Advances in uroradiological imaging

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Summary

The development of new imaging techniques and the refinement of established methods in uroradiological imaging is proceeding rapidly. In the last few years several important developments have been implemented in the routine diagnostic evaluation of urological patients. A milestone is the recent advent of multidetector helical computed tomography (CT), enabling the radiologist to provide the clinician with high-quality three-dimensional (3-D) reconstructions of the urological organs. Powerful workstations are an indispensable tool in the post-processing of CT and magnetic resonance imaging (MRI) data. Significant advances in imaging were obtained in the fields of oncological imaging (e.g. prostate MRI and spectroscopic imaging), paediatric uroradiology (e.g. MR urography) and the evaluation of stone disease by unenhanced helical CT.

Oncological imaging

Lesions of the upper urinary tract

Many renal lesions are detected incidentally during ultrasonography; common indications for renal ultrasonography are urological symptoms, e.g. haematuria or flank pain. In addition, abdominal ultrasonography is used routinely for a variety of medical or surgical conditions. The further diagnostic evaluation of a suspected renal mass should lead to multiphasic contrast-enhanced helical CT of the abdomen, including a delayed-phase scan. MRI and CT are equivalent in imaging quality, but MRI is not always available. The recent development of multidetector CT offers fast high-resolution imaging of the kidneys [1]. Arterial-phase imaging gives information about the contrast attenuation of the lesion and parenchyma, the renal arteries and the blood supply to the tumour [2]. Arterial-phase images are obtained ≈20 s after injecting contrast medium. Thin collimation images (1–1.25 mm slices) are necessary for CT angiography of the kidneys, which may substitute for conventional angiography in nearly every case. Helical multidetector CT angiography with a high spatial resolution can even be used to detect small arteries [1]. The volume-data acquisition by helical multidetector CT also enables the radiologist to produce high-quality multiplanar reformations (MPR), maximum and minimum intensity projection, and volume rendering [1].

Three-dimensional (3-D) models and multiplanar reformations of the kidney are especially useful for determining tumour size and location within the parenchyma, and detecting the intrarenal tumour vessels. This is invaluable information for the clinician and can be gained by advanced workstation postprocessing of the acquired volume dataset. Additional information about the renal mass is most important for patient selection and preoperative planning of nephron-sparing surgery. Herr et al. [3] reported a better prediction of the size of RCC by preoperative CT than with the pathological results after partial nephrectomy. Even with multiphasic multidetector CT of high quality, the classification of some lesions remains problematic. In these cases, contrast-enhanced MRI may be helpful for further evaluation (Fig. 1).

MRI can determine the presence of fat in a renal tumour, independent of the presence of haemorrhage, and can therefore often help in differentiating between RCC and angiomyolipoma. Also, some renal lesions cannot be definitely classified as being solid or cystic on helical CT. MRI is better than CT in detecting haemorrhage into a cyst. The presence of haemorrhage is always suspicious for malignancy. Only simple cystic lesions with water-equivalent content should be characterized as being uncomplicated cysts. MRI has certain limitations in evaluating cystic lesions with calcifications, which cannot always be identified. This may lead to underestimation of a malignancy [4].

MR angiography (MRA) is a new technique which is becoming widely accepted. Compared with conventional digital subtraction angiography (DSA), MRA has several advantages: it is not invasive and does not use ionizing radiation, and the gadolinium-based contrast media are not nephrotoxic. MRA of the renal arteries is indicated in patients with impaired renal function and known allergies against iotinated contrast media. MRA offers true anatomical images comparable with conventional angiography. In addition, it enables MPR comparable
with helical CT angiography. Fain et al. [5] reported a sensitivity of 97% and a specificity of 92% for detecting renal artery stenoses by high spatial-resolution MRA with a small field of view compared with conventional angiography. Rankin et al. [6] investigated noninvasive CT angiography and MRA for their suitability for the preoperative evaluation in living-donor kidney transplantation. They showed that both CT angiography and MRA provided sufficient information about the vascular anatomy (Fig. 2). Schoenberg et al. [7] showed that a new multiphase 3-D MRA technique with five acquisitions for examining the renal arteries was better than conventional and traditional MRA. This new 3-D fast technique enables the differentiation of early and main arterial phases, and the early venous phase, thus providing additional information about contrast dynamics comparable with conventional DSA.

The diagnostic evaluation of patients with painless haematuria and suspected upper tract urothelial carcinoma remains difficult. Traditionally, IVU has been the first diagnostic test for evaluating the urinary tract. Many studies have shown that IVU is limited in detecting small renal masses and small tumours of the ureter and renal pelvis. Also, detected lesions have to be further characterized by ultrasonography, contrast-enhanced CT or MRI [8]. MRI and multidetector CT can detect suspicious intraluminal lesions of the upper urinary tract (Fig. 3), but sometimes the results are inconclusive or negative, mostly because the tumour volume is small. The diagnostic value of CT in evaluating tumours of the intraluminal upper urinary tract remains controversial, and often interventional diagnostic procedures are needed [9]. However, initial data about contrast-enhanced multidetector CT urography after injection with frusemide are very promising. Nolte-Ernsting et al. [10] showed that this new technique might offer better clinical potential for detecting early stage intrinsic tumours inside the undilated upper urinary tract. Even without frusemide injection, delayed-phase imaging of contrast-enhanced helical CT can be a useful tool in evaluating the upper urinary tract (Fig. 4).

MR urography has been refined over the last few years; two techniques are currently being used. In the first, heavily T2-weighted pulse sequences are used to obtain static-fluid images of the urinary tract (Fig. 5). This technique is useful in the diagnostic evaluation of the dilated urinary tract. The second technique uses a method comparable with conventional IVU, with the intravenous administration of non-nephrotoxic gadolinium. T1-weighted fat gradient-echo sequences visualize the gadolinium-enhanced excreted urine. An additional injection with frusemide is important for increased excretion and a good distribution of the contrast media in the urinary tract. This technique is feasible for evaluating the dilated and undilated urinary tract, even in patients with impaired renal function [11].

Fig. 1. a, b Contrast-enhanced multidetector CT of a 47-year-old woman with an unclear mass in the right kidney. Images show two large lesions in the right kidney and multiple small cysts in both kidneys. One lesion (S) appears solid (lower left) and shows marked contrast enhancement of 30 Hounsfield units on the delayed-phase imaging (upper left). This is highly suspicious for RCC. The other large mass (C) is cystic and does not show contrast enhancement. Upper left image: axial T2-weighted MRI with fat suppression, showing two lesions in the right kidney. One lesion (S) is solid with intermediate signal intensity. The other lesion (C) has a high signal intensity indicating a content comparable with water. Lower left and right image: axial and coronal T1-weighted fat-suppressed MRI after intravenous gadolinium contrast injection showing a marked contrast enhancement in the solid lesion of the right kidney and no significant enhancement in the cystic lesion. From the imaging characteristics, the cystic lesion was not suspicious for malignancy. The final pathology was RCC and a simple cyst.

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Bladder cancer

Painless gross haematuria is the predominant presenting symptom in patients with bladder malignancies. Such lesions are rarely encountered by chance during radiological examinations. Most exophytic malignancies of the bladder, and of large muscle-invasive tumour, can be visualised easily on CT and MRI (Fig. 6). However, detecting small bladder tumours (Ta and T1), intramural tumour growth and minimal extramural growth remains difficult on CT and MRI. These tumour stages and their detection are still a domain of urological endoscopy. The indication for CT or MRI in a patient with bladder malignancy is in those with a tumour histologically confirmed to be ≥T2, a multicentric in situ tumour or G3, respectively, and a discrepancy between histologically confirmed minor tumour stage (Ta or T1) and clinical, endoscopic or ultrasonographic impression of a higher tumour stage. In these cases CT and MRI can help in staging and exclude possible lymphadenopathy, and may be useful for preoperative planning of radical tumour surgery.

CT staging of a patient with bladder cancer should always include intravenous injection with contrast medium, and subsequent scans of the whole abdomen in the venous and delayed phase. The delayed phase should be acquired ≈ 20 min after injection with contrast medium to ensure optimal filling of the lower urinary tract. Urinary catheters should be clamped before the examination, to ensure sufficient bladder filling.

MRI is more accurate than CT for regional imaging of the bladder and perivesical tissue [12]. New technological developments, e.g. improved MR sequences and MR scanners, may further improve the image resolution and allow faster multislice dynamic imaging, and thereby increase the diagnostic validity [12]. The use of intravesical instillation of superparamagnetic iron oxide particles for high-resolution T2-weighted MRI showed the feasibility of detecting small bladder neoplasms (4 mm) [13]. However, differentiating the layers of the bladder wall and determining the exact tumour depth was not possible [13].

Over the last few years the technique of virtual cystoscopy has been significantly refined and clinically tested. A volumetric dataset is acquired with helical CT or MRI. The images are computer-rendered to generate 3-D images; special software then allows ‘navigation’ through the bladder. One of the current issues is the choice of medium for bladder filling. CT and MR cystoscopy require a sufficient threshold value for surface-rendered images, and therefore the bladder is often filled with air for CT and MR cystoscopy. However, Merkle et al. [14] used a contrast-enhanced multiphase CT scan with delayed-phase imaging for virtual endoscopy of the bladder, and stated that the reconstruction results of the delayed-phase scan were better than those of the arterial and portal venous phase, because there was sufficient contrast filling. One of the major problems of virtual cystoscopy is the differentiation between collapsed bladder wall and possible tumour.
Song et al. [15] used carbon dioxide insufflation through a Foley catheter for virtual CT cystoscopy and showed adequate bladder distension in 24 of 28 patients. Virtual cystoscopy may prove to be feasible for detecting bladder lesions of > 5 mm.

Prostate

Prostate cancer is frequently detected by screening (using a DRE and/or PSA testing). Currently, imaging has no role in detecting prostate cancer but has in staging before therapy. TRUS can help to diagnose prostate cancer by guiding biopsies in patients with abnormal findings on screening. A large prospective trial found no difference in detection between a DRE and TRUS [16]. Grey-scale TRUS is limited for detecting and staging prostate cancer, but promising results for the combination of grey-scale and colour Doppler ultrasonography, with a higher specificity and positive predictive value than grey-scale TRUS alone, have been published [17]. Also, Bogers et al. [18] reported a high sensitivity and specificity (80–85%) for detecting prostate cancer in contrast-enhanced 3-D Doppler ultrasonography of the prostate.

However, in patients with biopsy-confirmed prostate cancer, endorectal MRI is better for staging than TRUS and CT [19] (Fig. 7). In patients with implanted brachytherapy seeds, endorectal MRI is feasible and useful for evaluating seed distribution and to detect treatment-related changes [19].

Over the last decade, spectroscopy of the prostate has been significantly refined: 3-D spectroscopic MRI (MRSI) with a high spatial resolution of the prostate has been developed [20]. MRSI detects the decrease in citrate levels and increase in the ratio of choline/creatinine in prostate cancer cells. MRSI extends the diagnostic evaluation of prostate cancer beyond the morphological information provided by MRI. The combined metabolic and anatomical information provided by MRI and MRSI allows a more accurate evaluation of the presence, location, extent and aggressiveness of prostate cancer. 3-D MRSI is used routinely in two diagnostic centres in the USA and has been evaluated in several clinical studies. Yu et al. [21] examined the addition of MRSI to endorectal
MRI of the prostate alone for evaluating extracapsular extension, and found an improved accuracy for less experienced readers and a reduction of interobserver variability. MRPI could detect a time-dependent loss of metabolites and metabolic atrophy correlating with the therapy duration and decreasing serum PSA levels [22]. Wefer et al. [23] found a similar accuracy of MRI and MRPI compared with biopsy for intraprostatic localization of cancer. MRI and MRPI are more accurate than biopsy in locating tumour in the prostatic apex.

Genitourinary trauma and acute abdomen

Urinary tract injury

Gross haematuria is apparent in many patients with blunt or penetrating abdominal trauma and urinary tract injury, but the absence of haematuria does not exclude an injury to the urological organs. With the development and increasing availability of helical CT, the diagnostic evaluation of these patients has changed. The whole abdomen can be examined in <1 min with contrast-enhanced helical CT. The evaluation of all parenchymal abdominal organs and the retroperitoneum, as well as detecting free fluid and air in the abdominal cavity, is reliable with this technique [24]. The recent advent of multidetector CT with high spatial resolution and extra-fast imaging has further improved trauma imaging. Multidetector CT allows the examination of the trauma patient from the thoracic aperture to the pelvic floor in 20–30 s [1].

A delayed-phase CT scan 15–20 min after injection with intravenous contrast medium can be used to evaluate the renal pelvis, ureter and bladder. Often this scan is combined with retrograde contrast filling of the bladder to exclude bladder rupture [25] (Fig. 8).

An intravenous injection with 50 mL contrast medium in the emergency room 15 min before abdominal CT may provide good intrinsic contrast filling. With this method, the delayed-phase scan may become dispensable and valuable time can be saved. This method is currently under evaluation in our management scheme for multiple trauma.

MRI should not be the first diagnostic choice in managing the patient with trauma, because it is time-consuming and limits access to the patient in the magnet during the examination. Ultrasonography is useful for the fast detection of free abdominal fluid in these patients in the emergency room. However, every patient with abdominal trauma should be examined by contrast-enhanced helical or multidetector CT, because it is more sensitive for organ lesions and perfusion. Ultrasonography is suitable for the routine follow-up of renal parenchymal lesions or retroperitoneal haematoma in the intensive care unit.
**Urethral injury**

MRI is helpful in assessing the presence and extent of anterior or posterior urethral injury, and in predicting the occurrence of complications [26]. Retrograde urethrography is commonly combined with cystography. MRI is helpful in the preoperative planning of delayed reconstruction after urethral disruption.

**Scrotal trauma**

Ultrasoundography is the first choice for examining scrotal trauma; it can help to differentiate between scrotal
Fig. 7. Axial T1-weighted and axial and coronal T2-weighted MR images with an endorectal coil in a 63-year-old patient with histologically confirmed prostate cancer, taken for preoperative staging. The T1-weighted image (left) shows marked intraprostatic haemorrhage after biopsy in the right mid-gland (H). On the axial T2-weighted image (middle), this region shows low signal intensity (H). Because of the haemorrhage, this part of the prostate cannot be evaluated for the presence of cancer. In the left mid-gland to apex there is a region with decreased signal intensity in the peripheral zone (arrows), indicating cancer. No extracapsular extension of tumour growth was seen.

Fig. 8. Contrast-enhanced multidetector helical CT image of a 19-year-old patient with multiple trauma. The image shows normal contrast enhancement of the right kidney. A parenchymal defect (renal laceration) is easily apparent.

haematoma, testicular haematoma or testicular rupture [27]. However, MRI may be suitable for further evaluating testicular rupture; even small ruptures of the tunica albuginea are well depicted on T2-weighted and contrast-enhanced T1-weighted scans [27].

Penile trauma

Traumatic injuries of the penis are rare; in patients with suspected penile fracture, MRI is best for assessing the integrity of the tunica albuginea. On T1-weighted images, the corpora cavernosa and the tunica albuginea are well depicted. In penile fracture, the rupture is detected as a discontinuity of the low signal-intensity tunica albuginea [28]. Additionally, a subcutaneous haematoma is seen at the site of tunica albuginea rupture.

Acute abdomen

Underlying urological conditions are frequently found in patients with an acute abdomen. Flank pain caused by stone disease is a very common symptom in emergency rooms. However, patients with acute pyelonephritis and renal infarction present with similar symptoms. The indication for imaging in acute pyelonephritis is mainly in those patients with suspected complications. Imaging can also be helpful in patients with poorly located pain and unclear symptoms [29] (Fig. 9). Besides ultrasonography, helical contrast-enhanced CT is the method of choice for examining the acute abdomen. Urological diseases such as pyelonephritis and renal infarction are well depicted on helical CT. A helical contrast-enhanced CT scan for renal infarction should include arterial-phase scans for detecting renal artery anatomy and the possible correlation of segmental defects with vascular anatomy [29].

Stone disease

Since the introduction of helical CT, the evaluation of a patient with acute flank pain and suspected stone disease has changed. Many studies have shown that unenhanced helical CT is better than IVU and plain abdominal films. Unenhanced helical CT is fast and does not require the administration of contrast medium [30]. Nearly all ureteric stones can be visualized, regardless of their composition, size or location. Even ‘radiolucent’ stones consisting of pure uric acid, xanthine and cystine are visible on CT images, because of their significantly greater X-ray attenuation than soft tissue [31]. Two exceptions are indinavir stones (in HIV therapy) and pure matrix stones [32]. Katz et al. [33] also showed that a wide spectrum of significant alternative or additional diagnoses.
Pelvic floor imaging

The pelvic floor anatomy is complex; imaging techniques for evaluating congenital pelvic anomalies and pelvic floor dysfunction include MRI with a body, endovaginal or endorectal coil. Conventional examination techniques are endosonography and fluoroscopy. An integrated approach is necessary for the evaluation. For pelvic floor dysfunction, a new dynamic technique termed colpocystorectography has been described. The patient is encouraged to evacuate the filled bladder and rectum within the MRI scanner. This examination is inconvenient for the patient and examiner, but provides useful information about pelvic floor dynamics [36]. Recently, initial results of a preclinical experiment using MRI with an endourethral coil have been published. The performance of the coil was promising and there was a good correlation between urethral coil imaging and histology [37].

MRI can be useful for examining urethral diverticula, because it provides direct visualization of the diverticulum and the surrounding anatomical structures (vagina and bladder base) [26].

For assessing urinary incontinence and prolapse, MRI is becoming increasingly useful because of increased resolution; MRI can depict the anatomical relationship between the pelvic floor compartments, including muscles, urethra, fascia and ligaments. In addition, pathological pelvic conditions, e.g. cystocele, rectocele, prolapse and pelvic floor descent, can be depicted and dynamic examination in the MR scanner is possible [36]. The combination of anatomical information gained on MRI with the results of conventional dynamic fluoroscopic examinations enables the clinic to develop an individual therapeutic approach for the patient, leading to a better clinical outcome.

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Fig. 9. Contrast-enhanced multidetector helical CT of a 39-year-old HIV-positive man with severe diffuse flank and abdominal pain. The indication for CT was his unclear symptoms. The images show severe thickening of the wall of the renal pelvis bilaterally and of the bladder wall (arrows). Although very rare, these findings indicate malignant lymphoma (which was the final pathology).
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Abbreviations: MPR, multiplanar reformations; 3-D, three-dimensional; MRA, MR angiography; DSA, digital subtraction angiography; MRSI, spectroscopic MRI.