for imaging dilated systems, and is supplemented if necessary by micturating cystourethrography (MCUG), IVU, and scintigraphy.[32] It is a widely available, inexpensive bedside investigation with no risk from ionising radiation. Presently, widespread use of preliminary obstetric US has led to early detection of congenital abnormalities in the prenatal stage. It is also a sensitive means of detecting dilated urinary systems. These factors have further increased the number of radiological examinations carried out on paediatric patients.[33] Depiction of renal and bladder

Figure 6. A 1-year-old boy with antenatal dilatation which progressed on follow-up: T2-weighted coronal image showing a severely hydronephrotic left kidney with a dilated renal pelvis and calyces down to the pelviureteric junction (white arrow). Note the paper-thin cortex (black arrow).

Figure 7. An 8-month-old girl with an antenatal diagnosis of right hydroureteronephrosis: T2-weighted maximum intensity projection coronal image showing the right kidney is enlarged and grossly hydronephrotic (black arrow). There is also a right hydroureter (white arrow) extending down to the vesicoureteric junction (VUJ). Features are consistent with right VUJ obstruction.

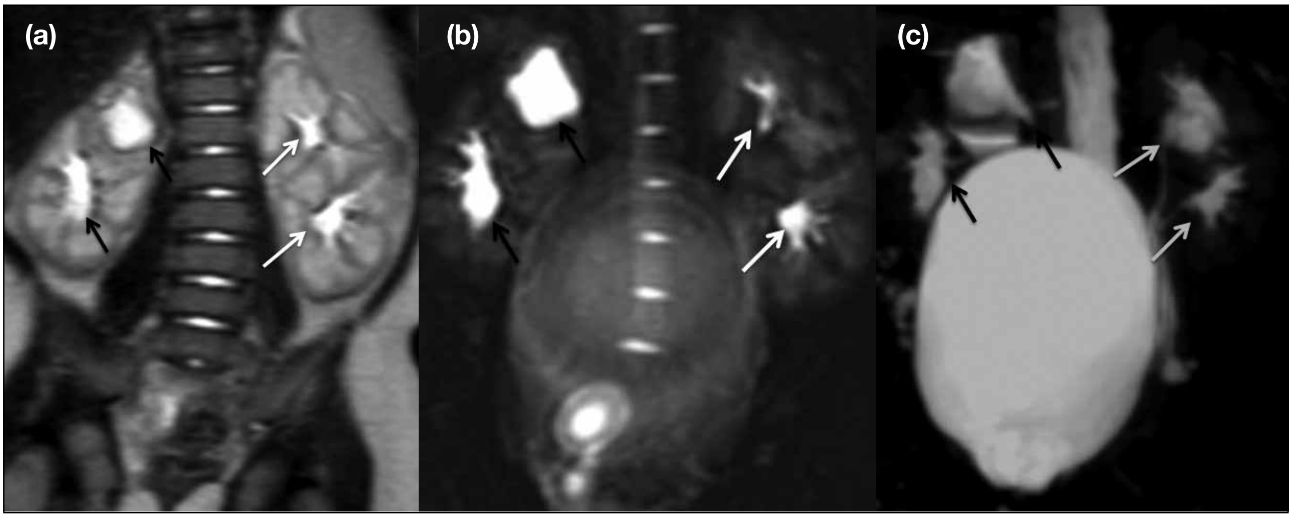

Figure 8. A 4-month-old girl presented with recurrent urinary tract infection: T2-weighted (a) coronal and (b, c) maximum intensity projection coronal images showing bilateral duplex kidneys. Note mild dilatation of the right pelvicalyceal system (black arrows). There is no ectopic insertion of ureters, however. The left excretory renal systems (white arrows) are not dilated. The urinary bladder is much distended as the bladder catheter was clamped during the examination.

morphology and their abnormalities are relatively easy using US, though demonstration of the ureters is often difficult. Functional information is limited, necessitating complementary techniques such as scintigraphy and IVU.[4,34]

(2) IVU provides morphological as well as functional information about the kidneys. However, owing to the risk of ionising radiation and complications related to the iodinated contrast media, it is less frequently used nowadays.

Figure 9. A 7-year-old girl complained of daytime enuresis: T2-weighted maximum intensity projection coronal image showing a duplex right kidney with a dysplastic upper moiety and vaginal insertion of the dilated upper moiety ureter (white arrows). The ureter of the lower moiety is normal in calibre with orthotic insertion (black arrow). Vaginal insertion of the ectopic ureter is a common structural cause of persistent enuresis in girls.

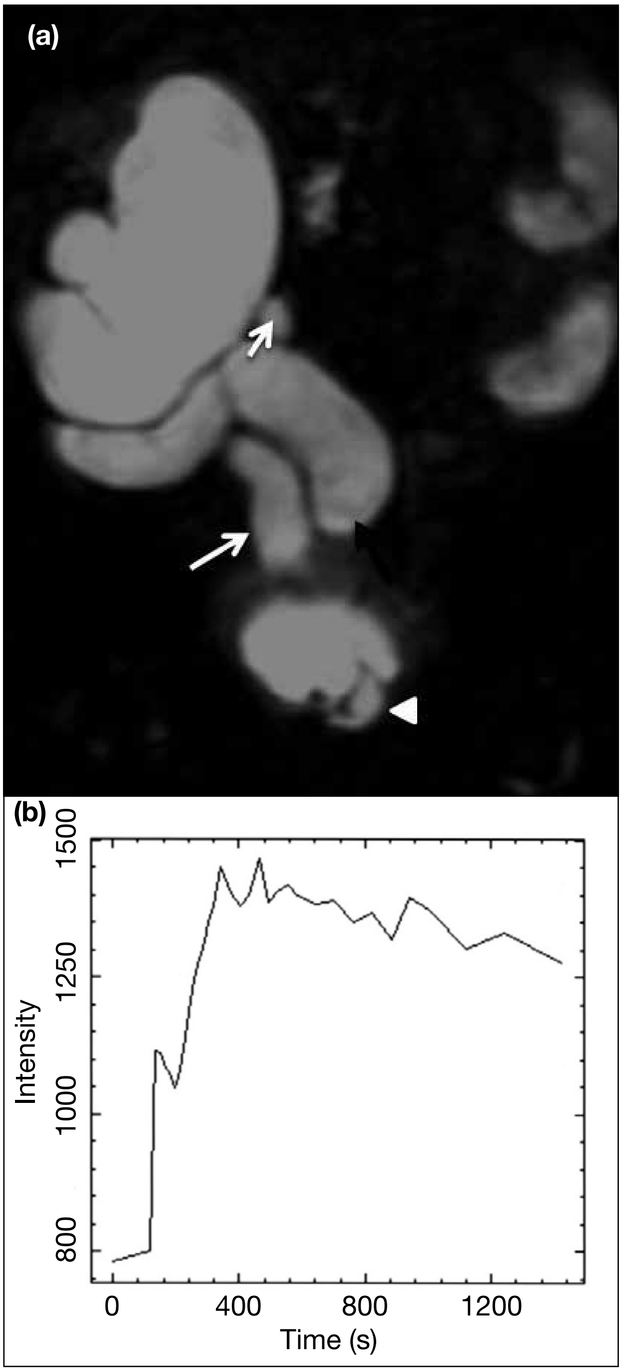

Figure 10. A 5-month-old girl with an antenatal diagnosis of right hydronephrosis: (a) T2-weighted maximum intensity projection coronal image showing a dysplastic duplex right kidney with gross hydronephrosis and hydroureter (white arrows) of both moieties. One of the dilated ureters crosses to the left side (black arrow) and is inserted into a ureterocoele (white arrowhead) at the bladder base. (b) The time intensity curve showing hold up of contrast (i.e. a plateau) suggestive of obstruction.

(3) MCUG, the gold standard technique for the assessment of vesicoureteral reflux, is capable of showing the urethra and reflux within the urinary tract.[34] Risk of ionising radiation and invasiveness are the limiting factors.

(4) CT is useful for delineating extent of the disease and monitoring the treatment response. It plays a vital role in the imaging of renal tumours, trauma to the urinary tract, and urolithiasis. In addition, CT angiography also permits non-invasive evaluation of renal vascular structures. However, the use of ionising radiation and iodinated contrast media limits its role in routine morphological and functional assessment of urinary tract anomalies, particularly in children.

(5) Nuclear scintigraphy is a very sensitive technique for viewing renal scars; however, the resulting spatial resolution is poor and it entails ionising radiation.[3,11,35,36] It also provides information about functional renal parenchyma.

Advantages of Magnetic Resonance Urography

MR urography has proven to be a one-stop comprehensive morphological and functional imaging technique for the urinary tract.[3,16,26] It provides multi-planer images with high resolution and avoids ionising radiations. The total cost of conventional techniques can often surpass the costs of MR urography, because usually more than one imaging technique is required to diagnose the uropathological problem. Whilst sedation and anaesthesia are required for MR urography, these are also necessary for scintigraphic examinations. Both scintigraphy and MR urography can provide functional information with similar durations of scanning. However, MR can show better anatomical details of the pathology, therefore its advantages override its disadvantages.[1,10] Moreover, both morphological and functional information can be obtained simultaneously in a single examination of a sedated / anaesthetised patient.[37] As illustrated by our examples, MR urography is particularly useful for demonstrating the morphology of duplicated collecting systems with associated obstruction, ectopic ureters, ectopic ureterocoeles, or vesicoureteral reflux.[4,9]

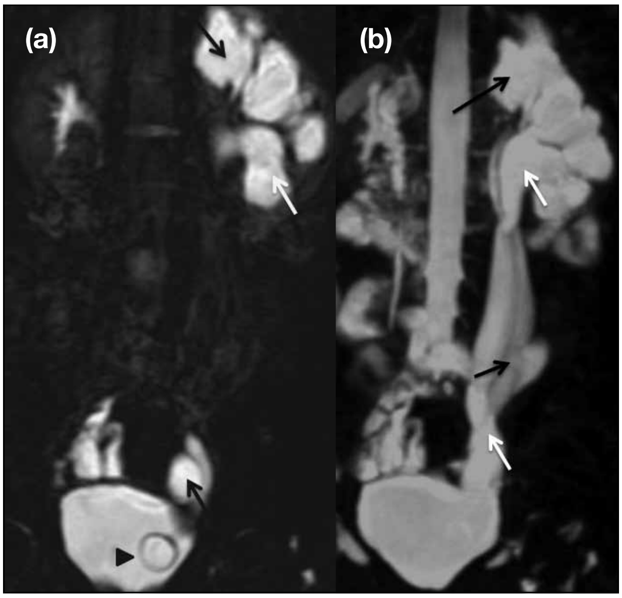

Figure 11. A 3-year-old girl presented with recurrent urinary tract infection: (a) T2-weighted and (b) maximum intensity projection coronal images showing a duplex left kidney. The upper moiety and ureter (black arrows), and the lower moiety and ureter (white arrows) are dilated. Note the left ureterocoele (black arrowhead).

In summary, MR urography does not involve radiation and can provide simultaneous morphological and functional information about pathology in the urinary system in children. As reported earlier, in our practice, it was particularly useful for the evaluation of double collecting systems with complex congenital pathologies, particularly in those with impaired excretory function.

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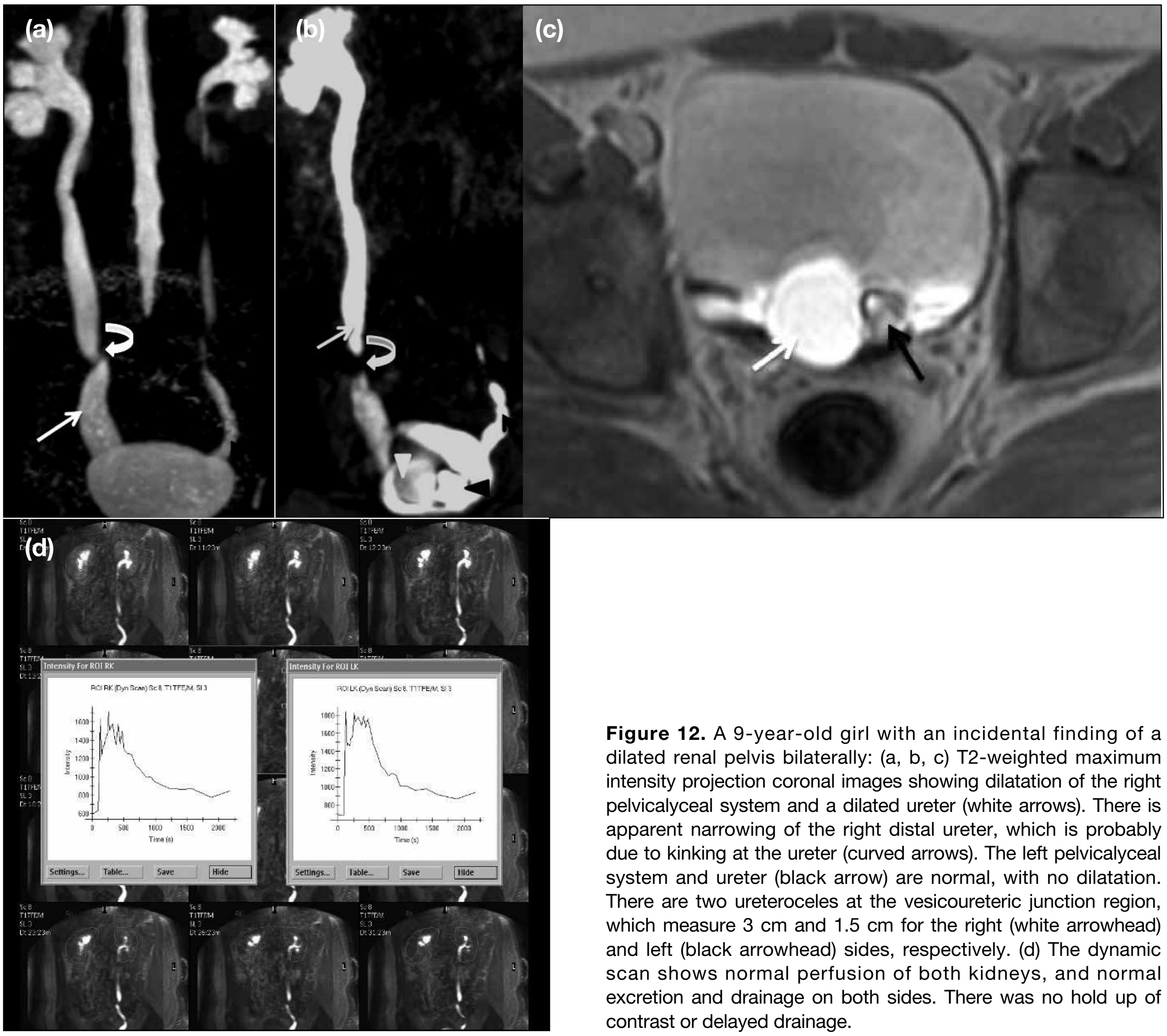

Figure 12. A 9-year-old girl with an incidental finding of a dilated renal pelvis bilaterally: (a, b, c) T2-weighted maximum intensity projection coronal images showing dilatation of the right pelvicalyceal system and a dilated ureter (white arrows). There is apparent narrowing of the right distal ureter, which is probably due to kinking at the ureter (curved arrows). The left pelvicalyceal system and ureter (black arrow) are normal, with no dilatation. There are two ureteroceles at the vesicoureteric junction region, which measure 3 cm and 1.5 cm for the right (white arrowhead) and left (black arrowhead) sides, respectively. (d) The dynamic scan shows normal perfusion of both kidneys, and normal excretion and drainage on both sides. There was no hold up of contrast or delayed drainage.

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