Eur Radiol (2002) 12:1442–1450
DOI 10.1007/s00330-001-1180-6

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Feasibility of MR urography in neonates and infants with anomalies of the upper urinary tract

Received: 5 June 2001
Revised: 17 August 2001
Accepted: 10 September 2001
Published online: 16 November 2001

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Abstract The aim of this study was to evaluate the feasibility and diagnostic potential of dynamic MR urography (MRU) in neonates and infants with sonographically detected abnormalities of the upper urinary tract. Thirty infants (age range 5 days to 3 years, mean age 7.9 months; male:female: 22:8) underwent MRU using T2 and contrast-enhanced dynamic T1-weighted sequences. The results were compared with the findings of ultrasound (*n*=30), intravenous urography (IVU, *n*=19) and/or scintigraphy (*n*=25) based on the criteria suggestive of obstructive uropathy. Oral sedation was sufficient to perform MRU with diagnostic quality in 20 of 21 patients younger than 1 year; 9 older patients needed intravenous sedation. Diagnosis of the 66 renal units (58 kidneys, 29 successful examinations) included normal systems (contralateral units), duplex systems, vesico-ureteral reflux, obstructive megaureter, ureteropelvic junction obstruction and accompanying renal parenchymal disease, with complex pathology in 10 patients. Magnetic resonance urography demonstrated anatomy better than IVU, particularly the renal parenchyma, (ectopic) ureters, and poorly functioning dilated systems. Magnetic resonance urography was superior to US in showing ureteral pathology. Tiny cysts in dysplastic kidneys were better seen by US. Gadolinium-enhanced dynamic MRU allowed accurate assessment of obstruction applying IVU criteria. Here MRU matched IVU results, and most of the scintigraphic findings. Magnetic resonance urography can be performed in young infants with diagnostic quality using oral sedation. Magnetic resonance urography correctly depicts anatomy and allows assessment of the urinary tract better than US and IVU, with additional functional information. Magnetic resonance urography thus has the potential to replace IVU for many indications.

Keywords Magnetic resonance · Urography · Paediatrics · Neonates · Infants · Urinary tract · Dilating uropathy

Introduction

Imaging of the urinary tract is an essential part of paediatric radiology. With the introduction of prenatal US screening the importance of paediatric uroradiology has been markedly increased. Early diagnosis and adequate treatment/management of congenital urinary tract malformations has improved prognosis and long-term outcome in some of these entities. As now many neonates and infants are referred for investigation of prenatally suspected or detected congenital urinary tract malformations, reliable imaging strategies applicable to small infants have become of utmost importance. At present, this work-up is performed by US including colour Doppler sonography (CDS), intravenous urography (IVU), voiding cysto-urethrography (VCU) and scintigraphy [1]. These well-established methods still suffer from some restrictions: US does not allow complete and reproducible assessment of urinary drainage and degree of obstruction, and does not visualise the ureter; IVU should not be performed in neonates because of the risk of contrast nephropathy; VCU can only help in patients with vesico-ureteral reflux (VUR); scintigraphy allows for functional evaluation, but offers only poor anatomical resolution. Most of these modalities also impose radiation burden on the neonates and infants, diagnosis is usually made in synopsis of the findings of all these investigations and different diagnostic algorithms are in use in various centres.

The advent of magnetic resonance urography (MRU) has facilitated the assessment of both function and morphology of the urinary tract without radiation. Magnetic resonance urography has been described to be accurate in adults and children [2, 3, 4, 5, 6, 7, 8, 9]; only few reports exist that include the very young paediatric subpopulation [6, 10, 11, 12, 13, 14, 15, 16, 17, 18]. Modern MR techniques have improved spatial and temporal resolution in any plane, acquisitions have become faster, and dedicated paediatric coils have improved signal-to-noise ratio. Certain pathological conditions, particularly neoplasms, have been studied by MR in young children and infants with good results [3, 16, 17, 18, 19]. The fast imaging MR techniques allow evaluation of parenchymal perfusion and glomerular filtration as well as visualisation of the renal excretory function and urinary drainage [3, 11, 12, 13, 14, 15, 20, 21, 22]. This makes MRU appear feasible for evaluating the neonatal urinary tract, thus maybe replacing other ionising imaging techniques offering equivocal results in this age group, however at the cost of the need for sedation.

The aim of our prospective study was to evaluate the feasibility, accuracy and diagnostic potential of dynamic MRU in the very young paediatric subpopulation (neonates and young infants) with sonographically detected abnormalities of the upper urinary tract, compared with the results of conventional imaging algorithms. Furthermore, we evaluated the potential of oral sedation in this age group.

Patients and methods

Thirty infants (age 5 days to 3 years, mean age 7.9 months; male:female: 22:8) with abnormal upper urinary tract either on prenatal US or on postnatal imaging (as indicated by clinical symptoms such as external stigmata, hypospadia, urinary tract infection, voiding disorders, syndromes and MMC) underwent MRU additionally to their standard imaging protocol after informed consent was received. Twelve patients were 2 months or younger, 9 patients between 3 and 12 months of age.

Sedation was performed with oral chloralhydrate (50–80 mg/kg) administered prior to the examination in patients up to 12 months of age; infants older than 12 months underwent intravenous sedation with propofol infusion (5–9 mg/kg/h). All infants were monitored throughout the procedure (heart rate=ECG; breathing and oxygen saturation=pulsoximetry).

Magnetic resonance urography was performed under standardised hydration, as used for IVU and scintigraphy, with 1200–1500 ml/m^2 body surface area, on a 1.5-T system (Siemens Symphony, Siemens, Erlangen, Germany). Magnetic resonance urography sequences consisted of initial unenhanced coronal T2-weighted (HASTE) sequences (slice thickness=5 mm, TR=5000 ms, TE=200 ms) for anatomical display of fluid-filled structures. In patients with cysts an additional axial acquisition was performed. For dynamic and functional evaluation sequential coronal contrast-enhanced T1-weighted 3D gradient-echo-recalled (GRE) sequences (TR=6 ms, TE=2.16 ms, flip angle=25°, matrix=50×1.25 mm) were obtained over 20–30 min. Gadolinium dose was 0.1 ml/kg, diluted in 2.5 ml NaCl (in neonates and young infants) or 2 ml/kg NaCl (in infants older than 1 year). Frusemide (1 mg/kg) was administered 10 min after gadolinium application intravenously in the first 10 patients; in the other patients the frusemide was given together with the gadolinium in order to try to shorten the duration of the examination. The MRU matrix was 512×256, the field of view was 250 mm. In patients with additional suspected parenchymal renal disease additional breath-triggered axial acquisitions were performed.

The MRU results were compared with the findings of standard imaging. This imaging consisted of:

1. US as the primary imaging (including techniques such as duplex Doppler sonography, amplitude-coded CDS, harmonic imaging, and M-mode)
2. IVU in suspected uereteropelvic junction obstruction (UPJO), megaureter (MU), ectopic ureteral insertion, duplex systems
3. VCU to diagnose or rule out vesico-ureteral reflux (VUR), as a part of routine work-up in patients with dilated renal collecting system or clinical symptoms (e.g. external stigmata, hypospadia, urinary tract infection, voiding disorders, syndromes and MMC)
4. Scintigraphy (static scintigraphy with Tc-99m DMSA, dynamic renography with Tc-99m MAG3 and frusemide) for evaluation of inflammatory renal disease, scars, reflux nephropathy and assessment of the degree of obstruction in dilated systems (MU, UPJO). Dynamic renography was considered the gold standard for assessment of obstruction, using a classification based on renal tracer uptake and consecutive tracer washout curves, thus defining a normal state, a dilative non-obstructed hydronephrosis, a partially obstructive dilatation (symmetrical tracer uptake, positive frusemide response) and decompensated obstruction (delayed and flattened tracer uptake, no adequate response to frusemide application=no proper tracer washout) [23]

Most conventional investigations, except for some routine VCU in, for example, multicystic dysplastic kidney (MCDK), were performed within 3 days prior to or after MRU.

Evaluation of IVU and MRU results was performed by two specialised radiologists independently who were blinded to all other imaging results. Besides establishing the diagnosis, a scoring system was used to grade the anatomical–morphological image quality of the individual investigation focusing on the different compartments of the urinary tract (renal vessels and parenchyma, renal collecting system and ureteral anatomy). For functional assessment a subjective impression was stated (based on conventional IVU criteria such as quality and time of dynamic contrast enhancement of the renal parenchyma, time and duration of renal collecting system enhancement, change of dilatation of the collecting system and dynamics of pelvico-ureteral drainage). The anatomical-morphological scoring was quantified by points (2 points= excellent, 1 point=good, 0 points=poor or non-diagnostic). For functional grading the scintigraphic terminology was used and the systems were rated as normal, dilated and non-obstructive (=prompt symmetric perfusion and gadolinium excretion), partial-obstructive=compensated obstruction (=delayed gadolinium excretion, but normal symmetrical perfusion and adequate response to frusemide, some increase in pelvic dilatation after frusemide with prompt ureteral enhancement), or severely obstructed (=asymmetrically delayed cortical perfusion and poor or missing response to frusemide, i.e. increasing pelvic dilatation, no or insufficient uereteral gadolinium enhancement).

Statistically, the diagnostic accuracy was assessed and a conspicuity index was calculated.

Results

Magnetic resonance urography was successfully performed in 29 of 30 patients; in one 10-month-old patient the oral sedation failed due to inadequate dose (the chloralhydrate was not swallowed totally, and partially spit out). Otherwise, the oral sedation was sufficient to perform MRU with diagnostic image quality in all other 20 patients under the age of 13 months, with superficial effect and short duration in 2 infants causing suboptimal results (9 and 12 months of age, at a dose of 50 mg/kg chloralhydrate, still diagnostic quality for anatomical evaluation in both, no adequate functional assessment possible in one of them). Intravenous sedation was successful in all cases, with motion artefacts due to superficial sedation in 2 infants; however, their investigations were still diagnostic. Mean study time was 38 min, with a total table time of less than 1 h (mean table time 45 min).

Ultrasound was performed in all 30 patients, IVU (as indicated) in 19 patients, and one additional infant underwent percutaneous nephrostomy. Voiding cysto-urethrography as part of the uroradiological work-up was performed in 23 patients (not performed in patients with external VCU or some of the patients with renal parenchymal disease), and 25 patients underwent scintigraphy.

Diagnosis of the 58 kidneys in the 29 patients with successful MRU (66 collecting systems) included: normal renal units (*n*=18); duplex systems (*n*=8); VUR (*n*=9); UPJO of various degrees (*n*=22); obstructive MU (*n*=7, with ectopic insertion in 2 patients, and secondary UPJO due to kinking at the uretero-pelvic junction), and associated renal parenchymal disease (RPD; e.g. dysplastic/cystic, inflammation=segmental pyelonephritis, renal infiltration/lymphoma/nephroblastomatosis, *n*=12), with complex pathology and more than one disease entity in 10 patients.

Magnetic resonance urography demonstrated overall anatomy better than IVU in 41 systems, particularly concerning the renal parenchyma, the ureter and the dilated collecting system of non- or poorly functioning systems, the latter using T2-weighted sequences. Gadolinium-enhanced dynamic MRU allowed accurate anatomical assessment of the complete collecting system and enabled reliable estimate of pelvi-ureteral drainage. The results generally matched IVU results, and, applying IVU criteria, dynamic MRU showed similar results in assessing obstruction. Magnetic resonance urography was superior to US in showing ureteral pathology and for functional evaluation in demonstrating the dynamics of gadolinium excretion into the collecting system. Tiny cysts in dysplastic kidneys of newborns were better shown by US. There was no difference between MRU and US with regard to renal anatomy, renal vasculature, and assessment of dilatation.

When looking at the various different entities the following results were observed:

1. UPJO: 22 renal units suffered from pelvi-calyceal dilatation (=UPJO of various degrees); 4 of them had an accessory renal artery crossing the ureteropelvic junction. These 4 vessels were all depicted by CDS and MRU; IVU only depicted 2 of them by showing the typical vessel impression. The dilated renal collecting system was equally well seen by US, MRU and IVU except for severe obstruction in poorly functioning systems, where IVU did not sufficiently contrast the renal pelvis. The ureter was seen best by MRU (Fig. 1); particularly in high-grade obstruction IVU did not sufficiently contrast the ureter, whereas IVU demonstrated the ureter sufficiently only in non- or partially obstructive dilatation. There were five systems with severe obstruction, eight systems with partial obstruction and nine non-obstructing systems on diuretic renography. Magnetic resonance urography was as good as IVU in grading the degree of obstruction in 20 systems but overestimated obstruction in 2 patients compared with scintigraphy (as did IVU): these patients showed asymmetrical delay in cortical gadolinium uptake and poor response to frusemide, classifying them as severe obstruction on MRU, whereas scintigraphy classified them as partially obstructive UPJO; however, both patients showed progression and deterioration. They had to be operated on because of deterioration of obstruction within 6 months. Ultrasound, using both morphological and Doppler findings (i.e. asymmetrically elevated resistive index) for grading the degree of obstruction, properly recognised acute severe obstruction but could not differentiate between non-obstructed dilatation or partial obstruction [24].
2. Megaureter: There were seven systems with obstructive MU, with 2 ectopic insertions. Magnetic resonance urography was superior to IVU in demonstrating the ureteral anatomy, particularly in poor- or non-functioning units by using T2-weighted sequences (Fig. 2), as well as for demonstration of the ectopic insertion. Ultrasound properly depicted all 7 MU, as well as the ectopic insertion, but 3D-reconstructed maximum intensity projection MRU images demon-

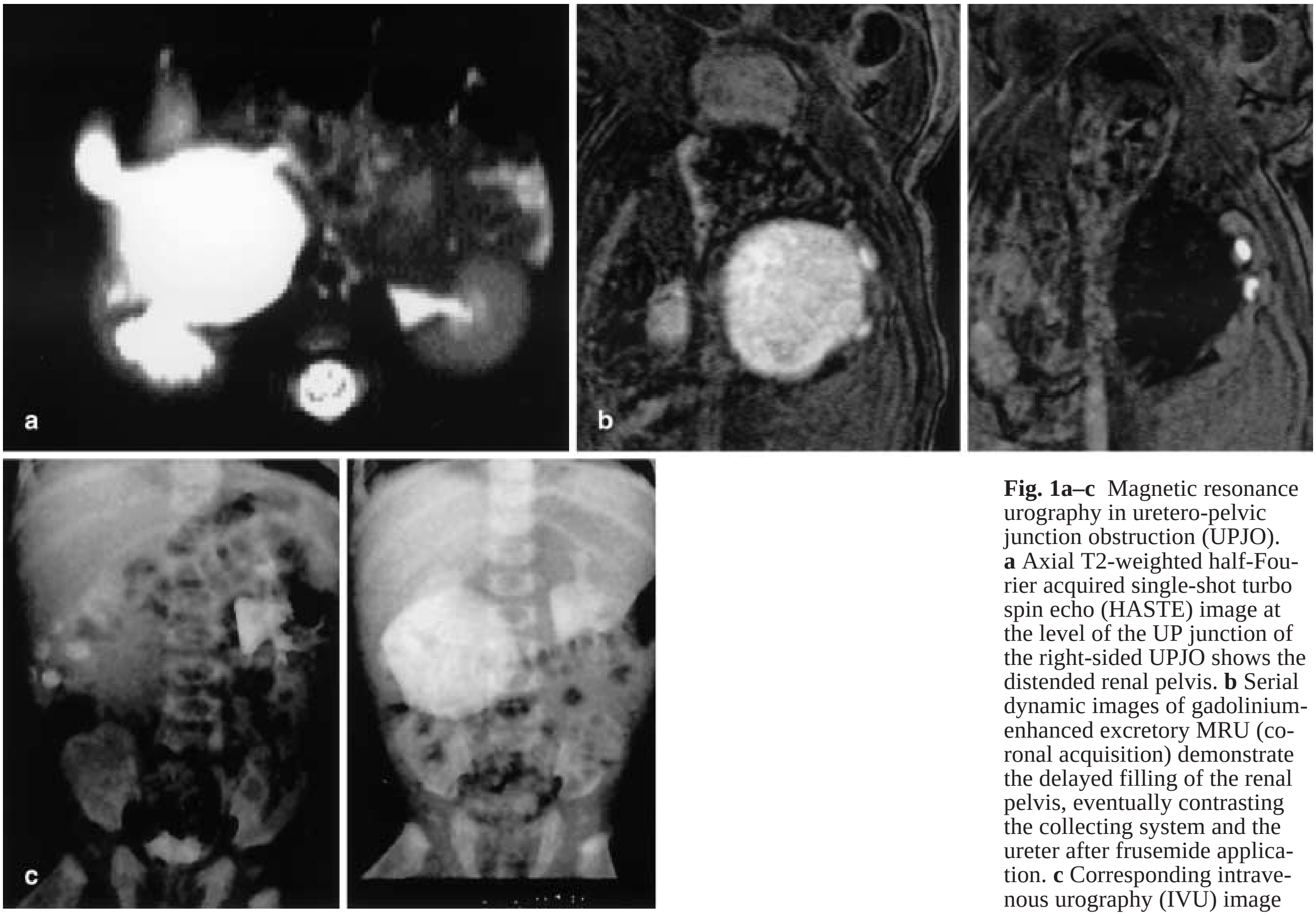

Fig. 1a–c Magnetic resonance urography in uretero-pelvic junction obstruction (UPJO). **a** Axial T2-weighted half-Fourier acquired single-shot turbo spin echo (HASTE) image at the level of the UP junction of the right-sided UPJO shows the distended renal pelvis. **b** Serial dynamic images of gadolinium-enhanced excretory MRU (coronal acquisition) demonstrate the delayed filling of the renal pelvis, eventually contrasting the collecting system and the ureter after frusemide application. **c** Corresponding intravenous urography (IVU) image

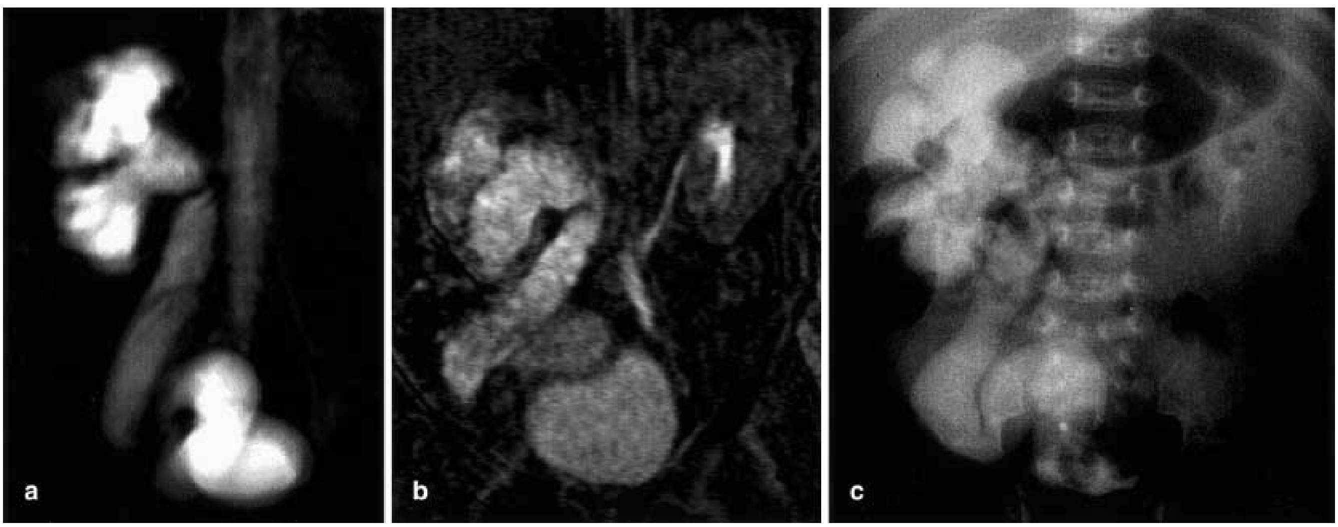

Fig. 2a–c Magnetic resonance urography in obstructive megaureter. **a** T2-weighted coronal HASTE sequence showing the megaureter and its insertion. **b** Excretory MRU (late-phase coronal images) demonstrates the contrast-filled megaureter. **c** Corresponding IVU image

Fig. 3a–d Magnetic resonance urography in vesico-ureteral reflux (VUR) and duplex systems. **a** Initial coronal excretory MRU image showing the bilateral duplex system with the dysplastic parenchyma and delayed excretion of the lower moiety of the right kidney, with prompt enhancement of the other moieties. Note the visualisation of the initially small ureters. **b** Later-phase coronal excretory MRU image demonstrates gadolinium-enhanced ureteral anatomy (note the excellent visibility of the ureter even in the non-dilated, normal left systems), with growing dilatation of the refluxing system with increasing bladder filling. No direct bladder filling with diluted gadolinium was attempted. **c** Corresponding IVU image. **d** Corresponding voiding cysto-urethrography image

strated topographic anatomy much better. The MRU assessment of obstruction was based on IVU criteria and was accurate (compared with renography, and to IVU in those systems with normal renal function). Ultrasound grading relayed on morphology and ureteral peristalsis. These results also matched scintigraphic grading.

3. VUR: VCU revealed nine refluxing systems in patients with sonographically dilated collecting systems. Intravenous urography naturally did not help in diagnosis of VUR. Magnetic resonance urography depicted only indirect signs for VUR by increasing ureteral diameter and ureteral contrast enhancement in later dynamic phases (with filling of the bladder) in four systems with dilating VUR (grades IV and V; Fig. 3). Low-degree VUR was missed, as it was by conventional US (no echo-enhanced sonographic cystography included in this study). Magnetic resonance urography was superior to IVU in demonstrating ureteral anatomy and renal parenchyma, particularly in showing associated dysplasia and scarring. These parenchymal abnormalities were also depicted by US and (amplitude-coded) CDS. No bladder filling with diluted gadolinium was performed for direct visualisation of VUR.
4. Duplex systems with sonographically dilated collecting system: MRU clearly demonstrated the anatomy of the renal parenchyma, the renal collecting system, and the ureter in the eight duplex systems. Particularly the renal parenchyma and the ureteral orifice (ectopic ureters!) were better seen by MRU than by IVU (Fig. 3). Ultrasound performed poorly in demonstrating ureteral anatomy as well as non-dilated renal collecting systems; renal parenchyma was adequately visualised.
5. Renal parenchymal disease: The 12 systems with RPD consisted of one neonate with MCDK and associated proximal atretic MU as well as cystic malformation of the ipsilateral seminal vesicle (Fig. 4), one kidney with a severe segmental pyelonephritis (associated with VUR causing sonographically detected hydronephrosis), 1 patient with a unilateral multifocal renal lymphoma and consequently some dilated calyces, 1 patient with bilateral nephroblastomatosis and mild hydronpehrosis, 1 kidney with a renal cyst referred for assessment of suspected calyceal diverticula, and six systems with associated parenchymal dysplasia (of various origin, with or without small cysts). Ultrasound and MRU performed equally well, except for tiny cysts, where high-resolution US was superior due to better temporal and spatial resolution in 2 neonates, as breath triggering did not sufficiently compensate for motion artefacts (short inspiratory plateau, superficial breathing with low amplitude causing difficulties for triggering). Intravenous urography was not used for these indications.

Fig. 4 T2-weighted coronal MRU HASTE image in a multicystic–dysplastic kidney (MCDK) demonstrating the huge left-sided MCDK, with associated complex cystic malformation of the ipsilateral seminal vesicle

6. The 18 additional normal (contralateral) renal units did not pose a diagnostic challenge; however, MRU was superior to IVU and US in completely demonstrating the ureter in all these systems, and the trust in a “normal finding” on MR was superior to the confidence in US and/or scintigraphy.

In summary, MRU was equal or better than IVU in all queries. The rating for overall image quality/anatomical assessment, according to our scoring system, was better for MRU (mean score=1.75 points) than for IVU (mean score=1.3 points). The mean grading for assessment of ureteral anatomy was 1.65 for MRU vs 0.8 for IVU, with a conspicuity index of 1.35 and 2.06, respectively, both in favour of MRU. Magnetic resonance urography was better than US for evaluation of the collecting urinary system, and equally good as US for parenchymal evaluation – except for demonstration of tiny cysts in 2 neonates. Magnetic resonance urography naturally was inadequate for diagnosis of VUR, and showed similar results for functional estimation of obstruction as dynamic renography.

Discussion

Magnetic resonance urography has been successfully used for evaluation of both paediatric and adult urinary tract pathology [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22]. Our study confirms the feasibility of MRU in neonates and infants. Our results demonstrate that MRU is better than the conventionally used IVU in many aspects, particularly in evaluating renal parenchymal disease, for assessment of ureteral anatomy and ureteral orifice, and for evaluation of poorly functioning systems, with an improved overall conspicuity for MRU results.

However, MR needs sedation in this age group. Breast-feeding and immobilisation with elastic bands may enable MRU in some neonates and small infants, but still a considerable failure rate has to be accepted with this approach [12]. This causes difficulties in very busy places and needs sufficient time for preparation only available at dedicated paediatric MR units, still with the risk of failure and the waste of precious investigation time for other patients and queries. Discussions may rise for both economical and efficiency reasons in such a setting, particularly in the situation with growing financial pressure on health care systems worldwide. Our experience shows that oral chloralhydrate sufficiently sedates neonates and infants for up to 1 h. Together with immobilisation techniques, this approach guarantees a sufficient time slot for high-quality investigations in patients younger than 1 year, and allows a practical and efficient use of the MR unit. Older infants still need intravenous sedation; this is not discussed herein, as numerous reports and established sedation protocols exist [25, 26, 27, 28]; however, since for scintigraphy sedation may also be required in some infants, sedation for MRU, particularly for functional assessment, appears less problematic: invasiveness is not increased; overall radiation burden is reduced; and additional anatomical information as well as visualisation of even non-functioning systems can be gained.

Magnetic resonance is considered an expensive technique. It can be argued that applying this modality to diseases and patients that/who can be sufficiently diagnosed with other conventional methods and less expensive techniques is a waste of resources and only increases health care costs. Furthermore, US, IVU and often also scintigraphy are readily available, whereas access to MR, particularly in the paediatric age group, is still limited. Our results show that particularly in patients with severe and/or complex pathology, in ectopic ueretral insertion and duplex systems with poor function, and in evaluating associated genital malformation MR is superior to conventional imaging. In these situations MRU appears to be indicated, as it is not only diagnostically better, but may replace some conventional imaging and thus may help to save costs by replacing inferior, non-diagnostic methods in the individual query. Reports exist on the potential of MRU to assess renal function and dynamics of urinary drainage [11, 12, 13, 14, 15, 20, 21, 22]. Therefore, when MRU replaces IVU and scintigraphy, with even improved overall diagnostic accuracy, and MRU is not significantly more expensive than the combination of IVU and scintigraphy (in the Austrian reimbursement system), the use of MR in these patients with complex pathology is reasonable. More simple pathology (e.g. uncomplicated UPJO) should still be diagnosed and followed using the conventional approach.

Magnetic resonance urography overestimated the degree of obstruction in 2 infants with UPJO compared with dynamic scintigraphy; however, both had to be operated on because of scintigraphic deterioration within months. This suggests that MRU might be more sensitive in depicting those systems that need surgery, even earlier than scintigraphy. Another benefit of MRU is the potential of MR angiography: the first gadolinium pass can be used as an angiographic acquisition; using subtraction and 3D maximum intensity projection techniques, it allows evaluation of renal vessels (e.g. accessory renal artery causing UPJO).

Only little experience exists on the value of MR in evaluating paediatric cystic renal disease and renal parenchymal disease. Some reports confirm a great potential for MR in these diseases [13, 17, 20, 29, 30, 31, 32]. We observed a few cases not warranting a conclusive statement, but we also see a big potential for MRU in the diagnosis, differential diagnosis, and follow-up of patients with cystic renal disease and for evaluation of inflammatory renal parenchymal disease. Future prospective studies will have to evaluate the exact role of MR in these entities. There is no discussion on the importance of MR in evaluating malignant renal disease and nephroblastomatosis [3, 4, 15, 17, 18, 19]; still, MR is underutilised in evaluating paediatric complicated renal cysts and abscesses. As gadolinium is applicable even in patients with elevated serum creatine, dynamic contrast-enhanced MRU allows assessment of suspected renal pathology even in situations where IVU or contrast-enhanced CT may be contraindicated by the risk of contrast nephropathy [33, 34, 35]. This applied to 2 of our patients, where US suggested inflammatory disease or multifocal renal lymphoma, and CT/IVU was not performed due to renal functional impairment. Restrictions of renal parenchymal MR imaging at present still is the reduced temporal resolution in small infants and neonates. Improvement of triggering techniques and new, promising techniques, such as retrospective gating, diaphragmatic tracking and ultrafast acquisition using stronger gradients, will hopefully help in overcoming these problems.

Our experience in the two subgroups of patients with different frusemide timing shows that MRU protocols may be adapted towards the individual query helping to shorten certain investigations. For anatomical evaluation, T2-weighted sequences and only a few gadolinium enhanced 3D-T1 sequences will be sufficient, with frusemide application 10 min before the investigation to guarantee good distension of the collecting system. For dynamic assessment a protocol similar to scintigraphy with standardised hydration, frusemide application 10–20 min after gadolinium, and a longer observation period (up to 30 min after frusemide), appears to be beneficial for optimal results. Non-functioning systems and purely anatomical evaluation of dilated systems can be evaluated by T2-weighted sequences only [6, 9, 10, 11, 36, 37].

Conclusion

In conclusion, MRU can be performed in infants and neonates with sufficient image quality, using oral sedation for the first year of life. Magnetic resonance urography properly depicts anatomy and allows assessment of urinary tract obstruction better than US and IVU. Magnetic resonance urography additionally provides functional information without using radiation. It therefore has the potential to replace IVU for many indications, and should be considered the diagnostic modality of choice in complex pathology, for evaluation of ectopic ureteral insertion and in poor functioning systems or patients with impaired renal function, despite the sedation needs. Specific protocols have to be established for different queries and entities to optimise imaging efficacy.

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