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MR urography: examination techniques and clinical applications

Abstract Modern MR urography is performed on the basis of two different imaging strategies, which can be used complementarily to cover almost all aspects in the diagnosis of upper urinary tract diseases. The first technique utilizes unenhanced, heavily T2-weighted pulse sequences to obtain static-fluid images of the urinary tract. T2-weighted MR urograms have proved to be excellent in the visualization of the markedly dilated urinary tract, even if the renal excretory function is quiescent. Static-fluid MR urography is less suitable for imaging of disorders that occur in the nondilated collecting system. The second MR urography technique is analogous to the methodology of conventional intravenous pyelography and is, therefore, designated as excretory MR urography. For this purpose, a non-nephrotoxic gadolinium chelate is intravenously administered and after its renal excretion, the gadolinium-enhanced urine is visualized using fast T1-weighted gradient-echo sequences. The combination of gadolinium and low-dose furosemide (5–10 mg) is the key for achieving a uniform distribution of the contrast material inside the entire urinary tract and, secondly, to avoid high endoluminal gadolinium concentrations, which cause signal loss of the urine due to T2* effects. Gadolinium excretory MR urography allows to obtain high-quality images of both nondilated and obstructed urinary tracts in patients with normal or moderately impaired renal function. This article reviews the principles of T2- and T1-weighted MR urography in detail and informs how to use these techniques safely in potential clinical applications such as chronic urolithiasis, intrinsic and extrinsic tumor diseases, and congenital anomalies. Magnetic resonance urography performed in combination with standard MR imaging offers a potential to reduce the need for invasive retrograde pyelography. Although the economic aspect is still problematic, it is obvious that MR urography will continue to increase its role in clinical uroradiology.

Keywords Kidney · Urography · MR imaging · Gadolinium · Furosemide

Introduction Especially during the past 5 years, MR urography has advanced from the state of basic research to use in clinical practice. Clinical MR urography, however, is still in its infancy and seeks widespread dissemination. Most of us have already seen impressive MR urograms, but the various underlying examination techniques, hardware requirements, MR pulse sequences, and potential indications are not commonly known. The goal of this re-
view is to offer a thorough approach to this new way of imaging of the upper urinary tract and to provide general guidelines for the performance of MR urography, which is easy to put into operation. Unenhanced T2-weighted and gadolinium-enhanced T1-weighted MR urography techniques are described in detail, which forms the basis for a safe application of MR urography in the clinical routine. With regard to the major urinary tract disorders, potential indications for MR urography are presented and illustrated by numerous clinical examples.

**Hardware requirements**

Magnetic resonance urography is most practically carried out at 1.5 T. Nevertheless, several investigators have successfully performed MR urography at low- and mid-field strength between 0.23 and 0.5 T [1, 2, 3, 4, 5]. High field strength magnets can be equipped either with a conventional gradient system [6] or, preferably, with ultrafast high-performance gradients [7]. Different surface coils were employed in several studies dealing with MR urography [3, 6, 8, 9, 10, 11]. The body coil alone is also able to do a good job in most of the MR urographic examinations performed in adult patients [7, 12]. In the near future, modern surface coil techniques will certainly help to improve the image quality in high-resolution MR urography. The use of external ureteric compression has been recommended by a few authors [10, 13, 14]; however, modern MR urography techniques actually obviate the need for an inconvenient compression device [6, 15, 16].

**T2-weighted MR urography**

T2-weighted MR urograms simply generate static water images (static-fluid MR urograms). The water that we want to see is, of course, the urine itself, which can be regarded as an “intrinsic contrast medium.” Static-fluid MR urography offers a diagnostic tool, which is independent of the renal excretory function. Thus, the important advantage is that T2-weighted MR urography can be performed even in patients with non-excreting kidneys [3, 6, 8, 12, 13, 14, 17]. On the other hand, the methodology of static-fluid MR urography does not yield functional information about the urinary tract [3, 8, 12, 16, 17].

In order to obtain water images of the urinary tract, heavily T2-weighted pulse sequences are necessary, which display the urine with a hyperintense signal intensity and with a high contrast toward surrounding extrarenal tissues. Turbo spin-echo sequences have proved to be optimal for obtaining heavily T2-weighted images within short data acquisition times. The principle of turbo spin-echo imaging was pursued in the mid-1980s by Hennig and co-workers who called this technique rapid acquisition with relaxation enhancement (RARE) [18]. Indeed, it was the RARE sequence which was first used to obtain urogram-like MR images [1].

In RARE imaging, more generally referred to as turbo spin-echo (TSE) imaging, the reduction in scan time is achieved by the characteristic feature that each 90° excitation pulse is followed by multiple 180° pulses generating a train of consecutive echoes, each of which experiences a different phase-encoding step. The number of echoes following a 90° pulse is called echo train length (ETL) or TSE factor. The number of necessary 90° pulses per image equals the number of repetition times (TR), which importantly determines the sequence duration. Compared with a standard spin-echo pulse sequence, the number of 90° pulses applied in a TSE sequence is markedly reduced, namely by the division of the TSE factor. In a multi-shot TSE sequence, still several 90° pulses have to be applied per acquisition of a single MR image. With increasing ETL, the total number of necessary 90° pulses decreases and, accordingly, the TSE sequence becomes faster.

A single-shot TSE sequence is even more rapid, because only one 90° pulse is applied and the echo train must be long enough to complete a whole single image. Since we only apply a single 90° pulse per slice, there actually does not exist a real TR. The TR that is usually given by the sequence protocol of our magnets (Table 1) equals the time between two single shots, each of which is applied for an individual slice. Another important parameter in TSE imaging is the so-called effective echo time (TE). In a single-shot TSE sequence, the effective TE indicates the echo profile, which is placed in the center line of the k-space and which is, therefore, the most pronounced echo of the train because it experiences the weakest phase-encoding gradient. Since we want to obtain a heavily T2-weighted image, the effective TE should be long (Table 1).

Finally, the combination of a single-shot TSE sequence and a half-Fourier data acquisition provides the fastest variant of the RARE technique which is called HASTE (half-Fourier acquisition single-shot turbo spin echo). The HASTE sequence allows us to acquire a single T2-weighted MR image within a breath-hold of less than 5 s and, to date, the most commonly recommended technique for use in static-fluid MR urography [9, 12, 15, 17]. Typical parameter values of the HASTE sequence are listed in Table 1. Additional spectral fat suppression can help to further improve the contrast between urinary tract and retroperitoneum [5, 9, 12, 13, 14, 17].

Basically, there are two possibilities of how to use the RARE or HASTE sequences in T2-weighted MR urography: On one hand, the whole urinary tract can be visualized by acquisition of only a single-slice projection image (Table 1). The slice thickness must be very thick,