

Updated Role of Magnetic Resonance Urography in Evaluation of Obstructive Uropathy In pediatrics

Eman Ghazy Ibrahim El Shenawy; Prof. Dr. Rania Ali Maorouf; Dr. Mona Ali Nagi

Radiodiagnosis Department, Faculty of Medicine, Ain Shams University, Cairo, Egypt
eman_elshenawy86@yahoo.com

Abstract: Purpose of review: Magnetic resonance imaging has emerged as a powerful diagnostic tool for the imaging of the pediatric genitourinary tract. The aim of this review is to evaluate updated role of magnetic resonance urography in evaluation of obstructive uropathy in pediatrics. **Recent findings:** Magnetic resonance imaging can provide both a detailed anatomic and functional assessment of the pediatric genitourinary tract in a single study without the use of ionizing radiation. Magnetic resonance urography combines static and dynamic evaluation of the urinary tract following contrast administration and has been most often applied to the evaluation of hydronephrosis. In addition to unparalleled anatomic assessment, it allows for the evaluation of glomerular filtration rate, renal transit time, and differential renal function. It also provides unique insights into a wide range of obstructive uropathies and has been demonstrated to be useful in the evaluation of complex genitourinary anomalies. Magnetic resonance voiding cystourethrography has been used to rule out vesicoureteral reflux. **Summary:** Magnetic resonance imaging has emerged as a powerful tool for the diagnosis of pediatric genitourinary anomalies. It provides functional and anatomic assessment with a single procedure that in most cases is superior to conventional procedures., MRU may serve as the most comprehensive and definitive study in the evaluation of urinary tract obstruction, complex genitourinary anomalies, and infection.

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Introduction:

Urinary tract obstruction is a relatively common problem. The obstruction to urinary flow may be acute or chronic, partial or complete, unilateral or bilateral, and may occur at any site in the urinary tract. Obstructive uropathy with resultant hydronephrosis is the eventual outcome of most urological disorders. In patients with normal renal function, excretory urography (IVP) remains the investigation of choice for imaging the detailed anatomy of the pelvicalyceal system and ureters. In patients with abnormal renal function, IVP is contraindicated and the traditional methods of diagnosing obstructive uropathy start with noninvasive plain abdominal X-ray (KUB) combined with abdominal gray-scale ultrasonography (US). Alternative methods of visualizing the upper urinary tract, such as retrograde or antegrade pyelography or ureteropyeloscopy, are invasive. In the last few years some recent noninvasive investigations have been introduced for the diagnosis of obstructive uropathy as non-contrast helical computerized tomography (NCCT) (2) and magnetic resonance urography (MRU) (3).

The recent development of fast sequences has extended the use of MRI to antenatal diagnosis. MRI can accurately show many urinary tract anomalies in third-trimester fetuses. It may be a useful complementary tool in the assessment of bilateral urinary tract anomalies of fetuses, particularly in cases

with inconclusive sonographic findings (4). MR urography is clinically useful in the evaluation of suspected urinary tract obstruction, hematuria, and congenital anomalies, as well as surgically altered anatomy, and can be particularly beneficial in pediatric or pregnant patients or when ionizing radiation is to be avoided (5).

MR Urography:

MRI is particularly has become a useful adjuvant in evaluating urogenital because of its excellent delineation of water/urine-containing structures. There has been great expectation that dynamic contrast enhanced MRI would be able to substitute to both renal ultrasonography and scintigraphy. Indeed, MRI has the ability to provide very detailed anatomical description, combined with a functional evaluation. This promising technique, which has been under evaluation for more than 10 years, still struggles to provide functional informations as accurate as conventional isotope studies (6).

Patient Preparations:

Patient preparation is a crucial part of the successful MRU examination. The examination begins with discussion with the family as to the purpose and operations of the study. The patient preparation portion of the MRU examination typically takes approximately 1 hour, which includes sedation, hydration, and catheterization (7). Patients younger than 7 years are typically sedated to eliminate patient

motion artifact. Although sedation protocols must be adapted according to the experience of each center, a combination of versed, fentanyl, and phenobarbital is typically used in most of centers. All children undergoing sedation are under continuous close electrocardiogram (ECG) and pulse oximetry monitoring under the control of an appropriately trained member of the sedation unit. Older nonsedated children are asked to breathe quietly, or if they are able to cooperate, breath hold imaging is performed.

Patients are given 20 mL/kg (maximum of 1 L) of normal saline or Ringer's solution intravenously over the course of 30 to 60 minutes before the start of imaging if no contraindications is present (eg, fluid restriction, congestive heart failure) exist. The infusion is stopped before entering the MR scanner room to minimize the need for additional manipulations during the scan.

The administration of intravenous (IV) fluid helps to reduce the MR contrast concentration and thus decrease the potential of T2* effect, making a linear relationship of the gadolinium concentration to the signal intensity possible and to improve the visualization of the pelvicalyceal system and ureter and optimizes the baseline for subsequent furosemide (Lasix) administration.

A bladder catheter without inflatable balloon is placed. In a patient with planned sedation, this is done after sedation. The catheter helps to decompress the bladder. A decompressed bladder is important, as it ensures that the contrast washout is not disturbed by full bladder effect and/or reflux. The catheter may also serve as a urethral marker in cases of possible ureteral ectopy. The patient is positioned in the MRI scanner supine with the arms above the head.

Furosemide is administered intravenously with a dose of 1 mg/kg up to a maximum dose of 20 mg once the patient is appropriately positioned, before the start of imaging. **The purpose of the furosemide** injection is that it increases urine flow and ensures that the urinary tract is distended. This increased distension of the urinary tract allows improved visualization of nondilated collecting systems. It also serves to reduce the gadolinium concentration for the same reasons as discussed under hydration. Furosemide also results in a more uniform distribution of gadolinium-based contrast, which reduces susceptibility artifacts. Furosemide is necessary for the evaluation of the excretory function under diuresis. Furosemide administration shortens the examination time.

Contraindications to furosemide administration include anuria, electrolyte imbalance, hypotension and that Patients with sulfonamide allergies may also be allergic to furosemide (7).

Technique:

The most common MR urographic techniques used to display the urinary tract can be divided into:

1. **Pre contrast techniques:** consist of conventional T1-weighted, fast spin echo and T2-weighted which known as **Static-fluid MR urography** (also known as static MR urography, T2 weighted MR urography, or MR hydrography).

2. **Post contrast techniques:** dynamic three-dimensional gradient echo sequences known as **Excretory MR urography** (also known as T1-weighted MR urography).

There is a fundamentally complex relationship between signal intensity and gadolinium concentration, with T1 effects predominating at lower concentrations and T2* effects at higher concentrations, which may lead to signal loss. Phantom studies have shown that the relationship between signal intensity and gadolinium concentration is relatively linear at low concentrations. To stay within this linear portion of the curve, the authors keep the gadolinium concentration low by hydrating the patient, by giving furosemide 15 minutes before the contrast is administered, and by infusing the contrast agent slowly for the dynamic series (8).

Pediatric MRU can be performed successfully in children of all ages using both 1.5- and 3-Tesla (T) MR scanners. **The primary advantage of 3 T** is superior spatial resolution with improved visualization of small urinary tract structures, particularly in young children, **while the primary advantages of 1.5 T** include more homogeneous fat saturation and decreased T2* effect of excreted contrast material in the urinary tracts. A multi-channel surface coil should be used to maximize image quality, including signal-to-noise ratio and spatial resolution, and to minimize examination length. Dedicated infant, knee, or head and neck coils can be used to acquire images to prevent artifacts related to patient motion (9).

Pre contrast techniques:

Coronal, two-dimensional, flow compensated T1- and T2-weighted series and a respiratory gated, heavily T2-weighted three-dimensional sequence are acquired. **The two-dimensional series** served to provide detailed anatomic reference scans, whereas **the heavily T2-weighted three dimensional scan:**

- provides the basis for a precontrast maximum intensity projection (MIP) of the collecting system, ureters, and bladder. To create the MIP other T2 structures with long T2 relaxation times, such as cerebrospinal fluid and the gallbladder, are manually edited out from the images.

- Heavily T2-weighted static-fluid MR urograms resemble conventional excretory urograms and are useful for quickly identifying the level of urinary tract obstruction. However, identifying the

cause of obstruction often requires additional sequences.

- T2-weighted imaging, or MR hydrography, allows assessment of fluid (urine)-filled urinary tract structures and the renal parenchyma, including evaluation for structural anomalies and dysplasia. These systems are generally associated with marked hydronephrosis or cystic changes.

- Heavily T2-weighted images are able to delineate the anatomy even if little contrast excretion occurs as it does not require the excretion of contrast

material so, The T2-weighted images are particularly useful to define the anatomy of nonfunctioning or poorly functioning systems..

Commonly employed T2-weighted pulse sequences include single-shot fast spin-echo (SSFSE), 2D fast spin-echo (FSE), and 3D FSE. **SSFSE imaging** allows for free-breathing, respiratory-triggered, or breath-held renal and urinary to. Conversely, Postcontrast imaging provides excellent depiction of non-dilated/non-obstructed kidneys and urinary tracts (10).

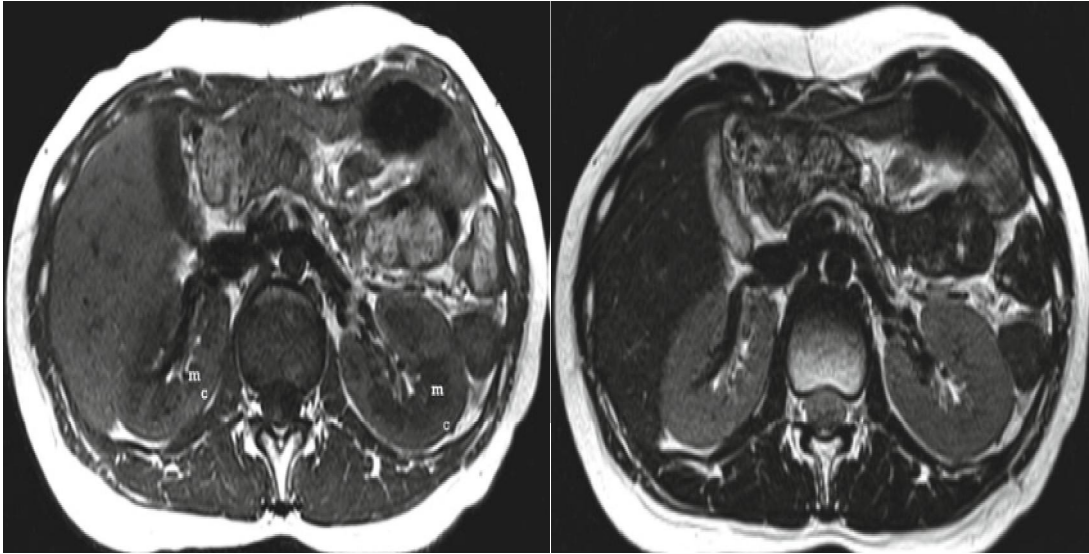


Fig (1): Normal turbo spin-echo MR images of the kidney

(A) T1-weighted turbo spin-echo MRI (repetition time [TR]/echo time [TE] = 490/8.3 ms; flip angle = 150°) shows distinct corticomedullary contrast demonstrated by high intensity of the renal cortex (c) and low intensity of the renal medulla (m). (B) On T2-weighted turbo spin-echo MRI (TR/TE = 2,500/98 ms; flip angle = 150°), the signal intensities of the renal cortex and medulla are increased, and they are not differentiated.

Post contrast techniques:

There are two basic postcontrast techniques used in pediatric MRU protocols:

- (1) dynamic postcontrast imaging
- (2) delayed postcontrast excretory phase imaging.

Dynamic MRU not only provides anatomic information including that of the vascular system, but it also offers functional information, which is in many ways analogous to a nuclear medicine study. Intravenous gadolinium is administered and sequential 3D dynamic sequences of the whole urinary tract are acquired. These images can be presented as a MIP and a cine loop. The former provides morphologic information. The dynamic sequences are the basis of the functional calculation, assess renal perfusion, evaluate renal transit and excretion, and allow generation of signal intensity versus time curves (11).

Dynamic postcontrast imaging involves the repeated acquisition of 3D spoiled gradient recalled echo images through the kidneys and ureters over a

period of up to 10–15 min during and after the slow intravenous injection (0.1–0.3 mL/second) of contrast material (A dose of 0.1 mmol/kg Gd-DTPA is slowly infused using a power injector (a minimum dose of 2 mL is used in smaller babies). This allows detailed assessment of the renal vasculature, renal parenchyma in multiple phases (e.g., corticomedullary and nephrographic phases), and contrast-opacified urinary tract. A typical dynamic postcontrast acquisition may obtain 50 or more 3D image volumes, which can be reviewed individually or as a concatenated maximum intensity projection (MIP) image series. Dynamic postcontrast imaging (sometimes referred to as functional MRU, or fMRU) also can be used to assess differential renal function using the Patlak–Rutland method as well as to evaluate urinary tract drainage using the combination of subjective visual assessment, renal parenchymal time vs. signal intensity curves, and quantitative parameters (such as calyceal transit time and renal transit time (12).

Delayed postcontrast excretory phase imaging can be performed in the axial, sagittal, or coronal planes (commonly all three planes) and used to obtain high spatial resolution images of the kidneys and ureters, including the ureteropelvic and ureterovesical junctions (UVJ). Such images also can be used to create 2D reformations and 3D reconstructions (12).

The images are transferred and postprocessed on an external computer using a freely available custom-made software package. The software package is used to calculate a number of functional parameters including calyceal and renal transit times, parenchymal volume, Patlak number and differential renal functions (DRF) based on renal parenchymal volume and Patlak number (an index of GFR). Moreover, the software package provides time-signal intensity curves of the renal parenchyma and contrasted part of the pelvicalyceal system corresponding to the renal enhancement and excretion (washout) curves, respectively (13).

Calyceal transit time (CTT) and renal transit time (RTT) refer to the time period between the appearance of contrast in the aorta and just before its appearance in the calyces and proximal ureter, respectively. CTT is the more reliable parameter, as RTT can vary according to the volume of the renal pelvis and the morphology of uretero-pelvic junction (UPJ); the RTT value alone may not always differentiate between stasis and obstruction. CTT and RTT should be interpreted only in conjunction with both the static and dynamic images. The influence of parenchymal disease on these values should not be underestimated. The cut-off points for normal and abnormal RTT as published in one study do not seem to be universally reliable in classifying UPJ obstruction as compensated and decompensated (13).

Differential renal function:

DRF is among the most widely used measures of renal function. The DRF as measured by dynamic renal scintigraphy (DRS) is based on the integration of the tracer curve over a range of time-points at which the tracer is assumed to be located predominantly in the parenchyma. Because of the limited spatial resolution of DRS studies, fixed time points are used because the exact location of the tracer cannot be confirmed by visual inspection of the images. Because DRS measurements are based on projection images of the whole kidney, they measure the activity in the whole kidney and the background. Most techniques developed for measuring the DRF with MRI have attempted to duplicate this approach by combining the area under the time-intensity curve obtained from either a single slice or a few slices, with a separate volume measurement. Signal intensity versus time curves for each kidney is generated. Although it is possible to generate separate curves for the cortex and

medulla, this is currently too time consuming for routine studies. The global curves for each kidney describe the perfusion, concentration, and excretion of the contrast agent over time. The two kidneys are easily compared and contrasted, which is especially helpful when one kidney is normal. The signal versus time curves are converted to relative signal versus time curves by calculating $(S_t - S_0)/S_0$, where S_0 is the mean precontrast signal, for each time point. The relative signal has a linear relationship with contrast agent concentration over a limited range of concentrations and compensates for spatial variations in the background signal, facilitating comparison of the two kidneys (13).

Role of MR Urography in obstructive uropathy using MR in pediatric patients:

MRI is particularly suited to urological imaging, because of its excellent delineation of water/urine-containing structures. There has been great expectation that dynamic contrast enhanced MRI would be able to substitute to both renal ultrasonography and scintigraphy. Indeed, MRI has the ability to provide very detailed anatomical description combined with a functional evaluation and identifying other pathology that could influence prognosis (14).

The most common indication for MR urography has been the evaluation of hydronephrosis, especially in infants and young children. In the evaluation of hydronephrotic systems with MR urography, we analyze both anatomic and functional information to determine whether obstruction is present, to evaluate its severity, and to identify its location and, if possible, its cause. The anatomic information includes grading the hydronephrosis, identification of transition in caliber, evaluation of underlying causes (14).

MR urography was used to evaluate hydronephrosis especially in UPJ obstruction by calculating the RTT. If the transit time is less than 245 seconds, the system is considered nonobstructive. If the RTT is greater than 490 seconds, the system is probably obstructed. RTT times between 245 seconds and 490 seconds are considered equivocal and are managed conservatively with close follow-up to ensure that renal function is stable. The calyceal transit time is usually symmetric and is used as an indicator of hemodynamic and pathophysiologic changes in the renal parenchyma itself. The calyceal transit time is determined both by the GFR and the tubular reabsorption of urine. Delayed calyceal transit is usually seen in the setting of acute-on-chronic obstruction and occasionally with renal artery stenosis. Rapid calyceal transit times may be the result of glomerular hyperfiltration (pressure effect) or impaired concentration within the tubules (volume effect) (13).

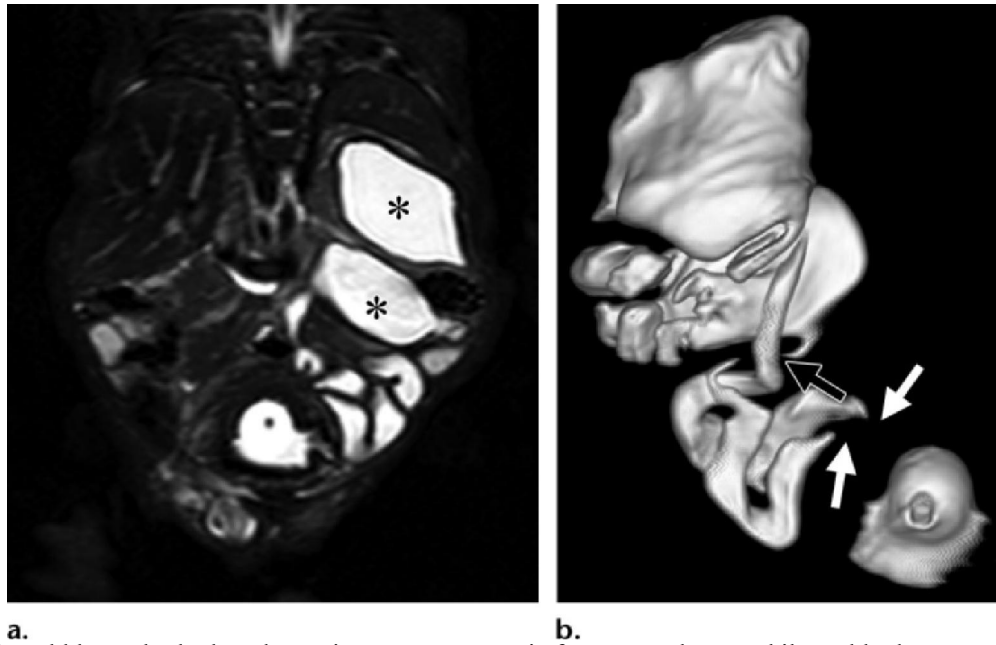


Fig 2: 10-day-old boy who had unclear urinary tract anatomic features and severe bilateral hydronephrosis at US. Static MRU was done, gadolinium-based contrast material was not used because of acute renal failure. Cutaneous pyelostomy was performed to relieve the urinary tract obstruction and preserve renal function. **(a)** Coronal 3D T2-weighted FSE MR image shows severe left hydronephrosis (*). **(b)** Volume-rendered 3D T2-weighted FSE MR image (posterior view) shows a duplicated left upper urinary tract with severe lower moiety ureteropelvic junction narrowing (black arrow) and severe narrowing of the distal ureters (white arrows).

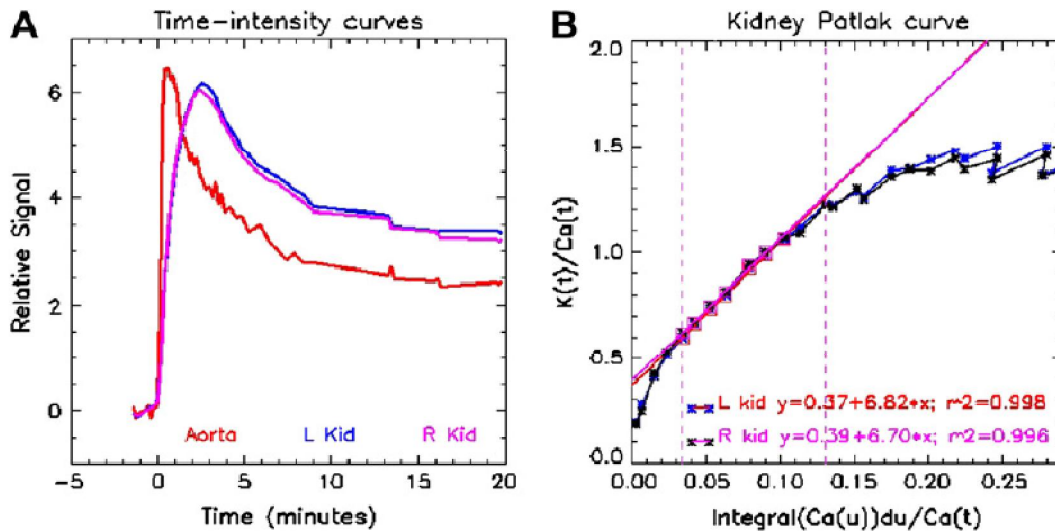


Fig3: Functional evaluation for 7-week-old boy shown in: (A) Relative signal intensity versus time curve showing curves for the aorta and both kidneys. Note the symmetric parenchymal curves with equivalent perfusion, concentration, and excretion of contrast agent. (B) The Patlak plot is used as an index of the individual kidney GFR. The slope of each plot reflects the GFR of each kidney (6.8 mL/min on left and 6.7 mL/min on right). The y intercept represents the fractional blood volume of each kidney. The body surface area corrected Patlak (BSA Patlak) is 92 mL/min. The Patlak DRF is calculated at 50:50.

Recently By evaluating the changes in signal intensity in the renal parenchyma following contrast

administration, the hydronephrotic systems are classified as compensated or decompensate. If there

are symmetric changes in signal intensity of the nephrogram, we classify it as a compensated hydronephrotic system: the fluid challenge is accommodated without increasing the pressure in the pelvicalyceal system. However, when the signal intensity changes are asymmetric they most often indicate acute or chronic obstruction: the fluid challenge has exceeded the capacity for renal drainage and the pressure in the collecting system rises. These are classified as decompensated hydronephrotic systems. Signs associated with decompensation include parenchymal edema on T2-W images, delayed CTT, a delayed and increasingly dense nephrogram (13).

With MR urography, signs to suggest underlying uropathy and permanent damage on the T2-W images include architectural disorganization with loss of the corticomedullary differentiation, small subcortical cysts and low cortical T2 signal intensity. With MR urography, however, a kidney contributing 30% of total renal GFR may simply be a decompensated system with normal renal parenchyma or it may be severely uropathic with little chance for return of function. Identification of obstructive uropathy has prognostic implications in that these changes seem to be permanent and that functional improvement is unlikely if surgery is performed (13).

The distal ureteric anatomy is also well demonstrated with MR urography.⁴⁸ Ectopic ureteric insertion either in single systems or in combination with duplex systems can usually be obtained on the delayed postcontrast images or on the T2-weighted images in markedly dilated or poorly functioning system. The diagnosis of primary megaureter is made when the ureter measures more than 7 mm in diameter and the ureteric insertion into the bladder is normally located. The differentiation of obstructed from nonobstructed megaureter is arbitrarily made on the basis of RTTs because most cases are followed conservatively. Most cases of megaureter appear as compensated hydronephrosis and with follow-up studies there is elongation and lengthening of the ureter with improvement in RTT. MR urography can also demonstrate both simple and ectopic ureteroceles (14).

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