Urinary Obstruction, Stone Disease, and Infection

23

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Learning Objectives

- To understand indications for imaging and choice of cross-sectional imaging method depending on pathology
- To identify "high-risk" patients to develop severe and/or chronic urogenital inflammations
- To learn about sequence composition of a "standard" MRI protocol and additional potentially useful functional sequences
- To see the MRI appearance of various acute and chronic inflammatory urogenital pathologies
- To think of the differential diagnosis (e.g., lymphoma or posttransplant lymphoproliferative disorder)

23.1 Background

23.1.1 Uncomplicated Versus Complicated Urinary Tract Infection

Acute infection is mostly diagnosed based on clinical presentation and laboratory tests without imaging examinations [1]. Urinary tract infections are regarded as uncomplicated in otherwise healthy patients without structural or functional urinary abnormalities. Complicated urinary tract infections are accompanied by factors that potentially decrease therapy effectiveness, such as immunocompromission, unusually virulent pathogen, and patient-related factors (Table 23.1). Imaging of uncomplicated cystitis or pyelonephritis is regarded as unnecessary by most authors. In contrary, patients who suffer from complicated urinary tract infections may benefit from imaging [1, 2].

23.1.2 Imaging

MRI plays an increasingly important role in the diagnostic work-up of urological patients as an alternative or complementary imaging of CT. However, on the one hand, the availability of MRI scanners is lower than that of CT scanners, and on the other hand, the cost of an MRI is significantly higher than that of a CT scan. In emergency situations, such as trauma, acute bleeding, or renal colic with suspected underlying urolithiasis, CT is the imaging modality of choice.

MRI examinations usually require more patient cooperation than CT examinations. Non-compliance can significantly affect the image quality and thus the diagnostic confidence.

Moreover, in the first trimester of pregnancy, MRI should only be performed when absolutely necessary and at low-field strengths only (1.5 T or less). Certain questions can only be answered to a limited extent, as contrast agents are contraindicated during pregnancy.

The narrowing of the MRI tube may lead to additional problems in emergency situations, on the one hand, caused by claustrophobia (if necessary, a premedication with an anxiolytic drug may be considered) and, on the other hand, by obesity.

Despite these limitations, owing to the superior soft tissue contrast, MRI can provide useful information as a supplementary modality in the assessment of inflammatory urinary tract diseases.

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J. Hodler et al. (eds.), *Diseases of the Abdomen and Pelvis 2018–2021*, IDKD Springer Series,
https://doi.org/10.1007/978-3-319-75019-4_23

Table 23.1 Complicated urinary tract infection (Patient-related factors)

Complicated urinary tract infection
(Patient-related factors)
• Delayed therapy
• Male
• Childhood urinary tract infections
• Immunocompromised (e.g., HIV)
• Leukemia
• Pregnant
• Elderly patients
• Diabetes
• Failed antibiotic treatment
• Prolonged symptoms

23.2 MRI

23.2.1 Standard Protocol

In clinical routine, there is currently no "universal protocol" as the sequences or the image contrasts can differ between MRI scanners (especially depending on field strength and manufacturers). The examination of the kidneys is performed as a standard procedure in supine position using body coils, which are placed directly on the abdomen.

A typical protocol for the evaluation of structural and inflammatory kidney disease consists of morphological sequences such as T2-weighted sequences with or without fat saturation in different plane orientations and non-contrast-enhanced T1-weighted sequences with or without fat saturation. In this context, most readers prefer the axial and coronal plane directions for the evaluation of the urinary tract. In addition, normally in-phase and opposed-phase sequences ("chemical-shift imaging") are obtained to detect intracellular fat proportions. Increasingly, this "standard imaging" is flanked by functional techniques, which generate information beyond pure morphology (e.g., dynamic contrast-enhanced imaging (DCE) or diffusion-weighted imaging (DWI)).

For most MRI examinations, intravenous contrast medium is injected. After contrast, dynamic axial fat-saturated T1-weighted sequences are acquired in arterial, venous, and later contrast agent phases. In addition to the axial plane direction, a coronal T1-weighted fat-saturated sequence is recommended. If, moreover, inflammatory disease in the course of the ureters is suspected, additional late phases are advisable. These urographic phases are acquired between 10 and 20 min after contrast medium injection. In order to optimize the urographic images, an additional administration of a diuretic or an i.v. water bolus and a parasympatheticolytic may be useful.

23.2.2 Additional Protocols

23.2.2.1 Stone Disease

Concrements have no intrinsic MRT signal and consequently appear hypointense on T1- and T2-weighted images. In addition to T2-weighted sequences, late urographic phases can be used for the detection of concrements in the urinary tract. In the latter, stones may be detected indirectly as a filling defect in the course of the ureter.

23.2.2.2 Diffusion-Weighted Imaging (DWI)

In principle, DWI is a technique which enables the visualization of diffusion properties (= uniform distribution of particles) of water molecules in vivo. The average spatial mobility of a water molecule per time unit is measured in a defined volume. Water diffusion is based on the Brownian molecular motion (= temperature-induced movement of particles in liquids) and can be quantified by measuring the "apparent diffusion coefficient (ADC)." A decrease in the space between individual cells in tissue, e.g., due to cell swelling, leads to reduced mobility of the free water. DWI allows indirect estimations of the cell density; this can be used to differentiate pathologies with increased cell density (e.g., tumors or abscesses). "Zoomed" single-shot echo-planar imaging (EPI)-DWI performed with a small FOV in the phase-encoding direction by employment of two independent radiofrequency transmit channels ("parallel transmit") to generate spatially tailored 2D parallel radiofrequency (RF). RF excitation pulses have been proven useful to increase image quality at 3 T. In clinical practice, DWI should now become an integral part of the standard MRI protocol renal zoomed EPI-DWI with spatially selective radiofrequency excitation pulses in two dimensions [3].

23.2.2.3 Advanced T1-Weighted Contrast-Enhanced Sequences

Isotropic, highly accelerated (e.g., by "compressed-sensing"), dynamic ("4D") post-contrast T1-weighted sequences with a temporal resolution below 10 s may be employed to generate perfusion maps in a "one-stop-shop" approach for the quantitative analysis of various perfusion parameters (e.g., to assess renal function or scarring) aside from high-resolution morphologic images. In this context, radial T1-weighted sequences are particularly useful in patients with impaired breath-hold capabilities as they help to reduce motion-induced artifacts. Sequences that combine speed and radial acquisition will soon be commercially available. To date, the clinical value of these sequences to assess renal inflammatory disease has not been assessed, and limitations include time-consuming image reconstructions that need to be carried out on an external server [4].

23.2.2.4 Blood Oxygenation Level-Dependent (BOLD) Imaging

BOLD imaging is a noninvasive procedure that allows a relative assessment of the oxygen partial pressure in tissue. The signal of BOLD imaging is based on the different magnetic properties of oxyhemoglobin and deoxyhemoglobin and thus allows an indirect estimation of the relative local oxygen concentration. This technique is currently subject of research and has not yet established itself in clinical routine [5, 6].

23.2.2.5 Sodium

In the future, completely new technical approaches could also play an increasing role. In studies, the extent to which sodium imaging is suitable for detecting and differentiating kidney pathologies is investigated. Sodium MRI uses the protons of sodium-23 for imaging instead of the hydrogen proton (H-1) used in the conventional MRI. Sodium nuclei occur much less frequently than H-1 nuclei in the human body. At the same time, they exhibit less favorable physical properties for MR imaging, which makes this process technically very demanding (e.g., the use of own coils and optimized sequences). The technique may also enable to assess kidney function (e.g., posttherapeutic after radiation therapy of retroperitoneal sarcomas). This method has not yet entered clinical routine [7, 8].

23.3 Acute and Chronic Inflammatory Renal Diseases

23.3.1 Spectrum of Kidney Infections

Renal inflammations range from acute to chronic and mild to severe.

Acute pyelonephritis can be diffuse or focal and may resolve or exacerbate to abscess-forming pyelonephritis. Immunocompromission might predispose patients to more severe or even life-threatening clinical courses like emphysematous pyelonephritis. Renal infections can develop into a permanently damaging chronic pyelonephritis or xanthogranulomatous pyelonephritis [1]. Prolonged untreated tuberculosis may lead to scarring, fibrosis, and stricture of the urinary collective system. Immunocompromised patients are particularly prone to fungal infections (mostly *Candida* and *Aspergillus*). Some rare infections include malakoplakia and eosinophilic cystitis (Table 23.2).

Table 23.2 Spectrum of kidney infections

Acute	Chronic	Others
Acute pyelonephritis Focal nephritis Abscess Emphysematous pyelonephritis Papillary necrosis Pyonephrosis	Chronic pyelonephritis Xanthogranulomatous pyelonephritis Malakoplakia Eosinophilic cystitis	Tuberculosis Fungal

23.3.2 Pyelonephritis

Acute pyelonephritis is the most frequent inflammatory change in the kidneys and is usually caused by gram-negative bacteria. The incidence of acute pyelonephritis parallels that of lower urinary tract infections. It occurs around five times more often in females with a steep increase after puberty. The parenchyma often enhances inhomogeneously, especially in the nephrographic contrast medium phase, with wedge-shaped zones of lower contrast as an indication of an inflammatory process. Unfortunately, a "striated nephrogram" is unspecific and can also be present in other conditions like contusion as well as obstruction or renal vein thrombosis. Diffuse acute pyelonephritis can lead to renal enlargement and poor enhancement of the parenchyma, absence or reduced excretion of contrast, and fat imbibition in fat-saturated T2-weighted sequences as a sign of inflammation.

MRI is superior to CT in the detection of nephritic components since the inflammatory changes in the (high) b values can present as signal elevations by means of DWI or as corresponding reductions of the ADC [9]. Furthermore, pus can be detected in the kidney globule system (the signal behavior is also signal elevation in b-value images and ADC reduction corresponding to dark areas on the ADC map), although differentiation from tumor or blood coagulation is often impossible (Fig. 23.1).

In the protracted course of pyelonephritis, the renal parenchyma may become scarred and lose function. Chronic pyelonephritis can also be triggered by urine infections in childhood, reflux, or frequent infections. MRI shows polar scars with underlying calyceal distortion and atrophy as well as hypertrophy of healthy parenchyma. Fetal lobulations can be discriminated by depressions located in between calyces rather than overlying calyces. Lobar infarctions are distinguished by absence of calyceal involvement [1].

23.3.3 Abscess

Abscesses of the kidneys usually develop in the context of pyelonephritis, when several small abscesses fuse. All ages can be affected, and there is no recognized gender predilec-

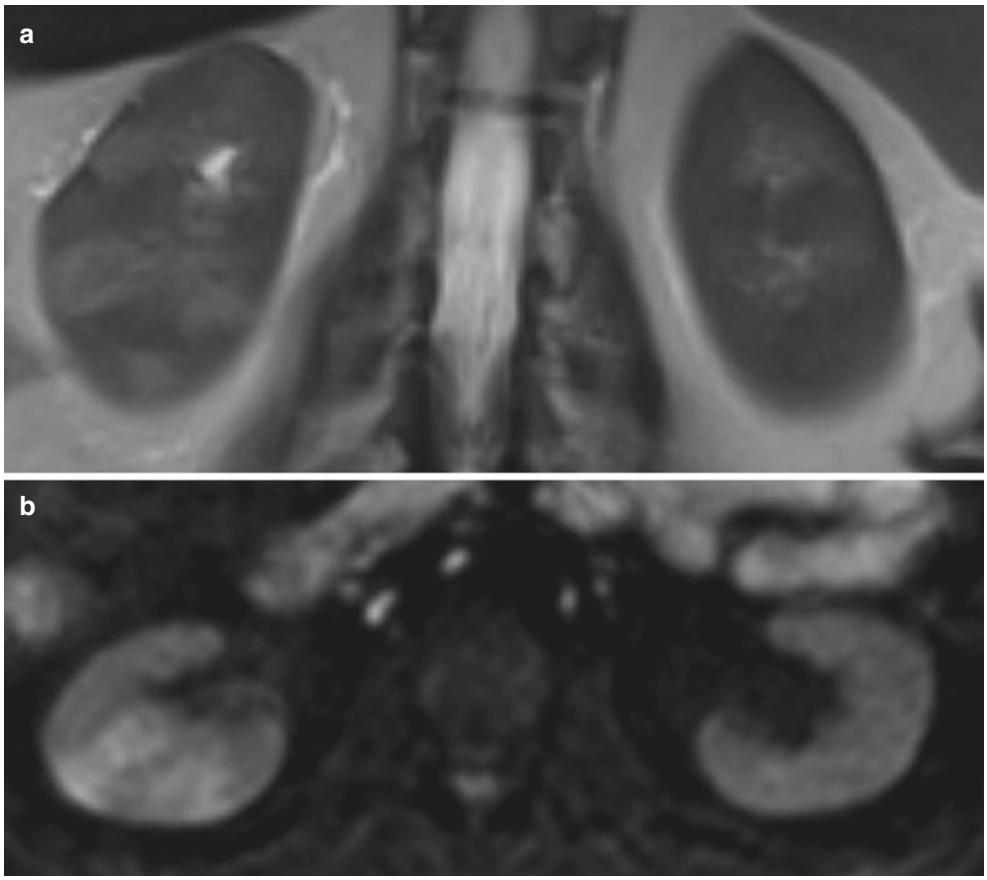

Fig. 23.1 A 54-year-old female patient presenting with fever and abdominal pain. Coronal T2 haste (**a**) depicting wedge-shaped areas of increased signal intensity in the renal parenchyma and organ enlargement. Fluid imbibition of the surrounding fat tissue is also seen. High b-value DWI (**b**) shows corresponding signal elevations in the affected areas

tion. Predisposing factors are diabetes and vesicoureteral reflux. Peripheral rim enhancement is frequently seen in contrast-enhanced T1-weighted MRT sequences. Abscesses may also contain air inclusions, for the detection of which CT is significantly more sensitive than MRI; in the latter air can only be detected indirectly as areas of signal loss. However, MRI allows a reliable detection of kidney abscesses, especially through the implementation of DWI into clinical routine, and is the imaging method of choice in case of unclear findings. Differentiation from renal cell carcinoma or lymphoma can, however, be difficult in some cases. In particular, the patient's history as well as short-term follow-ups may help.

23.3.4 Pyonephrosis

Pyonephrosis is an infection of the kidney which leads to pus deposition in the upper collecting system which can progress to obstruction. The most likely cause is concrements, but tumors or fibrotic changes can also trigger pyonephrosis. A contrast medium level in urine above pus is indicative of pyonephrosis. Since pyonephrosis is an emergency, which can be diagnosed well by means of CT, MRI is used less frequently.

23.3.5 Xanthogranulomatous Pyelonephritis

Xanthogranulomatous pyelonephritis (XPN) is a chronic granulomatous disease of the renal parenchyma, in which the parenchyma is progressively replaced by fat-containing macrophages, other inflammatory cells and cell detritus. Recurrent *E. coli* and *Proteus mirabilis* infection affecting middle-aged females and rarely diabetes are associated [10, 11]. In the overwhelming majority of cases, this inflammatory change arises from a chronic urinary obstruction, such as a ureteral constriction. In most patients (90%), a staghorn calculus is found. Atypical characteristics comprise lack of calculi (10%), focal instead of diffuse involvement (10%), and renal atrophy instead of enlargement. Chronic inflammation may develop into fistulae formation to adjacent organs. XPN is usually one-sided. Ureteral or renal pelvic stones can often be detected only unilaterally in affected patients. In addition to ureteral stones, however, subpelvic ureteral stenoses and ureteral masses may also be responsible for the chronic urinary accumulation.

The more frequent generalized form of the XPN shows the image of an extended renal pelvis and rarefied renal parenchyma with the tissue consisting of xanthoma cells (lipid-containing macrophages). This is also described as the "bear claw." In addition, the perirenal fat tissue exhibits an inflammatory co-reaction, which is characterized, in particular, by fluid collections.

MRI is particularly useful in patients with chronic renal dysfunction leading to renal impairment. The fat-containing cells appear iso-hyperintense in T1- and T2-weighted and a signal decrease is seen in fat-saturated sequences.

The diagnosis of the focal form of XPN is often difficult, whose appearance resembles that of renal cell carcinoma. In these cases, histologic confirmation of the diagnosis must be obtained.

23.3.6 Tuberculosis

Renal tuberculosis arises from hematogenous dissemination of the disease. In about 50% of the patients, lung involvement cannot be detected. Caliectasis is seen in early stages in urographic phases with a feathery contour; in the protracted course, a "phantom calyx" or a cavity communicating with a malformed calyx can be present [1]. Later, the granulomas coalesce forming mass-like lesions (tuberculoma) which may rupture into the pelvic collective system. Fibrosis leading to infundibular stenosis can also occur. The end stage is characterized by a shrunken ("putty") and/or calcified kidney or an enlarged sac with caseous material ("case cavernous-type autonephrectomy"). Involvement of the ureters is associated with wall thickening with strictures and shortening of the ureters. Bladder involvement leads multiple diverticula and organ contraction [1].

23.3.7 Fungal Infection

Immunocompromission in patients with HIV, hematooncological diseases, or diabetes is the main risk factor for fungal infection of the urinary tract that is mostly very severe and potentially life-threatening. The most common organisms found are *Candida* and *Aspergillus* which are usually acquired by hematogenous spread or urinary tract infection [1]. Multiple renal abscesses and striated nephrogram can be seen indicating acute pyelonephritis. Irregular defects in the collecting system may correspond to conglomerations of fungal hyphae and fungal balls. Fungal infections with mucor are rare, in which vessel invasion resulting in infarctions with high mortality can be present. Diffuse punctate calcifications, barely visible on MRI, in the kidneys or organs of the reticuloendothelial system can be indicative of a *Pneumocystis carinii* infection in HIV patients.

23.3.8 Stone Disease

MRI is the cross-sectional imaging method if, in case of a negative result of CT regarding the presence of calculi, a secondary imaging of the urinary tract is necessary to assess other soft tissue-related (e.g., urogenital malignancies) causes of urinary obstruction. Due to the low proton content, calculi have no MRI signal and can thus only be detected indirectly as a signal-free lesion. In T2-weighted sequences or contrast-enhanced MR urography, filling defects appear as indirect indicators for a calculus. A "perinephric imbibition," that is, fluid around the kidneys or ureters, can often be observed.

23.4 Retroperitoneum

23.4.1 Retroperitoneal Fibrosis

Retroperitoneal fibrosis, often referred to as Ormond's disease, is a probably autoimmune, in some cases, medically mediated chronic inflammation in the retroperitoneum which leads to an increasing fibrosis of the structures located there (Fig. 23.2). Correspondingly, in the majority of cases, the

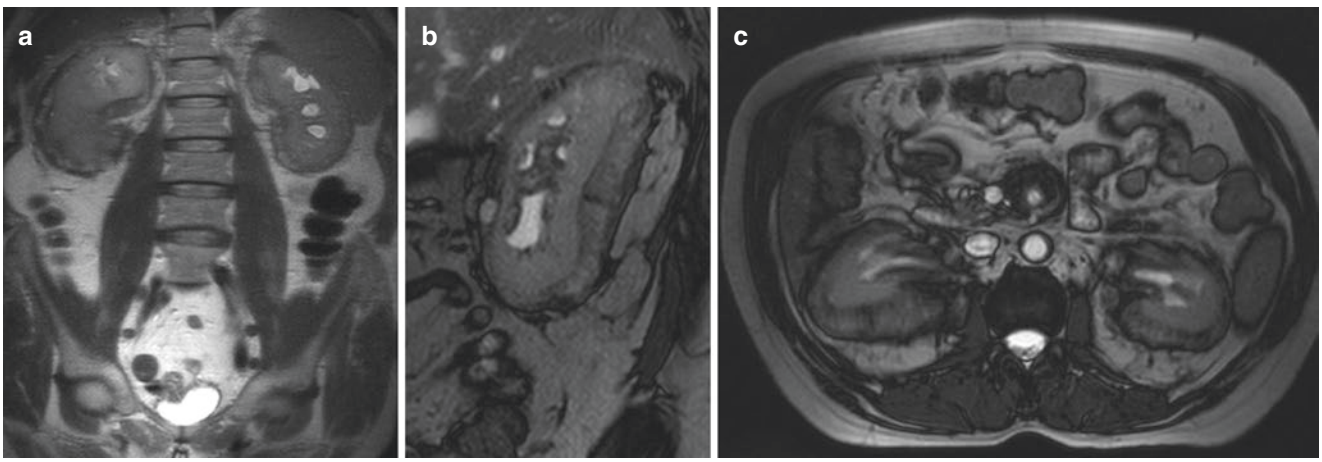

Fig. 23.2 Coronal (**a**), sagittal (**b**), and axial (**c**) T2-weighted images showing a rare case of entrapment of both kidneys by histopathologically proven retroperitoneal fibrosis leading to hydronephrosis

ureters running here are also affected. The fibrotic tissue, which usually spreads out cranially and caudally starting at the level of the lower lumbar spine, can be directly visualized with sectional imaging. A pannus-like growth around the aorta, iliac vessels, and ureters is typical. The ureters are displaced in a characteristic manner to the medial direction. The middle third of the ureter is most frequently affected, but all ureteral sections may be involved. In the regions surrounding the fibrotic tissue, a stenosis of the ureters with a consecutive dilatation of the upper sections can occur. Contrast-enhanced images indicate the activity of the inflammation since a strong contrast agent uptake of the fibrotic tissue indicates active inflammation.

23.5 Inflammations of the Bladder

23.5.1 Bladder Infection

The detection of an inflammatory bladder wall change is a diagnostic challenge, since it is mostly indicated only by an irregular thickening, possibly with an inflammatory reaction of the adjacent fat tissue. However, this is a primarily unspecific finding and initially does not permit a reliable differentiation between malignancies, benign inflammatory changes, or posttherapeutic changes. Therefore, it is absolutely necessary to take into account the clinic presentation, the history of the patient, and the further development of the patient's disease for a differential diagnosis. In MRI, high-resolution sequences for assessing the bladder wall or DWI can help resolve the diagnostic dilemma.

Another factor which affects the wall thickness of the bladder is the filling state. False-positive, pathological conditions can be simulated in a nearly empty bladder. In order to achieve a comparable filling state and to increase the detection of a potential tumor infiltration of the bladder wall, filling of the bladder is possible via a catheter with dilute contrast medium before an MRI examination. However, from a practical point of view, it should be noted that filling of the urinary bladder during a longer examination can lead to a reduced image quality in case of movement artifacts due to the urge to urinate.

Bladder infections often appear as nodular, irregular wall thickenings of the urinary bladder, since these can cause a bullous edema of the urinary bladder wall. Chronic infections, on the other hand, can lead to fibrotic changes with a subsequent contraction of the bladder wall.

Cystitis is defined by a bacterial count above 100,000 per mL urine and is most frequently caused by *E. coli*. In sectional imaging, this often impresses by a wall thickening of the urinary bladder. A rare, life-threatening form of cystitis found in diabetics and immunosuppressed patients is emphysematous cystitis. This shows gas accumulations in the bladder wall, which can expand into the ureter.

Likewise in diabetics the candida infection of the bladder is found. The fermentation of sugars in the urinary bladder can lead to detectable air, sometimes also to fungus balls.

In irradiated patients, radiation cystitis may occur. Here, in the acute phase, there is often a wall edema and hemorrhage. In the long term, ulceration, fibrosis, and shrinkage can develop. In imaging, the changes are often unspecific.

23.5.2 Schistosomiasis

Schistosomiasis, also referred to as bilharzia, is caused by parasitic worms. Over 200 million people are infected, with the majority in Africa. It is a major health concern in rural areas of developing countries predisposing individuals to squamous cell carcinoma and urothelial carcinoma. The infection generally occurs in the bladder but can spread to the ureters and kidneys via reflux. In the acute phase, nodular bladder wall thickening is seen in urography or MRI. Dystrophic, typically curvilinear calcifications, best seen on CT, in the bladder wall or ureter are common findings and are caused by calcified dead ova. Typical additional appearances are strictures of the ureters or reflux.

23.5.3 Fistula

Fistula formation can be attributed to various underlying pathologies. The most common cause of fistula in Europe is a secondary fistula in Crohn's disease. In smaller fistulae, the only clinical indicator can be a chronic cystitis. Frequently, larger fistulae lead to air or feces excretion via the urine. In MRI, fistula detection can be achieved directly (by filling the fistula with contrast medium) or indirectly (only by showing the connection of two structures or by air detection in the fistula). For fistula detection MRI is superior to CT, since the fistulae can be detected relatively specific, on the one hand, via T2-weighted sequences with fat suppression and after contrast agent application in fat-saturated T1-weighted sequences. Furthermore, MRI can be used to detect a concomitant abscess via diffusion-weighted imaging with high specificity. A direct (via a catheter) or an indirect (urographic late phase) filling of the urinary bladder can be performed. Depending on the localization of the presumed fistula, rectal contrast can also be helpful, although from a practical point of view a simultaneous filling does not appear to be useful (possibly at different time points).

23.6 Differential Diagnosis

23.6.1 Lymphoma

Retroperitoneal lymphomas are an important differential diagnosis of both, abscess-forming inflammatory disease of the kidneys and Ormond's disease. Renal lymphomas appear T1-hypointense and T2-iso−/hyperintense to normal parenchyma with poor enhancement relative to healthy renal tissue and may mimic acute pyelonephritis. Typically, renal lymphomas are associated with restricted diffusion and extremely low ADC values similar to those of abscesses (Fig. 23.3).

In renal transplants posttransplant lymphoproliferative disorders (PTLD) are quite common and an important differential diagnosis to abscess-forming pyelonephritis and graft-versus-host disease.

Retroperitoneal lymphomas, in contrast to retroperitoneal fibrosis, show a rather mass-forming growth, and structures (e.g., ureters) are rather laterally displaced. In doubt, CT can be used to guide biopsy, since the diagnosis of retroperitoneal fibrosis is ultimately made by means of histopathology, despite typical image criteria.

23.6.2 Posttherapeutic Change

Patients with gynecologic tumors and rectal or prostatic cancers are often treated surgically and/or with chemoradiation, which can lead to ureteric strictures. The ureter may be injured in the process of pelvic surgery or transected, potentially causing hydronephrosis or urinoma. Strictures or fibrosis leading to ureteric obstruction is common, as well as bowel and urinary tract fistulae. Lymphoceles may lead to an external compression of the ureter and/or bladder.

Take-Home Messages

- Sectional imaging, MRI in particular, may be useful in complicated urogenital infections.
- Clinical history of patients may help to differentiate certain pathologies and to identify "high-risk" patients.
- Acute and chronic inflammatory changes can be assessed with CT and MRI; MRI is possibly with greater significance in some differential diagnosis,

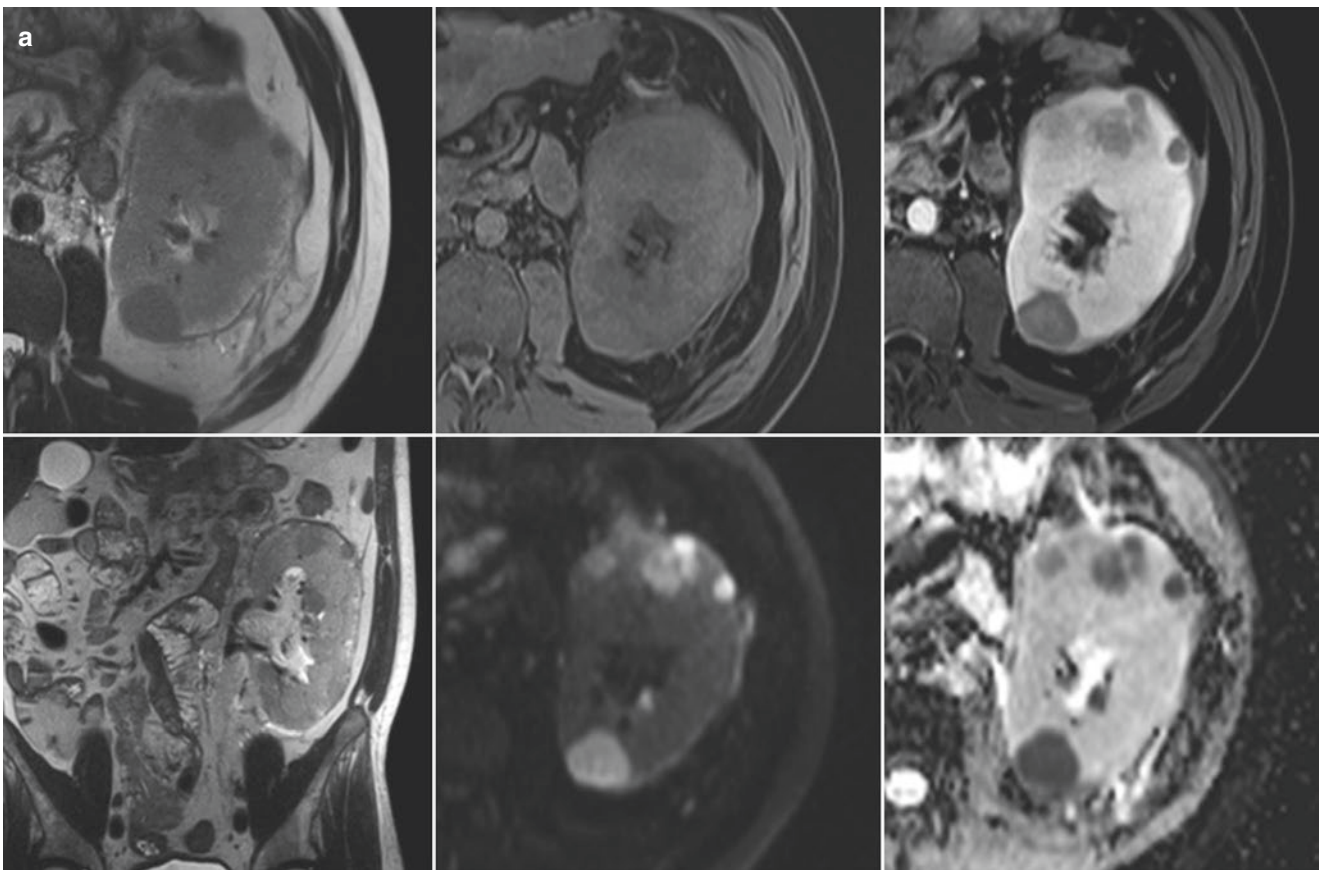

Fig. 23.3 A 35-year-old male patient with focal T2-hypointense/T1-isointense lesions showing poor enhancement. Lesions display very high signal on high b-value DWI and significantly reduced ADC values (**a**). Lymphoma was diagnosed based on histopathology. Patient responded to chemotherapy, which is indicated by increase of ADC values and decrease of signal on high b-value images (**b**)

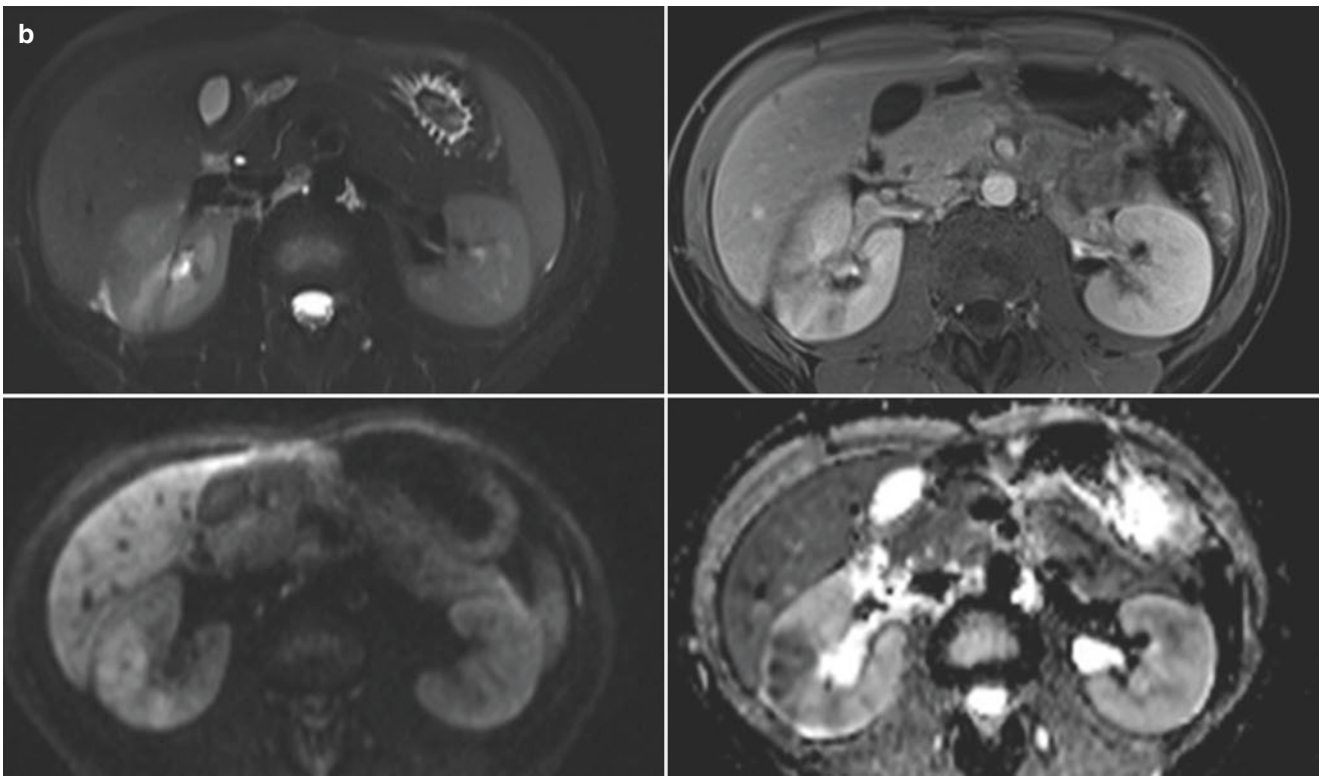

Fig. 23.3 (continued)

whereas CT offers the possibility of direct intervention, e.g., installation of abscess drainage.

- Standard sequences should be accompanied by functional imaging (e.g., DWI).
- CT is the modality of choice for imaging of urolithiasis; MRI may help in the further work-up of certain patients (e.g., to rule out malignancies if no calculi are detectable).
- In the investigation of retroperitoneal or ureteral pathologies, urographic phases are useful.
- Lymphoma should be considered as a differential diagnosis of lower and upper urogenital tract inflammation.

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