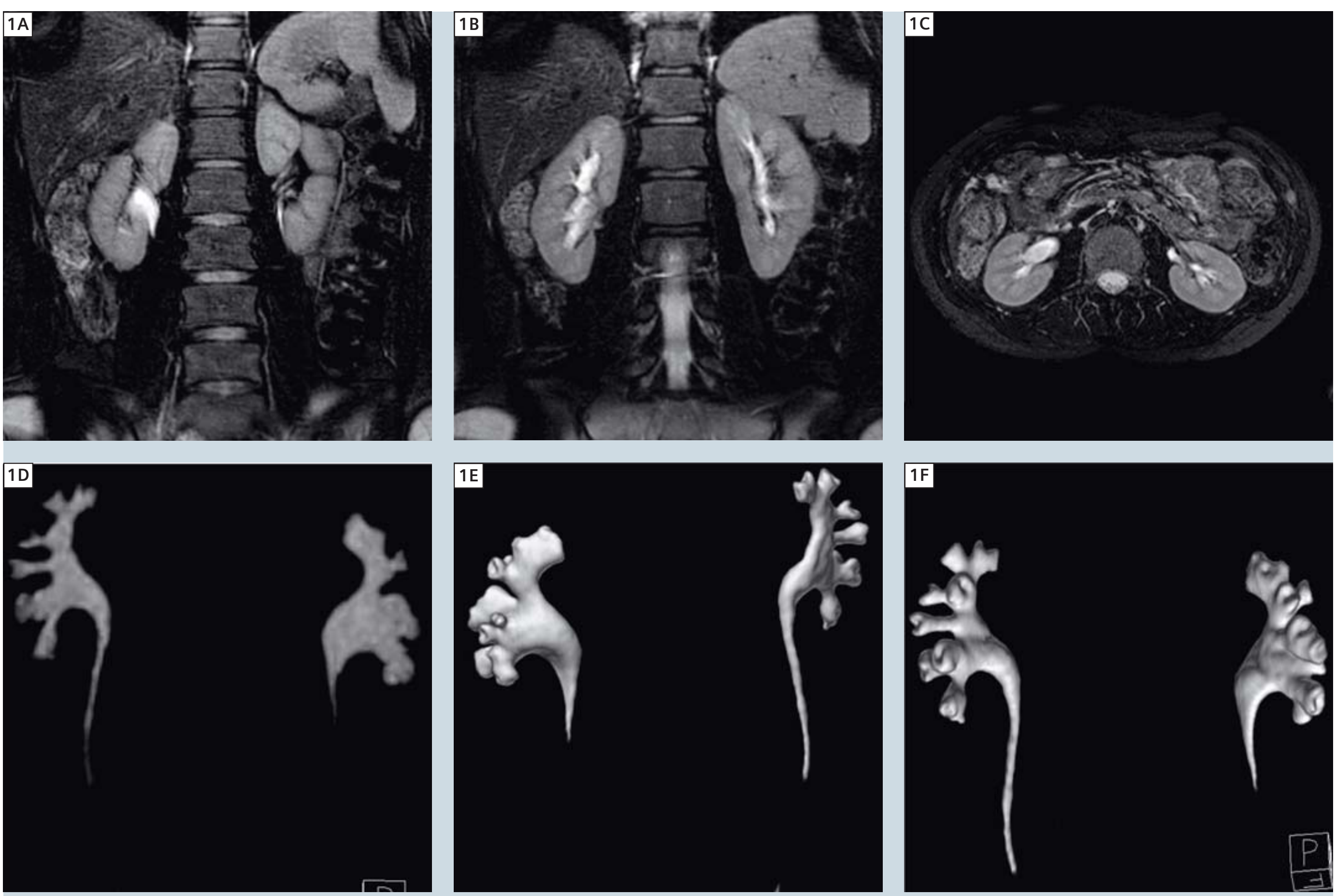
Pediatric* MR Urography

G. Hadjidekov; G. Tonev; G. Georgieva

MC "Pro-Vita", Sofia, Bulgaria

Introduction

MR urography (MRU) – a modern imaging modality – was introduced to pediatric uroradiology more than a decade ago and has evolved into an effective imaging tool for the assessment of various urologic abnormalities in children. MRU provides both morphological and functional information by means of different sequences with or without injection of gadolinium. Combined static and dynamic contrast-enhanced MR urography is particularly advantageous in the pediatric population, offering high spatial resolution morphologic imaging of the urinary tract with reliable information about kidney function and urinary excretion in a single examination, without exposure to ionizing radiation. The method is most commonly applied for the evaluation of hydronephrosis and provides valuable insight into a wide range of obstructive uropathies. It is also beneficial in tumor characterization, in preoperative planning and in the diagnosis of pyelonephritis and renal scarring where MRU has been shown to be superior to renal scintigraphy. Post-pro-



1 Static MR urography images of a 16-year-old patient with subtle hydronephrosis grade 1 of the right kidney. Coronal T2w *syngo* BLADE **(1A, 1B)** and axial T2w *syngo* BLADE **(1C)** images with fat saturation, 3D coronal T2w TSE maximum intensity projection **(1D)** and volume rendered images **(1E, 1F)**.

Table 1: Sequence parameters – 1.5T MAGNETOM ESSENZA

	t2_tru-fi_loc	haste_16sl_sag	t2_blade_tra_fs	t2_blade_cor_fs	t2_tse 3d_cor	t1_sin-gle_vibe_cor	t1_vibe_dyn_cor	t1_tse 3d_sag	vibe_fs_cor_bh	single_cor_CE
TE	2.09	59	123	123	627	0.83	0.83	9	2.38	1.09
TR	4.17	700	2280	1800	1600	2.62	2.62	696	4.38	3.11
FA	50	160	150	150	150	10	10	150	8,0	25
BW	501	789	362	362	219	1090	1090	219	610	520
FOV	40	38	30	32	34	38	38	34	40	38,5
ST	8.0	8.0	5,0	5,0	1,5	5,0	3.35	1,5	4,0	1,5
TA	0:13	0:36	0:48	0:43	2:48	0:04	13:51	1:13	0:11	0:14
SpS	7	–	–	–	60	32	32	60	80	56

Legend: TA = time acquisition in sec., TE = echo time, TR = repetition time, FA = flip angle, FOV = field-of-view, ST = slice thickness, bh = breathhold, SpS = slices per slab, BW = bandwidth, VIBE = Volume Interpolated GRE

cessing algorithms permit the evaluation of the split renal function by generating time-intensity curves representative for the renal function, as well as many other parameters. The use of MRU for the assessment of urolithiasis, vesicoureteral reflux, renal trauma, and fetal urinary tract abnormalities is still partially limited and technical refinements are required. Judicious use of gadolinium-based (Gd) contrast agents in children at risk for nephrogenic systemic fibrosis (NSF) should be employed with attention so as to avoid new occurrences.

Purpose

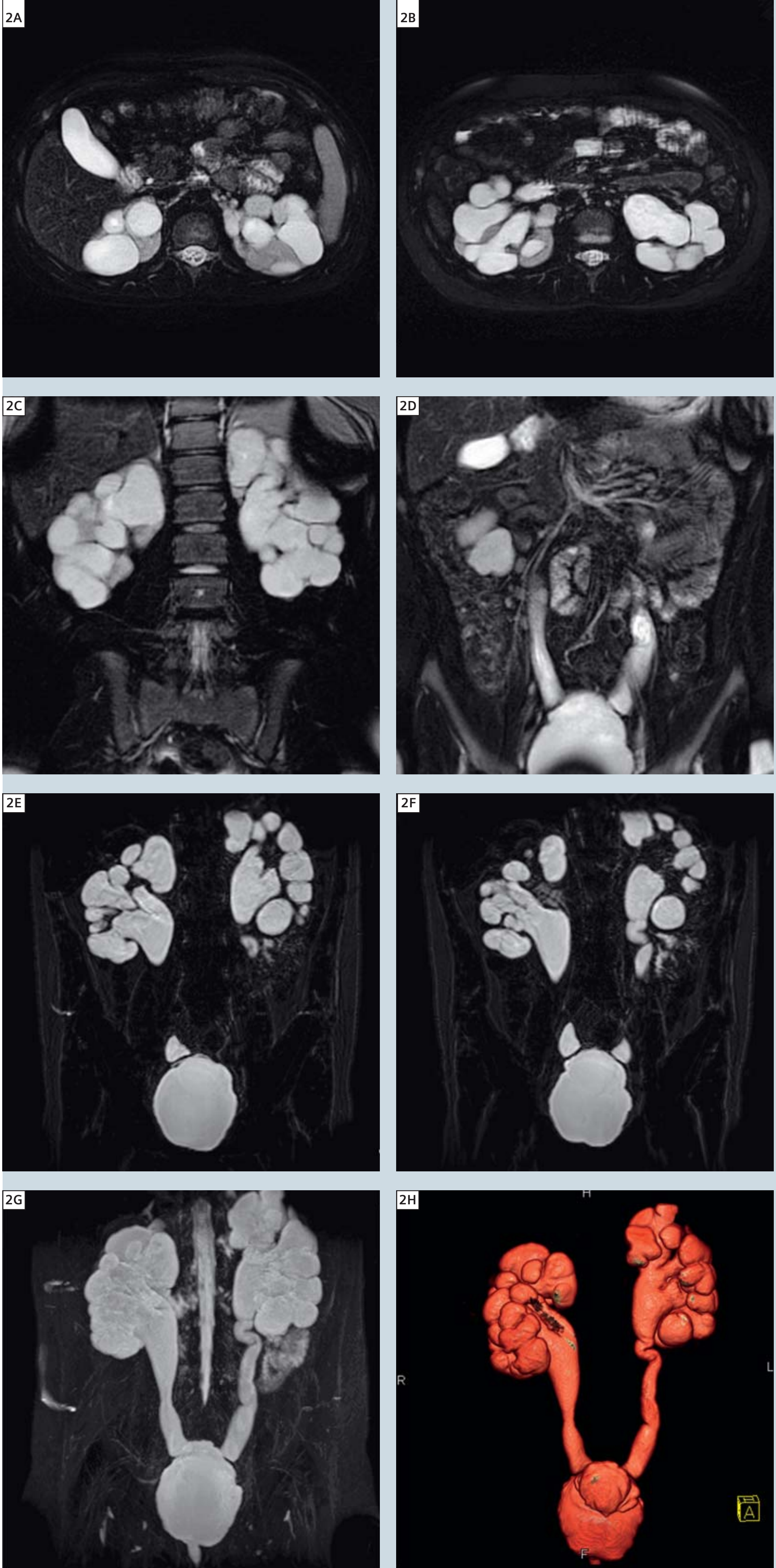
The aim of our work is to promote the use of MRU in pediatrics trying to present a safe and reliable MRI protocol for anatomic imaging that is generally accepted. Defining imaging and procedural recommendations in pediatric uroradiology is an important task, not only in standardization of pediatric uroradiologic imaging protocols but also in reducing invasiveness and radiation dose. The lack of standardization for quantitative renal functional evaluation and urinary excretion assessment requires new studies and extensive interdisciplinary consultations.

Patient preparation

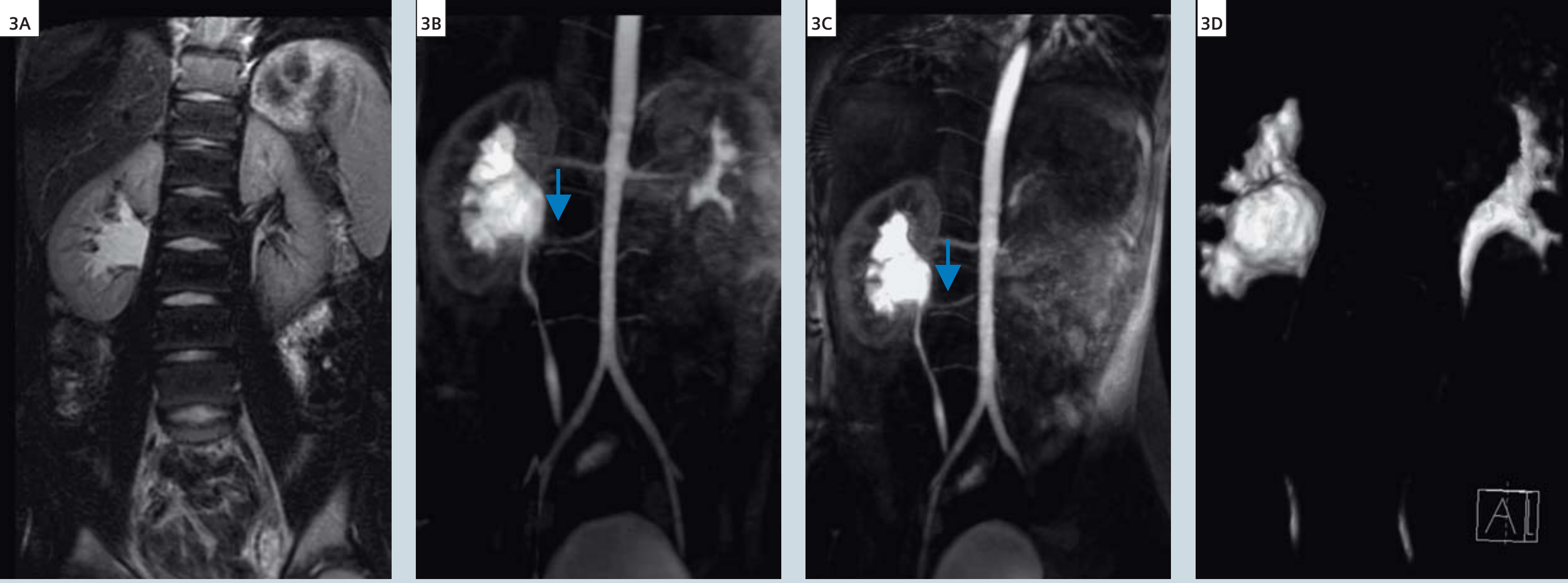
The adequate preparation is a prerequisite for good image quality [1–2]. We do not routinely place a bladder catheter in order to reduce invasiveness of the procedure, although catheterization of small children is recommended in case of megaureter (with or without reflux). The intravenous hydratation and administration of furosemide are crucial for reducing the concentration of Gd [1]. Diuretics are recommended in both static urography and dynamic urography 15 minutes before contrast administration. In this context, we adopted the F-15 protocol and we administered standardized hydratation and diuretics prior to Gd, in order to reduce artifacts and shorten the examination time [3]. In children younger than six years of age and those who are non-cooperative for breathhold techniques, sedation should be performed with ketamine (Ketalar) and midazolam (Dormicum) according to the department's standard sedation protocol [4–5]. Blood pressure, respiration, heart rate, and oxygen saturation are continuously monitored throughout MR imaging in all patients.

Imaging protocol

MRU examinations are performed on a 1.5T MAGNETOM ESSENZA, using a 4-channel Body Matrix coil. The MRU protocol should allow a correct evaluation of the renal parenchyma, upper urinary tract, bladder, renal vessels and surrounding structures. Such a comprehensive 'one-stop-shop' protocol must be able to provide the required morphological and functional information within 30–35 minutes. Our MRU protocol consists of a native MRI examination with T2w coronal, T1w and T2w axial sequences, administration of diuretic followed by a dynamic study with gado-



2 13-year-old boy with high grade bilateral hydronephrosis and megaureters. Persistent vesicoureteral reflux (VUR) following several ureterocystoneostomies (UCNS). Static MR urography axial T2w *syngo* BLADE images **(2A, 2B)**, coronal T2w *syngo* BLADE images **(2C, 2D)**, coronal 3D T2w TSE images **(2E, 2F)**, 3D coronal T2w TSE maximum intensity projection (MIP) **(2G)** and volume rendered image **(2H)**.



3 Ureteropelvic junction (UPJ) obstruction leading to hydronephrosis with dilatation of the right pyelocalyceal system in a 9-year-old girl. Coronal T2w *syngo* BLADE image **(3A)**. MR angiography following Gd administration (Single COR CE) demonstrates accessory right lower pole renal artery (arrows), compressing the ureteropelvic junction – Thin MIP images **(3B, 3C)**. Right side hydronephrosis demonstrated on 3D coronal T2w TSE maximum intensity projection **(3D)**. The girl was treated successfully by pyeloplasty.

linium (Gd) injection and 3D reconstructions. This MRU protocol allows the combination of the whole information, provided by conventional exams, ultrasound and scintigraphy in a single examination, with or without minimal drug toxicity – furosemid and Gd.
We commence the MRU examination with a 3-plane localizer and we use a sagittal view to depict the kidneys and bladder in order to obtain an oblique coronal plan angled parallel to the long axis of the kidneys, including ureters and bladder. We select a large field-of-view (FOV) above both hemidiaphragms so as to avoid artifacts from aliasing or post-contrast signal intensity decline in the upper renal poles. Following the coronal T2w plane, we perform axial T2w and T1w sequences. Fat-suppression techniques are used in T1 and T2 hyper intense findings and in cases of suspicion of tumor formation – in and out of phase sequences for contour delineation. An important pre-contrast sequence is 3D T2w urogram with fat-suppression. T1-weighted gradient-echo sequence with fat-saturation (3D VIBE dynamic) is used for the post-contrast scan. The dynamic scan is repeated within 15 minutes, following Gd injection with increasing intervals between acquisitions, for the need of post-processing. We inject the standard dose of 0.1 mmol/kg of gadolinium. Regardless of the patient's size, placement of the coils is crucial. In newborns and small children we use the smaller Flex coil. Otherwise we use the Body Matrix coil to scan older children. It is recommended to adjust the Body Matrix coil anteriorly to assure proper signal distribution throughout the volume. The technical parameters of our sequences are presented in Table 1.

Discussion

MR urography is a feasible method for evaluation of urinary tract pathology in neonates and infants [6]. It overcomes the limitations of the conventional imaging techniques and is a superior tool in many aspects, especially in the evaluation of parenchymal kidney diseases and poorly functioning systems, assessment of ureteral anatomy, renal vasculature and tumors. The method is particularly helpful for further therapeutic decisions, planning of surgical intervention and future diagnostic work-up.
The most common MRU techniques, used to visualize the urinary tract, are the static (T2w) MRU and excretory (T1w) MRU [7–9]. Static MRU uses the long relaxation times of the liquids by T2w sequences (Fig. 1). Three-dimensional (3D) respiratory-triggered sequences are used to obtain thin-section data sets that can be further post-processed to create volume rendered (VR) or maximum intensity projection (MIP) images of the entire urinary tract (Fig. 2) [10–11]. Excretory (T1w) MRU is similar to CT urography and intravenous urography and is performed after intravenous injection of Gd. The use of conventional dose – 0.1 mmol/kg and in some occasions low-dose Gd opacification – 0.01 mmol/kg allows to maintain the linearity between signal and Gd concentration, which is essential for quantitative measurements and analysis.
Administration of diuretics improves the quality of MRU by increasing the quantity of the urine and therefore lead to better dilution and appropriate distribution of Gd in the urinary tract [12–13]. The most important sequence of excretory MRU is 3D gradient-echo. Fat-suppression is recommended for better demonstration of the ureters. MR angiography, in addition to excretory MR urography, demonstrates excellently the renal vasculature (Fig. 3). Modern MR units scan simultaneously in one volume the kidneys, the ureters and the bladder, using 3D gradient-echo sequences in one breathhold [14–15]. Sometimes segmental scanning of the kidneys or bladder separately is recommended for more detailed image visualization. An advantage of static MRU over dynamic, T1w MRU is the demonstration of the ureters and the ureterovesical junction in cases of obstruction or impaired renal function [6, 16].
There is a growing number of publications concerning the criteria for assess-

ment of the renal function in children by dynamic MRU, but the achievement of consensus requires more and deeper investigations. Functional criteria include renal transit time, differential renal function, and time–signal intensity curves. The technique is challenging and is best performed in specialized centers. However, this single MRI examination could avoid the use of multiple modalities (e.g. US, conventional urography, renal scintigraphy) that individually help assess various morphologic features, renal function and excretion and there is an expanding use of MRI. Current limitations for widespread distribution of the technique are understaffed pediatric radiologic departments and time-consuming post-processing.

Alongside the advantages of MRU, mentioned above, it is necessary to note some limitations. Sometimes it requires a placement of bladder catheter, administration of furosemide and Gd, sedation and even anesthesia (for newborns and younger children), which is a complementary risk [16]. Breathhold techniques could not be applied in neonates and small infants. We use *syngo* BLADE to minimize motion artifacts. Patient preparation and the examination itself are time-consuming; post-processing and calculation of functional curves and differential renal function require an additional 30 minutes.

Until recently it was believed that the extracellular Gd-based contrast agents are safe. However, in 2006, it was demonstrated that some Gd-based contrast agents may provoke the development of NSF and/or a generalized fibrotic disorder in renal failure patients [17]. Gd-ions, released from Gd-based MR contrast agents, are the likely etiologic agent of NSF [18]. The guidelines of the European Society of Urogenital Radiology (ESUR) suggest a very careful administration of Gd in children with renal failure. Absolute contraindications are high levels of creatinine and a glomerular filtration under 30 ml/min/1.73 m^2 and in cases of glomerular filtration between 30 and 60 ml/min/1.73 m^2 discussions with pediatric nephrologists are mandatory. Written consent should be obtained in spite of the fact that most cases of NSF occur in adults and the reported cases of NSF without Gd administration. In all patients at high risk of developing NSF and in the pediatric group, cyclic Gd-helators should be used due to their higher stability [19].

Conclusion

MRU has the potential to become the leading diagnostic modality in the near future of a wide range of pathological conditions affecting the urinary tract in newborns and children. It integrates exquisite anatomical information with a variety of functional data and avoids ionizing radiation. MRU is increasingly employed as a problem solver when conventional imaging studies remain inconclusive and its growing application will likely improve availability and reduce cost in the future. The introduction of parallel imaging, higher field strength systems, multielement coil technology, and gadolinium-based contrast agents with increased T1 relaxivity will further improve the overall signal-to-noise ratio (SNR) and spatial resolution of the images. The advances of molecular imaging techniques will provide new insights about the nature of hereditary diseases in pediatric nephrology and urology. Potential future applications include also virtual endoscopy and MRU-guided procedures.

*MR scanning has not been established as safe for imaging fetuses and infants under two years of age. The responsible physician must evaluate the benefit of the MRI examination in comparison to other imaging procedures.

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Contact
Georgi Hadjidekov, MD
MC "Pro-Vita"
Montevideo str. N66
Sofia 1632
Bulgaria
jordiman76@yahoo.com