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Magnetic Resonance Urography as an Imaging Modality for Urinary Stone Diseases

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Abstract

Magnetic resonance urography (MRU) techniques have matured and have become applicable to the diagnosis of more and more diseases in urinary tract. Modern MRU offers not only increased spatial and temporal resolution, but also provides anatomic and functional information on renal perfusion, excretion and drainage. Patients with renal colic are better examined by non-enhanced computed tomography (CT) scanning because it is highly sensitive in detecting stones. However, one disadvantage of non-enhanced CT is the high radiation dosage. The goal of this review is to briefly discuss MRU indications for patients with suspected acute calculus ureteric obstruction, summarize MRU techniques as applicable in the diagnosis, and compare MRU techniques to other traditional imaging techniques such as unenhanced spiral CT, intravenous urography (IVU), and ultrasonography.

Keywords

MRU, Renal stone, Ureteral stone

Abbreviations

US: Ultrasonography; KUB: Plain Radiograph of the Abdomen; IVU: Intravenous Urography; CT: Computerized Tomography; MRU: Magnetic Resonance Urography; RARE: Rapid Acquisition with Relaxation Enhancement; GRE-EPI: Gradient Echo type Echo Planar Imaging; DTPA: Diethylenetriamene Pentaacetate; HASTE: Half-fourier Acquisition Single-Shot Turbo Spinecho; MRI: Magnetic Resonance Imaging; Gd-BOPTA: Gadolinium with the Ligand BOPTA; UPJ: Ureteropelvic Junction; S-MRU: Static MRU; B-TFE : Balanced-Turbo Field Echo; DW: Diffusion-Weighted; C-MRU: Cine MRU; TSE: Turbo Spin Echo; MRP: Magnetic Resonance Pyelography; MRA: Magnetic Resonance Angiography

Introduction

As urinary stone disease has a propensity to recur with significant associated morbidity, reliable and non-invasive imaging techniques both for initial diagnosis and in follow up of the disease are required [1]. Concerns regarding both radiation dose and cost-effectiveness have promoted investigation of different imaging modalities [2]. Imaging of urinary stone includes ultrasonography (US), plain radiograph of the abdomen (KUB), intravenous urography (IVU), unenhanced spiral computerized tomography (CT), and magnetic resonance urography (MRU).

Over the last 70 years, IVU has played a major role in the work-up of diseases in the kidneys and the upper urinary tract. However, modern cross-sectional modalities have shown that IVU does not fulfill current requirements. Patients with renal colic are better examined by non-enhanced CT scanning, as it finds more stones (60 versus 100%) [2]. However, one disadvantage of non-enhanced CT is the higher radiation dosage than conventional IVU, even though low dose CT has been studied to be effective in diagnosing stone diseases in circumstances. MRU is free of radiation and contrast media risks, so it is recommended to be a primary investigation in patients with no excretory function, in pregnant women, in children, in young persons, and in those with contrast medium allergy [3-9]. MRU techniques also possess image quality and diagnostic capability that are improving with increasingly sophisticated imaging sequences and

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shorter scanning times [10-13]. It provided high quality images for diagnosing and determining causes of urinary obstruction defining position and severity of dilatations, showing localization of the pathology, as well as evaluating renal morphological and functional changes post obstruction or lithotripsy [7,10,14-17]. However, MRU has been slow to gain wide acceptance in evaluating patients with urinary stone diseases. This may be explained by poor detection of nonobstructive or small obstructing calculi when compared with CT in some early studies [18,19].

MRU

MRU is performed by pursuing two different imaging strategies. On the one hand, heavily T2-weighted turbo spin-echo sequences are employed for obtaining unenhanced static-water images of the urinary tract. On the other, the T1-weighted MRU technique imitates conventional intravenous pyelography and is, therefore, referred to as excretory MR urography. For this reason, a gadolinium contrast agent is injected intravenously and, after its renal excretion, the gadolinium-enhanced urine is imaged with fast T1-weighted gradient-echo sequences [20]. Use of these two techniques, either individually or in combination, permits investigation of all relevant aspects in the diagnosis of urinary tract disease.

Although MR imaging is not recommended during the first trimester and use of contrast material is not recommended in pregnant patients, fast MR imaging is useful in various obstetric settings and can provide more specific information with excellent tissue contrast and multiplanar views. In pregnant patients with hydronephrosis, MRU can demonstrate the site of obstruction and the cause (e.g., a ureteral stone) [21,22]. A report on the application of standard 2D-FT (fiber tracking) MR combined with RARE (rapid acquisition with relaxation enhancement) - MRU in a pregnant woman with right sided abdominal pain, dilated upper urinary tract and possible stone or inflammatory disease. This technique visualized the complete obstructed ureter in relation to the surrounding organs (uterus, vessels), allows precise diagnosis of the cause of the obstruction and avoids ionizing radiation [23].

In a study with 74 patients, fast 3D gradient echo type echo planar imaging (GRE EPI) sequences improve the clinical practicability of excretory MRU especially in old or critically ill patients unable to suspend breathing for more than 20 second. Susceptibility effects were more pronounced on GRE-EPI MRU and calculi measured 0.8-21.7% greater in diameter compared with conventional GRE sequences [24].

Excretory MRU versus Static MRU

The imaging of the unobstructed urinary tract and pelvicalyceal system can be improved by giving gadolinium or low dose frusemide and external compression of the ureters [25-29], Excretory images enhanced by diuretics and gadolinium had well-filled upper urinary tracts with good contrast [30-32].

To compare the diagnostic value of static-liquid MRU in T2-weighted HASTE (half-fourier acquisition single-shot turbo spinecho) sequences and T1-weighted excretory MRU with i.v. diuretic and contrast material injection. One study included 29 patients (15 men, 14 women). The cases were evaluated by T2 HASTE sequences combined with T1-weighted FLASH 3D sequences after i.v. diuretics and gadolinium diethylenetriamene pentaacetate (DTPA) injection. Thirty-one urinary obstructions were detected on IVU. Thirty of which were confirmed by T2-weighted MRU and all were confirmed by excretory MRU. In one nonobstructive case, unilateral grade 1 ureteropelvicaliectasis related to ureteral stone was falsely interpreted by both sequences. There were no statistical differences among IVU, T2-weighted MRU and excretory MRU in detecting the obstruction levels. In 22 cases with ureteral stones, 12 of which were confirmed by T2-weighted MRU and 18 cases were confirmed by excretory MRU. Sensitivity and specificity of detecting the ureteral stones as a cause of obstruction with T2-weighted MRU were 50%and 89% and with excretory MRU were 77% and 89% respectively. In 9 obstructive cases due to causes other than the stones, 8 of which were detected by T2-weighted MRU and all of which were detected by excretory MRU. Sensitivity and specificity for detecting the causes other than the stones with T2-weighted MRU were 96% and 100% and with excretory MRU were 100% and 100% respectively. MRU should be used as an alternative imaging technique in cases which IVU cannot be applied. The existence and the causes of obstruction can be detected by HASTE MRU. Excretory MRU can supply additional information in cases with functional kidneys where the cause of obstruction cannot be revealed by HASTE MRU [30].

To compare the usefulness of breath-hold heavily T2-weighted sequences with gadolinium-enhanced three-dimensional fast low-angle shot (3D FLASH) MRU in the evaluation of patients with acute flank pain, 40 consecutive patients with symptoms of acute flank pain underwent MRU followed immediately by excretory urography. Heavily T2-weighted (combined thin-slice HASTE and thick-slab single-shot turbo spin-echo) and 3D FLASH sequences were evaluated separately and independently by two experienced radiologists for the presence, cause, level, and degree of obstruction. Twenty-six patients were found to have unilateral obstruction caused by ureteral stones. Both MRU methods were excellent for detecting obstruction. In the detection of stones 3D FLASH was superior, with a sensitivity of 96.2% and 100% and specificity of 100% and 100% for observers A and B, respectively, compared with a sensitivity of 57.7% and 53.8% and a specificity of 100% and 100%, respectively, for T2-weighted sequences. The best degree of obstruction was seen with 3D FLASH, and the interobserver agreement was excellent for stone detection (kappa = 0.97). T2-weighted sequences alone are not sufficient for examining patients with acute flank pain. However, the combined use of both T2-weighted and 3D FLASH sequences will ensure better confidence in the evaluation of acute suspected renal colic [33].

Despite of some encouraging results, it is the common sense that gadolinium is highly toxic and its deposition should be kept as low as possible, and that gadolinium contrast agents be used only when absolutely necessary, with preferential use of macrocyclic chelates, which seem to be deposited at lower concentrations [34].

MRU versus IVU or US

Ultrasonography and conventional intravenous urography are most common methods in diagnosis of obstructive uropathies. The disadvantage of ultrasonography is inability of visualizing middle and lower one thirds of ureter, while intravenous urography is using radiation, also functionally extra loading effect on kidneys. In one study of renal colic in pregnancy with 103 cases, ultrasonography was sufficient to confirm the diagnosis in 96% of cases. However, in 4% of cases, magnetic resonance imaging (MRI) or low-dose CT were necessary [35]. In other study on 45 patients who were suffered from obstructive uropathy, diuretic-enhanced excretory MRU by using MR-contrast-agent established accuracy rate of 92.8% for stone diseases which formed the largest group in this study, however, in other causes of obstructive uropathy, MRU provide 100% correct diagnosis [10].

In a study to evaluate the feasibility and clinical utility of gadolinium with the ligand BOPTA (Gd-BOPTA) enhanced excretory magnetic resonance urography without additional administration of diuretics in correlation with conventional urography. Caliceal fornices were better delineated on conventional urographies, whereas MRU was considered superior in the assessment of the inferior ureter sections, the urinary bladder. Non-diuretic Gd-BOPTA enhanced MRU is comparable to conventional excretory urography for the preoperative diagnosis. Further improvements of this technique seem possible by optimization of examination intervals and injection doses [36].

Another study on 30 patients of obstructive uropathy, low magnetic field, open MRI units and low-dose Gd-DTPA provided cost-effective MRU studies with excellent diagnostic utility. MRU scored over IVU in patients with moderate-severe dilatation, staghorn and urethral calculi, impaired renal function, extrinsic ureteric and ureteropelvic junction (UPJ) obstruction [37].

To compare the ability of MRU enhanced using gadolinium and frusemide diuresis, and conventional IVU to diagnose the cause of ureteric obstruction, 82 patients in whom IVU showed or suggested obstruction underwent MRU enhanced by gadolinium and frusemide diuresis. The diagnoses were ureteric calculi in 72 patients, ureteric tumors in eight and extra-ureteric tumors in two. In those with urolithiasis, the diagnosis was correct with IVU in 49 patients and with MRU in 64 [25].

MRU versus Unenhanced Helical CT

Traditional static MRU has been shown to be highly sensitive in the diagnosis of urinary obstruction, defining the severity of dilatation, the site, however, some early studies found that urolithiasis was frequently misdiagnosed, especially nonobstructive or small obstructing calculi. This is due to the limitation in level of resolution [19,38,39]. Also due to the relative unspecificity of filing defects which MRU was based on in detecting of stones [40,41]. However, MRU was superior to CT in its complete, detailed demonstration of the renal pelvic lesions [42].

In one study 49 patients underwent CT, static MRU (S-MRU) (with T2-weighted and gadopentetate dimeglumine-enhanced T1-weighted sequences), and excretory urography. The final conclusive diagnosis was based on the combination of excretory urographic, clinical, and interventional results. At final diagnosis, 65% patients were found to have ureteral stones causing unilateral obstruction. In ureteral stone detection, the sensitivity and specificity of CT were 90.6% and 100.0%, respectively (observer A) and 90.6% and 94.1% , respectively (observer B), while those of MRU were 93.8% and 100.0%, respectively (observer C) and 100.0% and 100.0%, respectively (observer D). Spearman correlation coefficients for stone size at CT were 0.76 ($P < 0.001$) and 0.75 ($P < 0.001$) and at MRU, 0.49 ($P = 0.005$) and 0.51 ($P = 0.004$). In routine clinical practice, CT is the modality of choice in the evaluation of patients with acute flank pain. MRU is an accurate and suitable alternative imaging technique in selected patients [38]. In addition, MRU may play a potential role in patients with chronic urolithiasis, in whom neither the CT nor sonography can sufficiently explain the complicated state of chronically affected urinary tract [43].

In a study to compare the inter-observer variability and the accuracy of MRU using a thin sectional balanced-turbo field echo (B-TFE) sequence for detecting ureteral calculi and to determine the effect of additional factors (size, density and location of the calculus) on the sensitivity and specificity of the MRU. According to the 1st and 2nd observers, the sensitivity of MRU was 65.9%, 71.8% and the specificity of MRU was 95.9%, 100%, respectively. Inter-observer agreement was 84.6% for stone detection. The larger size had a better effect on detectability. Also, the higher density had a better impact on detectability. They concluded that MRU is a reasonable alternative imaging technique for follow-up periods of selective groups like patients with large urinary stones, children or pregnant patients when ionizing radiation is undesirable [44].

MRI is helpful in demonstrating complications such as pyelonephritis [45]. In a prospective study with 42 patients with clinical and laboratory diagnosis of pyelonephritis who underwent CT and diffusion-weighted (DW) MRI examinations, DW MRI had a higher sensitivity of 95.3% as compared to that of non-contrast CT (66.7%) and contrast-enhanced CT (88.1%) in the diagnosis of pyelonephritis. However, CT is more useful for the diagnosis of renal calculi and emphysematous pyelonephritis [46].

Combine HASTE MRU with KUB

It has been recommended to include a single plain-film radiograph in the analysis of MR urograms for better detection of calcifications [29,47].

In one study 64 patients with suspected acute calculus ureteric obstruction were evaluated. MRU/KUB showed ureteric calculi in 21/29 (72%) of patients with calculi seen by CT. Overall, MRU/KUB revealed 2.4 abnormalities per acutely obstructed ureter compared with 1.8 abnormalities detected by CT. MRU/KUB using HASTE sequences can diagnose the presence of acute calculus ureteric obstruction with similar accuracy to spiral CT. The technique has less observer variability and is more accurate than CT in detecting evidence of obstruction such as perirenal fluid, and is easier to interpret than CT [47]. While MRU/KUB still misses small calculi (7 mm or less), these stones usually pass spontaneously, and do not require intervention [1,48].

Combine MRU with IVU

IVU is not routinely used for diagnosis of urinary stone nowadays. Despite of this, in a retrospective study with imaging data of 5 patients with congenital megaureter and 2 misdiagnosed patients, combined MRU and IVU could visualizethe characteristics of congenital megaureter, including the dilation of renal pelvis and ureter, calculi, urinary tract duplication, and stenosis location. The two techniques were found to be able to complement each other in disease diagnosis and provide more detailed information for preoperative treatment [49].

Combine MRU with Short Helical CT

Three percent of the population experiences a flank pain during its lifetime. A flank pain is explained by calculus disease in more than 70% of the cases [50]. In a study, 51 patients with symptoms of acute renal colic underwent MRU and then a total urinary tract helical CT. Combined MRU and short helical CT has a high sensitivity in detecting ureteral calculi with a reduced radiation dose [51].

Cine MRU

MRU using heavily T2-weighted images can depict the urinary tract without the need for contrast medium. However, this technique has potential problems with regard to evaluating the non-dilated ureter. To compare the efficacy of cine MRU (C-MRU) with static MRU (S-MRU), one study on twenty-two patients with suspected upper urinary tract disease underwent C-MRU. The final clinical diagnosis was compared with the diagnosis made using S-MRU and C-MRU, respectively. S-MRU was used in the initial phase of this sequence, while C-MRU was used for the entire sequence. A final diagnosis was made based on 1) existence of stenosis, 2) rate of certainty of existence of stenosis, 3) etiology of stenosis. S-MRU resulted in a correct diagnosis in 19 of the 22 patients (86.4%), while C-MRU resulted in a correct diagnosis in 20 of the 22 patients (90.9%). Both S-MRU and C-MRU correctly diagnosed all 3 cases with calculus. However, it is important to note that C-MRU excluded the suspicion of benign nature in one case. This study indicated that no statistically significant difference was observed between S-MRU and C-MRU, except in certainty of existence of stenosis, where C-MRU (average rate: 2.82 +/- 0.39) was significantly superior to S-MRU (2.41 +/- 0.73). C-MRU can improve the certainty of existence of urinary stenosis, and may be useful in excluding suspected stenoses in normal or undilated ureters [52].

Combine Static Fluid MRU with Excretory MRU and Conventional MR Images

To evaluate the role of MRU in the diagnosis of obstructive uropathy in selected groups of patients. The groups involved following pathologies: calculi; strictures of UPJ; benign and malignancy-induced ureterostenosis. Sixty patients with clinical diagnosis of obstructive uropathy were subjected to static fluid S-MRU with the use of 3D turbo spin echo (TSE) sequence in a 0.5-T magnet. In patients with urolithiasis S-MRU correctly depicted the degree of ureterohydronephrosis in 85%, in cases of UPJ stenosis and malignancy-induced ureterostenosis in 100% and in the group of benign ureterostenosis in 91% of patients. Determination of obstruction level in patients with stones was adequate in 92% and in cases of non-calculus ureteral strictures in 100% of patients. The S-MRU sequence alone could not specify the nature of obstruction except 1 case of bladder carcinoma. Filling defects in ureters visible on MR urograms were verified with IVU or CT to exclude intrinsic tumors. In conjunction with excretory MRU and conventional MR images S-MRU appears to be a highly useful technique in assessment of obstructive uropathy, especially that of non-calculus origin. Among different clinical applications MRU is superior in the evaluation of dilated urinary tract in altered anatomical conditions (e.g. in patients with ileal neobladder) [53].

MR Pyelography (MRP)

In a study on 315 patients who had originally been investigated by ultrasonography were evaluated with

MR pyelography (MRP) in order to define the etiology of obstruction. MRP was performed with two ultrafast breath-hold sequences in obstructive uropathy patients In 67 patients hydronephrosis was referred as caused by lithiasis. MRP, made with ultrafast breath-hold sequences, has a great value in identifying hydronephrosis in patients with ureteric stones. Furthermore, it provides the chance to identify pyonephrosis requiring an immediate drainage of the kidney before major complications develop [54].

Another study to investigate the diagnostic yield of MRP performed with two ultrafast breath-hold sequences in obstructive uropathy patients. Thirty-four patients with US demonstration of urinary tract dilation were examined with MRP. MRP examinations were considered technically adequate in all cases by both observers. As for the presence of urinary tract dilation, the values were 100% for the first observer and 97%, 100%, 100%, and 95%, respectively, for the second observer. Interobserver agreement was 0.98 for dilation presence (excellent), 0.80 for dilation degree (excellent), 0.62 for dilation site (good) and finally 0.69 for dilation cause (good). MRP performed with the ultrafast breath-hold technique provides very good results in diagnosing urinary tract dilation, as well as the obstruction grade, site and cause, with results equal or even superior to those of non-breath-hold sequences. Ultrafast MRP lasts only 10 minutes, meaning it occupies the magnet shortly and costs less: it can be thus considered a routine alternative to conventional diagnostic imaging, especially ivp, in the evaluation of obstructive uropathy [55].

Combine MRP with MRU

One study on 45 patients with dilated upper urinary tract was studied with combined MRU and MRP. MRP images were obtained by using a respiratory compensated 3D T2-weighted TSE sequence and were reconstructed with a MIP algorithm. In all cases, urography and/or ascending pyelography were also performed. Images were independently evaluated by two radiologists. The dilated tract ureter and the level of the obstruction could be correctly demonstrated in all cases. Fourteen stones were identified as the cause of obstruction. Examiner 1 identified 13 of them and examiner 2 identified 12. The interobserver agreement was high with a kappa-value of 0.96. In cases of obstructive hydroureteronephrosis MR imaging, combining MRP and conventional sequences, can be proposed as an accurate technique in the assessment of level and cause of obstruction [56].

Combine MRU with MRA and Dynamic MRI

Comprehensive "all-in-one" MR procedure including MRU, dynamic MRI and MR angiography (MRA). This "all-in-one" approach is useful in examining the kidneys, the renal vascular supply and renal perfusion, and the urinary tract [39,57,58]. It is a cost-effective diagnostically relevant method, especially for patients who are likely to have multiple examinations [58].

When this comprehensive MRI was used in the evaluation of patients with PUJO. MRU showed the morphology of the collecting system in all patients, and the ureter below the PUJ in 31 of 46 (67%), but renal stones were missed only in three of 10 patients. MRA showed crossing vessels in 22 patients (48%). There was a strong correlation between MR clearance and radioisotope clearance. Findings during pyeloplasty showed one false-negative and one false-positive result of the preoperative MRI. Therefore, the sensitivity, specificity and accuracy of MRA were 95%, 94% and 94%, respectively [57].

Another study on 64 patients (58 with urologic disease and 6 healthy volunteers), MR was performed including: (a) T1- and T2-weighted imaging; (b) 3D contrast-enhanced MRA, including the renal arteries, renal veins, as well as renal perfusion; and (c) 3D contrast-enhanced MRU in the coronal and sagittal plane. For the latter, low- and high-resolution images were compared. Prior to gadolinium injection, 0.1-mg/kg body weight of furosemide was administered intravenously. Visualization of the renal parenchyma, the vascular supply, and the collecting system was adequate in all cases, both in nondilated and in dilated systems and irrespective of the renal function. Both 2 cases with calculus were correctly diagnosed. Only one infiltrating urothelial cancer was missed; there was one false-positive urothelial malignancy [58].

This comprehensive approach can also be used in the diagnosis of Crohn's disease, which frequently can affect the genitourinary system, mainly in the form of urinary fistulae and urolithiasis [59].

Current Status and Future Perspective

MRU provides an unprecedented level of anatomic information combined with quantitative functional evaluation of kidneys and urinary tracts. In the evaluation of urinary stone disease in pregnancy, MRU is able to make the distinction of physiological renal dilation from obstruction due to calculi causes. MRU is therefore a safer and sensitive alternative to conventional imaging techniques in detecting urinary stones in selected groups of patients. Because ionizing radiation and contrast agents are not used, it is an attractive alternative to CT for people with contrast allergies, renal insufficiency, diabetes, pregnancy, and young age. One consistent indication for MRU in flank pain is during pregnancy in case of recurrent flank pain.

Compression, diuresis, enhanced agents, and improvements in coil design, imaging time, and combinations with other imaging techniques have provided us with higher resolution images and higher sensitivity for MRU in detecting urinary stones. Together with the presence of the clinical data, it should be possible to make the correct MRU diagnosis of urolithiasis in the majority of patients [26,31,42]. The major drawback of MRU is its low sensitivity in detecting nonobstructive or small obstructing calculi and parenchymal stones so there is still significant false negative rate, even though people has proposed some new techniques [11-13,60]. It other drawbacks are its relatively low accessibility and higher cost. We have not been able to define the best technique for MRU in diagnosing urinary tract calculi yet. However, MRU can be offered as an alternative to conventional urography and CT urography to avoid repetitive radiation exposure in patients with pregnancy or chronic urolithiasis.

Further improvements in resolution, technique, and cost will have to be addressed before MRU can be used regularly in the evaluation of urinary stone diseases and better detect small stones.

Conflict of Interests

The author declares that there is no conflict of interest regarding the publication of this paper.

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