Radiol Oncol 2005; 39(1): 23-35.

review

The MR imaging as a one-way shopping tool for detecting and staging renal tumours

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Background. *Magnetic resonance imaging is one of the most attractive approaches: the technology is widely available, it is not associated with the exposure to ionizing radiation, and does not require the injection of iodinated contrast agent. High-field strength clinical magnets, high-performance gradient hardware, and ultrafast pulse sequence technology are rapidly making the vision of a comprehensive »one-stop shop« urologic MR imaging examination a reality.*

Conclusions. *Difficulties that remain are related to the variable protocols of the examination and, therefore, it is mandatory to standardize as much as possible the techniques that are used in order to obtain reproducible information.*

Key words: kidney neoplasms - diagnosis; magnetic resonance imaging; neoplasms staging

Introduction

Since the only successful curative treatment of renal tumours is surgery, accurate radiological information is crucial during the initial tumour staging for an optimal operative planning. The preoperative assessment of renal carcinoma includes tumour size, tumour extent, in particular capsule invasion with tumour spread to perinephric fat with or without direct invasion of adjacent organs outside Gerota's fascia, regional lymph node metastasis, venous tumour thrombosis, and distant metastases.[1] Intravenous urography, angiography and ultrasound have been the main investigations for a long period of time. All these methods are complementary and each has advantages and disadvantages. None of these single methods are sufficient for the evaluation of all aspects involved in oncologic urologic pathology. Nowadays the pretherapeutic planning of renal carcinoma has dramatically improved in the use of cross-sectional imaging, in particular CT and MRI. Magnetic resonance imaging is one of the most attractive approaches: the technology is widely available, it is not associated with the exposure to ionizing radiation, and does not require the injection of iodinated contrast agent.[2]

Received 5 July 2004
Accepted 10 September 2004

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In recent years a number of reports on dynamic MRI have evaluated renal functioning and morphological changes. Dynamic MRI has proven able to integrate renal scintigraphy in documenting functional impairment and to supplement the information acquired by other imaging techniques on the morphology of the kidney.[3] Stimulated by the philosophy and results of the all-in-one examination for pancreatic neoplastic disease, Verswijvel *et al* invade a similar approach for the evaluation of urologic disease. Cross-sectional sequences, MR angiography in the arterial and venous phase, evaluation of the renal parenchymal and lesional perfusion, and contrast-enhanced MR urography were combined in one imaging session.[4] The method gained a widespread acceptance as a standard for patients in which several conventional complementary modalities must be performed and is fairly well illustrated for patients with neoplasms of the renal parenchyma or urothelium.

The aim of the paper is to describe an all-in-one approach protocol for MR examination of patients with suspected or proved renal tumours in order to achieve all necessary preoperative (pretreatment) information. Some explications of the possibilities and clinical usefulness of each one MR series will be done.

Paramagnetic contrast materials

Advances in the application of MRI in kidney's pathology depend predominantly on the use of magnetic resonance contrast

Table 1. Example of order of the sequences for an all-in-one approach protocol

1. AX T1 WI
2. AX T2 FSE WI
3. COR T2 FSE WI double echo half-Fourier acquisition single-shot turbo spin echo
   + FAT SAT
   + IN/OUT Phase T1
4. Furosemide+Gd (Gd-DTPA 0,2mmol/kg body weight, injection rate 2,5ml/s and Furosemide 0,1mg/kg body weight)
   Breath-hold 3D gradient echo MRA
   Breath-hold 3D gradient echo MRU
5. Postprocessing

Table 2. Parameters of the MR sequences (for GE 1.5T Signa). Phased-array torso coil. (TE-echo time, TR-repetition time, FA-flip angle, ST-slice thickness, FOV-field of view)

Pulse sequence	TR(ms)	TE(ms)	FA(')	ST(mm)	FOV(mm)	Matrix(mm)	orientation	Scan time
COR T2 SSFSF	2300	80	-	8	36	256/256	coronal	48s
COR T2 SSFSE	1300	200	-	3	36	256/160	obl	16s
AX T1 BH dual echo	160	2,2/4,4	80	8	36	256/128	axial	33s
AX T2 FRFSE	3000	85	-	8	36	256/256	axial	4,07min
AX 3D SPGR Dyn+CM	4,6	1,8	15	5	36	256/160	axial	20sec/phase
URO COR 3D SPGR	150	6	80	8	36	256/128	coronal	20s

agents to enhance both parenchyma and tumours. The most widely used contrast agents are chelates of gadolinium (Gd). Its chemical structure comprises a Gd-ion with a triple positive charge combined with a DTPA derivate, forming a very stable complex. The strongly paramagnetic gadolinium has several effects. It can change (relax) the magnetic state of hydrogen atoms in water molecules; this markedly changes the appearance of tissues, with a high contrast agent uptake in T1-weighted images, causing tissues to appear bright. High concentrations of gadolinium chelates can also induce local changes in the magnetic field (magnetic susceptibility). This is most apparent during the first pass of a bolus of contrast agent after the rapid intravenous injection. On gradient echo T2*-weighted images, this effect is apparent as a darkening of the image in well-perfused areas of tissue.

Gadolinium-DTPA is eliminated rapidly and completely by the renal excretion without tubular reabsorbtion. The half-time of Gd-DTPA in blood is ~90 minutes. More than 91% of the administrated dose is eliminated after 24 hours. The elimination depends only upon the glomerular filtration rate. The renal insufficiency is not a contraindication for the contrast material administration.

The recommended contrast dosage for magnetic resonance imaging of the kidneys is 0.1 mmol Gd-DTPA/kg BW. The administration of contrast material should be mechanical with the use of automatic injector after the correct timing of the bolus injection in order to synchronize the moment of the peak renal artery enhancement with the acquisition of central k-space data.[5]

The intravenous administration of an extracellular paramagnetic contrast material provides a means for imaging the circulation. Dynamic measurements, in which the uptake and washout of contrast in tissues is monitored with time, can assist in the diagnosis and can provide information on vascular permeability and perfusion, by quantifying and analyzing image intensity changes, and fitting these to analytical or model functions. Dynamic information shows the rate at which tissue enhances, and subsequently the rate at which contrast agent washes out. This depends on the delivery of the agent (perfusion), the ability of the agent to leak out of the vasculature (vascular permeability), and the extracellular volume. Usually, a region of interest (ROI) is selected within the tumour, and the software that is provided with the magnetic resonance scanner is used to evaluate the change in signal intensity with time in that ROI.

Technique of MR imaging of the kidneys

Patient positioning and coils

The patient is examined in supine position with both arms lying flat against the body, using a phased-array torso coil to optimize signal-to-noise ratio. Prior the examination patients would be informed about the necessity of breath-holding in some sequences.

Field strength

Presently recommended systems for the performance of MRI of the kidneys with contrast material have the field strength of 0.5 to 1.5T and most published studies using fast GE sequences have been performed on higher field strength systems. The advantage is that the paramagnetic contrast material has a greater effect on the signal due to the increased T1 relaxation time of enhancing tissues at higher field strengths. At the same time the high-field strength machines allow to perform fast techniques, required for the angiographic and dynamic studies.

Imaging protocol

The imaging protocol should be designed for the evaluation of the kidney and the entire upper urinary tract and should include unenhanced and enhanced phases.

Morphological assessment

The imaging protocol for renal tumour staging should include conventional or fast-spin echo sequences in axial and coronal projections for assessing the morphology of both kidney and tumour parenchyma.[6]

T2-weighted sequences

In T2-weighted sequences, hydrous or oedematous structures emit an intense signal. Spin-echo (SE) or fast-spin-echo (FSE) sequences are the T2-weighted sequences most commonly used in MR imaging of the abdomen. COR T2 weighted images using the half-Fourier acquisition single-shot turbo spin echo technique permits in a very short examination time to visualize kidneys, ureters and urinary bladder, giving the possibility for the rough orientation. Usually they are acquired before performing contrast enhanced dynamic measurements (Figures 1, 2a, 2b, 2c).

T2-weighted images are useful in recognizing small cysts only a few millimetres in diameter with high sensitivity.[7] This is an advantage of MR imaging compared with the CT, where the partial volume effect leads to confusion in such kind lesion characterization.

T1-weighted images

The axial T1WI focused at the kidney gives an excellent T1 contrast independent of patient breathing. If »bright« spots (hyperintense lesions in T1) are detected, breath-hold T1 *fat suppressed gradient echo pulse sequences* should be obtained to exclude or confirm the presence of fat lesion. This technique is especially useful in cases of the suspected intratumoural haemorrhage or fat-containing lesions.[8]

Chemical shift can be used as a tool for delineating structures that are surrounded by fat. Out-of phase images can aid in the demarcation of the renal contour, the margin of the adrenal glands, and the liver edge. Gradient-echo images that use out-of phase chemical shift demonstrate dark lines around organs embedded in fat. Those dark lines are created by the phase cancellation of the fat and water signals that exist within the voxels of the lipid-water interface. The width of the dark lines can be accentuated by increasing the field of view. The use of a narrower bandwidth will also increase the chemical sift banding seen on the images (Figures 3a, 3b, 3c).[9]

Chemical shift MR imaging has become a popular technique for diagnosing adrenal adenomas. Benign adrenal adenomas, which are typically composed of approximately 16% lipid based on *in vivo* studies,[10] can demon-

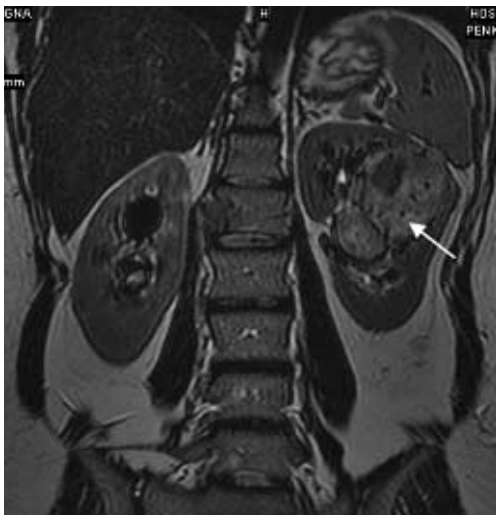
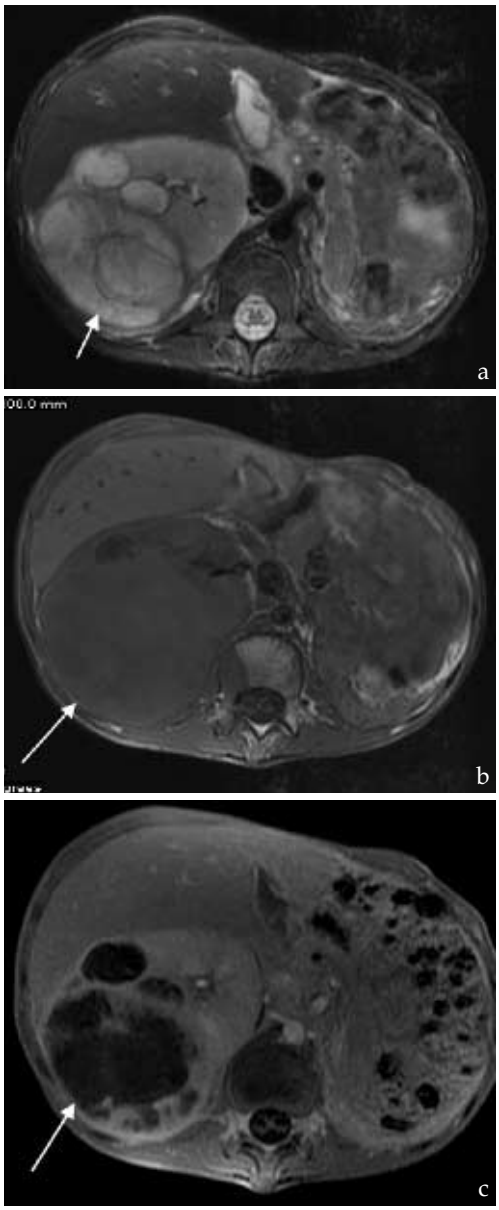
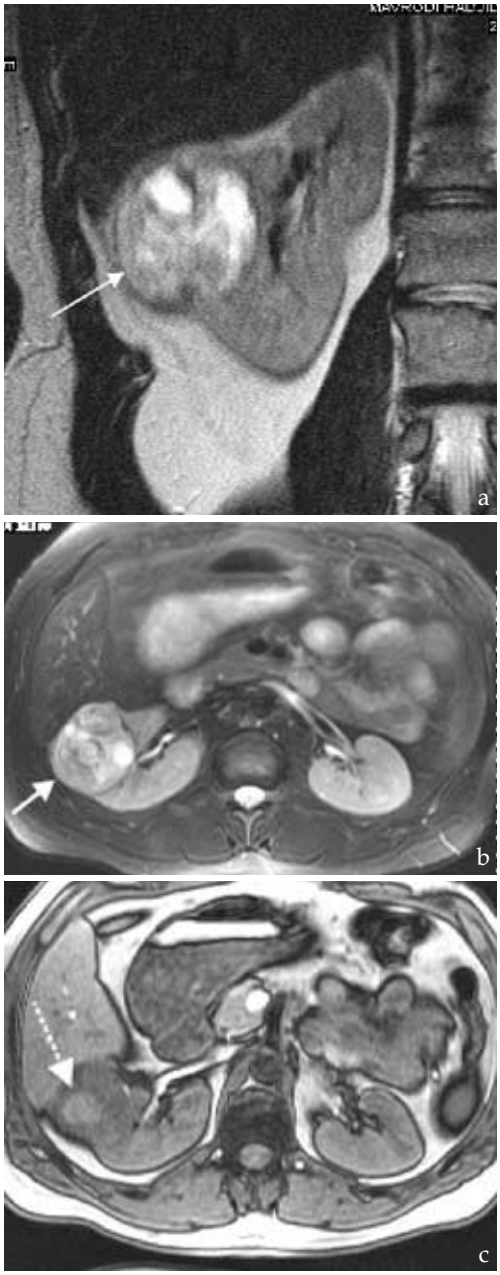


Figure 1. COR T2WI of a female patient with transitional cell renal cancer (arrow) of the left kidney. Note high-intensity bilobulated mass, obstructing the pelvicaliceal system of the kidney.

strate measurable differences in signal intensity when their appearance on in-phase gradient-echo images is compared with that on the



Figures 2a, 2b, 2c. 2WI (a), T1WI (b) and contrast enhanced T1WI (c) in a patient with relapsing Wilm's tumour demonstrating definite spread into the perirenal space (arrow). The structure of the tumour is nonhomogeniuos, highly vascularized with large areas of necrosis.



Figures 3a, 3b, 3c. COR and Ax T2WI of a 34 years old man with renal cancer demonstrate round high-intensity renal tumour, protruding the renal contours and invading the perirenal space (arrow in a and b). AX out-of phase T1 image of the same patient shows a mass invading into the inferior aspect of the liver, as evidenced by the interruption of the dark cortical line (arrow in c.) that demarcates the liver margin (c).

out-of-phase counterparts. A decrease in the signal intensity of greater than 20% within an adrenal mass on out-of-phase images helps to confirm the diagnosis of an adrenal adenoma.[11] Adrenal metastases, on the other hand, typically do not contain any significant lipid elements and will not demonstrate an appreciable change in the signal intensity with in-phase and out-of-phase chemical shift imaging (Figures 4a, 4b).

Combined morphological and functional assessment

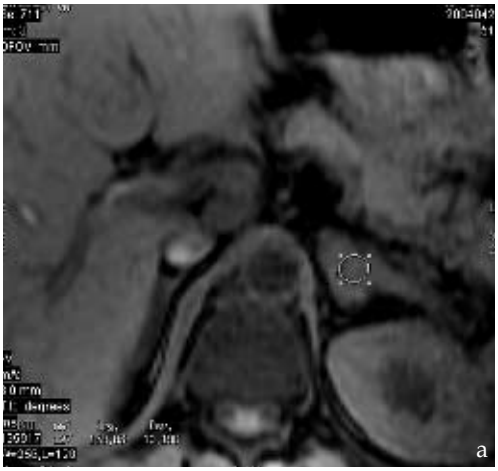
Contrast-enhanced MRI

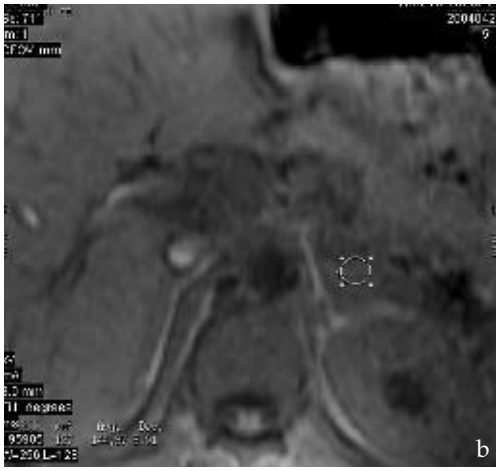
Multi-phase breath-hold 3D volume acquisition is the technique of choice for evaluating renal vessels and dynamic changes in renal parenchyma.[12,13]

Two technical developments are essential to the successful use of fast 3D MR sequence: the availability of high-performance gradient systems as well as dedicated surface coils. The implementation of high-performance gradient has enabled the acquisition of complex 3D sets with ultrashort repetition (TR) and echo (TE) times within a comfortable breath-hold period. The ultrashort TR in conjunction with a relatively high flip angle minimizes the signal of all abdominal tissues. Against this background, structures containing T1-shortening contrast agents can be made selectively visible.[14]

In the 3D technique, the entire part of the body is exited as a volume. This volume can be divided into the so-called partitions, or slices of variable thickness, in any desired plane. 3D imaging allows the depiction of thin slices without gaps in a defined slice profile. Generally a volume block of 150mm with, for example, 30 partitions is used for an examination with axial angulation. The resulting slice thickness is 5mm. The coronal angulation permits the use of a rectangular FOV. The resulting time gain allows the acquisition of a greater number of partitions, optimizing the spatial resolution.

For the purpose of tumor staging MRA is performed in the axial plane, with the top of the volume at the diaphragmatic level and the base below the level of lower renal poles. The volume should extend posteriorly to encompass both kidneys. This large field of view combined with an acquisition matrix of 512





Figures 4a, 4b. AX in-phase (a) and out-of phase (b) T1 images of a 56-years-old man with metastatic clear cell renal carcinoma in the left adrenal glad. No differences in signal are seen on the two images. Metastases generally do not contain fat and do not exhibit the signal loss by chemical shift effects.

in frequency and 128-256 in phase-encoding direction is typically used. The use of multiphase sequence gives the possibility to repeat the series from three to ten times, depending on the suspected pathology.[5]

Angiography for preoperative arterial and venous mapping

The determination of the extent of intravenous tumour growth is of paramount importance, since it affects the operative approach in many cases. Venous involvement is one of the cornerstones of the surgical planning in renal tumours. A few studies have reported the usefulness of MR angiography in the preoperative assessment of venous involvement in patient with renal cell carcinoma, as well in tumour characterization. In the study of J.P. Laissay et al venous diameter enlargement was the hallmark of tumour thrombus, with a sensitivity of 84% and a specificity of 94%. At the same time the use of Gd-enhanced imaging improved the diagnostic yield of morphological data by additional information upon the thrombus enhancement (Figures 5, 6, 7a, 7b).[15]

Serial MR imaging for evaluation of renal parenchyma and tumour vascularity

Regarding the functional evaluation, the kinetics of gadolinium chelates during passage through the kidneys has been described in many reports. In the normal kidney four phases can be distinguished in the transit of the paramagnetic contrast agent through the parenchyma: the cortical, corticomedullary, medullary and excretory phases. For these reasons, the generally accepted guidelines require that dynamic measurements (at least five measurements after CM administration) have a temporal resolution of 20-25sec per sequence. This makes possible the discrimination between pathological processes and surrounding parenchyma, as well as the acquisition of a sufficiently accurate dynamic curve. Researches in this field have established the way in which changes in the kinetics of the

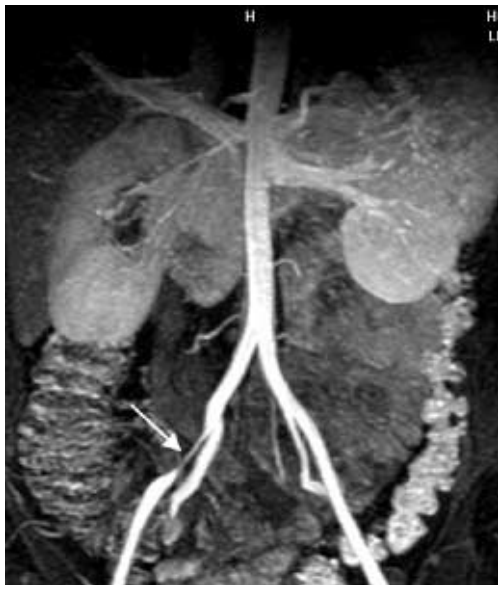


Figure 5. MR angiography in the arterial phase demonstrating gradual compression of the right external iliac artery from enlarged parailiac lymph nodes (arrow).

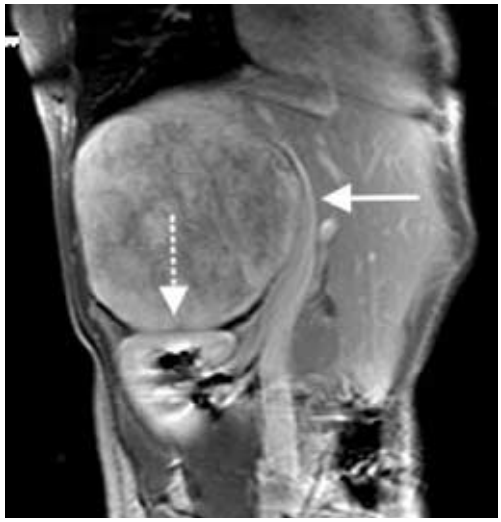
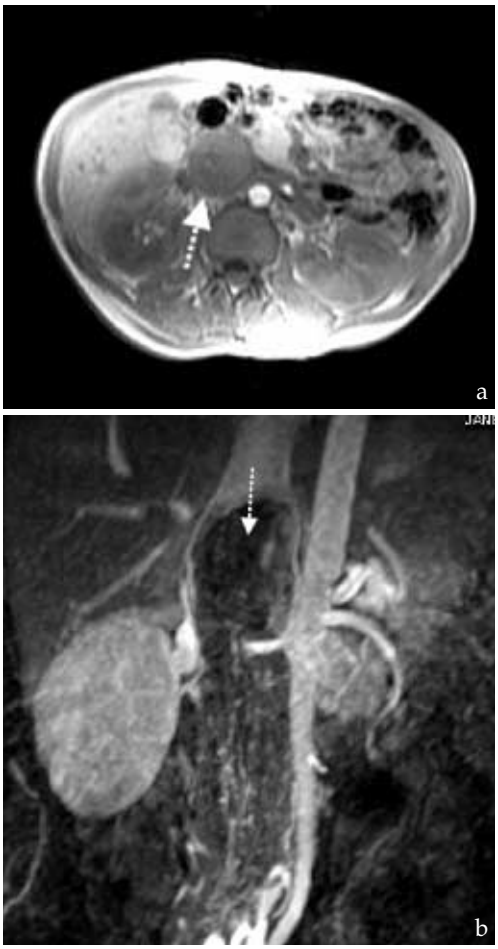


Figure 6. Parasagital T1 contrast-enhanced image of a retroperitoneal tumour in a 17 years-old male showing compression of the vena cava (arrow) and upper right renal pole (punctuate arrow) without invading or obstructing the vein.



Figures 7a, 7b. Postcontrast MR imaging of a patient with large left renal cell carcinoma with thrombus within the left renal vein and IVC. Ax image shows thrombus within IVC (arrow in a.) resulting in a filling defect. Reconstructive image in coronal plane in the same patient shows the large thrombus extending into the vena cava up to the level of hepatic veins (punctuate arrow in b.).

contrast agents in the kidney reflect alterations in the renal function.[16-19] Administration of gadolinium compounds is not contraindicated in patients with the impaired renal function, and it is therefore possible to study renal perfusion and excretion in patients with a chronic renal failure by dynamic MRI.[20]

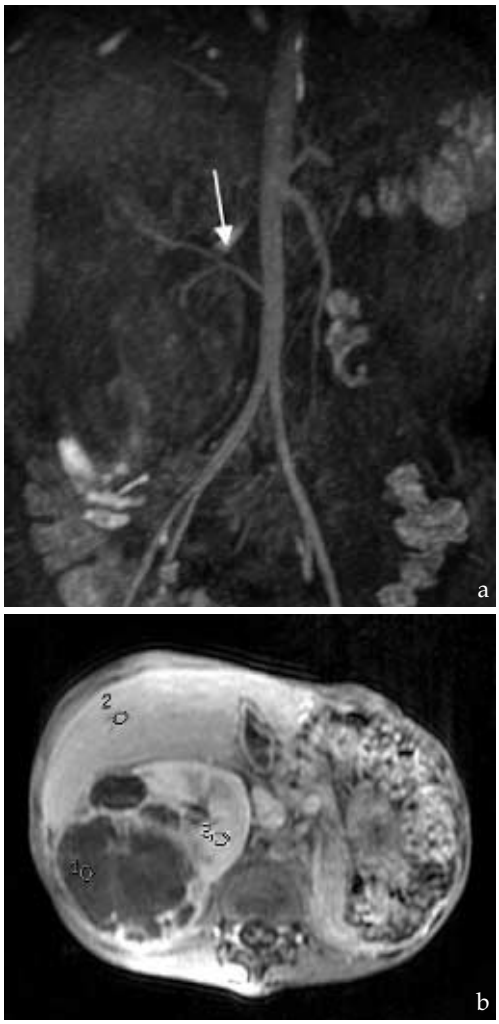
Assessing the corticomedullary phase alone may result in clinically significant errors, since small hypovascular tumours of the renal medulla may be missed since they are not sufficiently enhanced and hypervascular cortical renal cell carcinomas may enhance to the same degree as the normal cortex. During the early nephrographic phase inhomogeneous enhancement of the medulla may be also misinterpreted as a mass lesion. This artifact disappears later in the nephrographic phase.[21] Advantages of the corticomedullary phase include the differentiation of the normal variants of renal parenchyma from renal masses and the better depiction of tumour hypervascularity improving the characterization of solid renal mass lesions.[22]

The nephrographic phase is considered the optimal phase for the detection and characterization of renal masses, in particular of small renal masses, providing both homogeneous enhancement of cortex and medulla and lesion enhancement (Figures 8a, 8b).

In principle, it is possible to perform MRI examinations at any angulation. For dynamic MRU, the coronal slice orientation is generally preferred. The main advantage of the coronal slice orientation is that it permits the selection of a rectangular FOV, which makes to allow the reduction of the slice thickness and the optimization of the spatial resolution to ~2mm. The disadvantages are that the whole volume of the slab is reduced and it is not always possible to visualize the whole abdomen. This is very important in cases of abundant collateral vessels (after CVI thrombosis) or in cases of tumour staging, when the condition of the liver is crucial.

The axial slice orientation is that it makes a good assessment of the whole abdomen, which is of great importance in case of oncologic disease.

The sagittal and parasagittal orientation is not routinely recommended for use. They are, however, employed in the examination of pyelo-ureteral junction pathology and ob-



Figures 8a, 8b. Angiographic phase in a patient with relapsed Wilm's tumour (the same patient as in picture 2) showing a strengthed and displaced right renal artery (arrow in a.). Axial image of the same patient in the parenchymal phase, demonstrating the possibility of comparing the signal intensity levels in different tumor levels and the spared part of the kidney (b).

tained for each individual excretory system having the major advantage of data acquisition of nearly isovolumetric voxels. This is due to the fact that the effective slice thickness can significantly be reduced which increases the image resolution both in the native and MIP images.

MRU for evaluation of collecting system

The term MRU is used for a MR examination which combines different techniques for visualizing the urinary tract.[23] This can be performed with the so-called heavy T2 techniques receiving a signal from fluid-field structures or at the end of contrast-enhanced MR of the kidneys.[24,25] Later the collecting system and the ureters are visualized during the excretory phase as reformatted 3D images. MRU in the excretory phase provides the volume scanning of the kidney and the upper urinary tract within one breath hold. The visualization of the renal collecting system and ureter is significantly improved due to the avoidance of respiratory data misregistration improved resolution and data sets suitable for 2D and 3D reconstructions. The multiplanar reformation creates images similar in appearance to IVU. For this purpose the measurement volume should extend as far posteriorly as possible to encompass the pelvic segment of the ureters and anteriorly to encompass the anterior bladder wall. The top of the coronal volume should be set above the upper pole of the kidneys at the one end and just inferior of the bladder base at the other. In particular cases sagitally oriented images for each kidney could be performed using smaller field of view, reduced effective slice thickness and respective generating, more detailed images. The latter is obtained for each individual excretory system and has the major advantage of data acquisition of nearly isovolumetric voxels, which has a major benefit in the MIP images.

The lumen, the wall, the structures adjacent to the collecting system and ureter as well as the contrast enhancement are assessed on axial and MPR views. When pathology is depicted on axial images the reformatted images are of additional diagnostic value to the axial ones being not only a means to present an abnormality in an easily understandable manner. MRU has the potential to

become a primary investigation in the evaluation on the upper urinary tract; however, its sensitivity for the diagnosis of subtle urothelial lesions is unknown and needs to be evaluated by clinical validation studies (Figures 9, 10).

The evaluation of the images could be done on the original images (a), or on the edited MIP images (b) (Figures 11a, 11b, 11c).

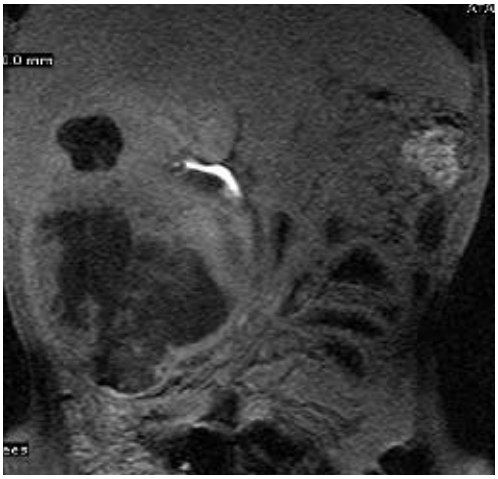


Figure 9. Late pyelographic phase in the patient with relapsing Wilm's tumour showing the invasion of the collecting system and the level of displacement.

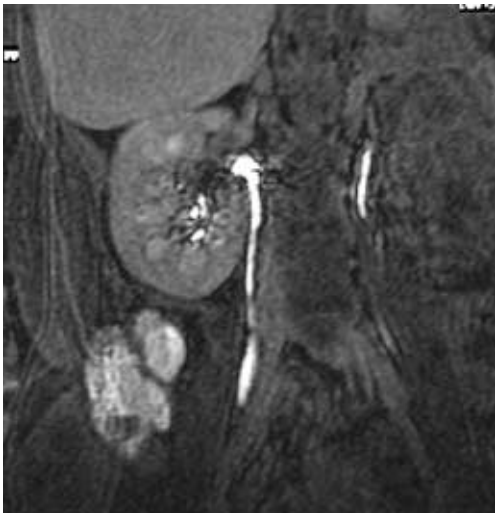
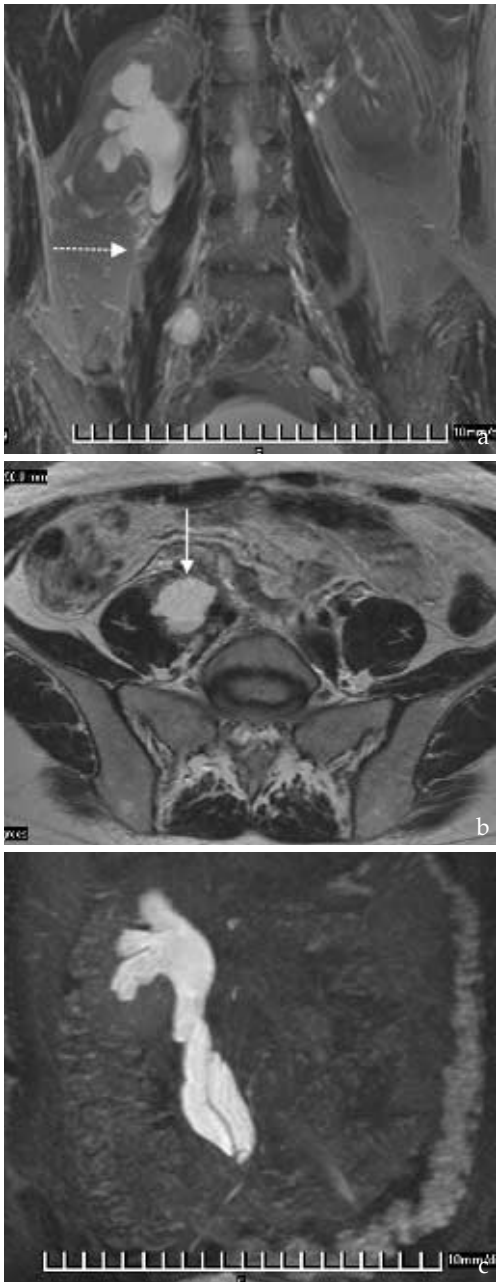


Figure 10. Picture in the late pyelographic phase in the patient with retroperitoneal tumour and the caudal displacement of the pelvi-caliceal system.



Figures 11a, 11b, 11c. Coronal and axial images in a patient with left renal cell carcinoma and retroperitoneal lymph nodes, leading to an obstruction of the right pyelo-ureteral system (arrow in a). Note the necrotic parailiac lymph node on the right side (arrow in b). Edited maximum intensity projection (MIP) of the MR urogram of the same patient (c).

Post processing

Postprocedure processing of the MRA and MRU data could be supplementary obtained by means of a maximum intensity projection algorithm. MIP technique yields a three-dimensional comprehensive view of both kidneys and their vessels. Based on post processed subtraction images in which only image pixels having at least a certain signal intensity are taken into account (threshold value algorithm), the representation of image information gives the impression of a real 3-dimensional angiographic or urographic views.[26] The resultant MIP images with subtraction techniques allow the adequate visualization of the renal vessels - renal arteries, renal veins and inferior vena cava. This form of imaging allows a simpler spatial orientation and is especially suitable for the presentation of suspicious findings.

MPR images allow the three-dimensional view of partial volumes within the abdomen. These are also based on postprocessed subtraction images. In special cases, these clarify the topographic relationship between a suspicious lesion and defined anatomical structures.

3D imaging of tumours using VRT and 3D data sets allow the ascertainment of the size (T1 and T2 staging) and the precise location of the tumour within the kidney as well of relation to the major vessels and the renal collecting system. This influences the decision as to whether nephron-sparing surgery can be performed. In case of tumour resection, the depth of incision can be calculated, the conservation of normal renal parenchyma is ensured and complications are minimized.[27,28]

In case of tumoural lesion, the time-resolved perfusion of the cortex of the lesion could be compared in a curve to the perfusion of the normal cortical parenchyma of the same kidney.

Conclusions

The concept of a comprehensive imaging evaluation has been an evolving theme during the past decade, with the vision of a complete examination that could be performed in a relatively short time. Advances in the rapid MRI technology and its application to oncology imaging have shown that MRI has a tremendous potential for the evaluation of renal tumours and renal disease in general. A comprehensive MR examination including CE 3D MRA, MRU and MR nephrogram offers several potential advantages compared with conventional X-ray studies. By combining all three techniques into an all in one protocol the same information can be obtained as with conventional studies; however, the patient convenience will be improved, the potential morbidity is lower and the substantial costs decrease. The use of contrast-enhanced dynamically collected multiplanar acquisitions permits local, lymph node, and hepatic staging, all within the same examination. At the same time the use of Gadolinium chelates are considered to be safe and can be performed in patients with the impaired renal function.

The combination of different MR techniques in one examination with the simultaneous morphologic and functional analysis appears to be the »Holly Grail« of Magnetic Resonance Imaging. Such kind of technique has several advantages:

1. The duration of the combined MR examination is approximately 30-40min.
2. The all-in one approach examination based on MR imaging provides the good visualization of the renal parenchyma, the renal vascular supply and the collecting system, irrespective of the renal function.
3. The combination of nonenhanced and enhanced MRU gives the possibility of the evaluation of both dilated and nondilated collecting systems.
4. The combination of standard MRI, MRA

and MRU expands the MR evaluation of patients with the oncologic disease of the urinary tract, which is probably the major current indication for the complex examination

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