Eur. Radiol. (2001) 11: 1878–1889
DOI 10.1007/s003300101011

Gerhard H. Mostbeck
Thomas Zontsich
Karl Turetschek

Ultrasound of the kidney: obstruction and medical diseases

Published online: 12 July 2001

*Categorical Course ECR 2002

G. H. Mostbeck (✉) · T. Zontsich
Department of Radiology,
Otto Wagner Spital SMZ Baumgartner
Höhe, Sanatoriumsstrasse 1,
1140 Vienna, Austria
E-mail:
gerhard.mostbeck@ows.magwien.gv.at
Phone: +43-1-91 06 04 62 08
Fax: +43-1-91 06 04 98 31

K. Turetschek
Department of Radiology,
University of Vienna Medical School,
Währinger Gürtel 18–20, 1090 Vienna,
Austria

Abstract Ultrasound has emerged as the primary imaging modality in conditions where either renal obstruction or renal medical disease is suspected on the basis of clinical and laboratory findings. In urinary tract obstruction, pathophysiologic changes affecting the pressure in the collecting system and kidney perfusion are well understood and form the basis for the correct interpretation of real-time US and color Doppler duplex sonography (CDDS). Ultrasound is very sensitive for the detection of collecting system dilatation ("hydronephrosis"); however, obstruction is not synonymous with dilatation, as either obstructive or nonobstructive dilatation may be present. To differentiate these conditions, CDDS with measurement of the resistive index (RI) in the intrarenal arteries is extremely helpful, as obstruction (except in the peracute stage) leads to intrarenal vasoconstriction with a consecutive increase of the RI above the upper limit of 0.7, whereas nonobstructive dilatation does not. Diuretic challenge to the kidney may further enhance these differences in RI between obstruction and dilatation. Based on these findings, the present value of US and CDDS in the assessment of the patient with flank pain or renal colic is suggested, especially with respect to promising results for spiral CT and based on cost analysis. In renal medical disease, distinguishing different pathologic conditions using gray-scale US and CDDS (RI) criteria is still very difficult. Nevertheless, US is the fistline imaging modality in the patient with renal insufficiency.

Keywords Ultrasound studies · Kidney · Hydronephrosis · Obstruction · Parenchymal disease

Introduction

Ultrasound imaging is a commonly used technique in the diagnosis of renal obstruction. In previous years US was limited to assess renal anatomy and pathologic changes of the collecting system which are characteristic, although not specific, for obstruction. During the past decade, color Doppler duplex sonography (CDDS) has allowed assessment of alterations of renal perfusion induced by collecting system obstruction noninvasively by interrogating intrarenal arteries or showing general renal perfusion in color; thus, real-time US and Doppler techniques provide not only morphologic, but also functional, information on altered blood flow and urinary flow in patients with urinary obstruction.

In the same way, there has been US evolution in the assessment of the patients with renal medical disorders. In addition to real-time US parameters, such as renal length, cortical echogenicity, or distinctness of the corticomedullary boundary, Doppler techniques demonstrate alterations in renal perfusion; thus, various, although unspecific, parameters are available to assess renal parenchymal diseases.

Table 1 Etiology of urinary tract dilatation. *UPJ* ureteropelvic junction. (Adapted from [6])

Obstructive dilatation, frequently unilateral	
	Stone, papillary necrosis, clot, tuberculous debris
	UPJ obstruction, crossing vessel
	Inflammatory stenosis of the ureter
	Neoplastic infiltration/compression retroperitoneum and pelvis
	Primary neoplasm pelvicocalyceal system and ureter
	Bladder neoplasm
	Mobile kidney, ureteral sling
Obstructive dilatation, frequently bilateral	
	Infravesical urinary obstruction
	Neurogenic bladder
	Bladder stone, clot in the urinary bladder
	Retroperitoneal fibrosis
Nonobstructive dilatation, frequently unilateral	
	Vesicoureteral reflux
	Following relief of obstruction
	Pregnancy
	Megacystis-megaureter syndrome
Nonobstructive dilatation, frequently bilateral	
	Full bladder
	Urinary tract infection

This article reviews the capabilities and limitations of real-time US and CDDS in the diagnosis of urinary tract obstruction and renal parenchymal diseases. For space reasons, this article does not cover specific aspects of urinary tract obstruction in infants and children, as well as the assessment of renal allografts.

Obstruction

What is urinary tract obstruction?

There is clear understanding that blockage of urine flow constitutes the key factor in obstruction. Nevertheless, there is difficulty in defining urinary tract obstruction precisely [1, 2]. Accordingly, there may arise some confusion if terms such as obstruction, dilatation, hydronephrosis, or urine flow blockage are used similarly. In addition, the semantics of US may lead to further confusion as well. A dilated collecting system is referred to as hydronephrosis; however, hydronephrosis in clinical and sonographic practice implies at least some form of obstruction. This information cannot be reliably provided by real-time US. From an anatomical, pathophysiologic, and clinical point of view, urinary tract obstruction may be acute or chronic, unilateral or bilateral, or complete or partial. It may be generalized, thus affecting the whole pelvicalyceal system of one kidney or localized, whereby only one or the other calyx may be obstructed by stone, stricture, or neoplasm.

Following Whitaker [3], obstruction is defined as “a narrowing such that the proximal pressure must be raised to transmit the usual flow through it.” As also pointed out by others [1, 3], three elements are of concern: (a) a lesion blocking urine flow; (b) the pressure in the collecting system; and (c) the urine flow. As shown by this pressure–flow–resistance relationship, there is elevated pressure in the collecting system in acute obstruction; however, dilatation of the collecting system, the hallmark of real-time US findings in obstruction, might only be one consequence of this pathophysiologic process in “urinary obstruction” but should not be used synonymously with obstruction.

Dilatation–obstruction

Dilatation of the renal collecting system is a finding commonly encountered in US imaging of the kidneys. The differentiation of true renal obstruction from nonobstructive dilatation is crucial [4, 5]. The differential diagnoses of a dilatation of the collecting system are listed in Table 1 [6].

Pathophysiology

Acute [7, 8, 9, 10] and to a lesser degree chronic [11] unilateral obstruction have been extensively investigated in order to understand underlying pathophysiology, clinical significance, and outcome.

With acute complete obstruction, there is an elevation of the intrarenal collecting-system pressure; however, with continuation of complete obstruction, this elevated pressure returns soon to normal, even if there is no decompression via pyelosinus extravasation of urine due to rupture of a calyceal fornix [1, 2, 7, 8, 9, 10].

One important factor possibly responsible for the reversible and irreversible damage to the kidney in acute obstruction are alterations in renal blood flow [1, 2, 7, 8, 9, 10, 11]. These hemodynamic changes are well documented and basic understanding is necessary in order to correctly interpret CCDS findings, especially the resistive index (RI). In the first 2–4 h after obstruction, there is a very transient increase in renal blood flow likely due to afferent arteriolar dilatation [1, 2, 7]. It has been speculated that this initial increase in renal blood flow may represent an attempt of the kidney to maintain a constant glomerular filtration rate [2]. Three to 5 h after urinary obstruction, there is an elevation of intrarenal resistance mediated by various circulating vasoconstrictor factors [1, 2, 7]. The third phase, 18–24 h after obstruction, is profound renal vasoconstriction resulting in reduced renal blood flow [1, 2, 7], even if the pressure in the collecting system has returned to normal values. From this stage on, increased renal vascular resistance and vasoconstriction may be the key factors for irreversible renal damage. It is neither precisely defined when acute obstruction becomes chronic nor are the pathophysiological changes in partial obstruction as well documented as those for complete obstruction [1, 2]; however, it is well described that even after a long recovery period after relief of obstruction the kidney will never again reach its original level of function [1]; thus, diagnosis of obstruction is crucial in order to allow the kidney to gradually achieve its new, lower level of function, once obstruction has been relieved [1].

Real-time US

Conventional real-time gray-scale US provides excellent anatomic information regarding dilatation of the collecting system. Generalized dilatation presents as dilatation of the renal pelvis which communicates with dilated calyces. Classically, dilatation is scored from grades 1 to 3, where grade 1 represents minimal calyceal dilatation, grade 2 moderate, and in grade 3 there is severe dilatation with thinning of the renal cortex (Figs. 1, 2, 3, 4, 5, 6) [12]. Additional findings may be ureteral dilatation. The acutely obstructed kidney may be enlarged compared with the normal contralateral kidney (difference in size of more than 10% in terms of the longest diameter as assessed by US).

Once dilatation of the collecting system has been diagnosed by US, the following questions are to be answered by examining both kidneys, pelvicalyceal systems, ureters, and the urinary bladder by percutaneous US:

1. Is this dilatation with or without obstruction?
2. If there is obstruction, what is the cause and the level of obstruction?

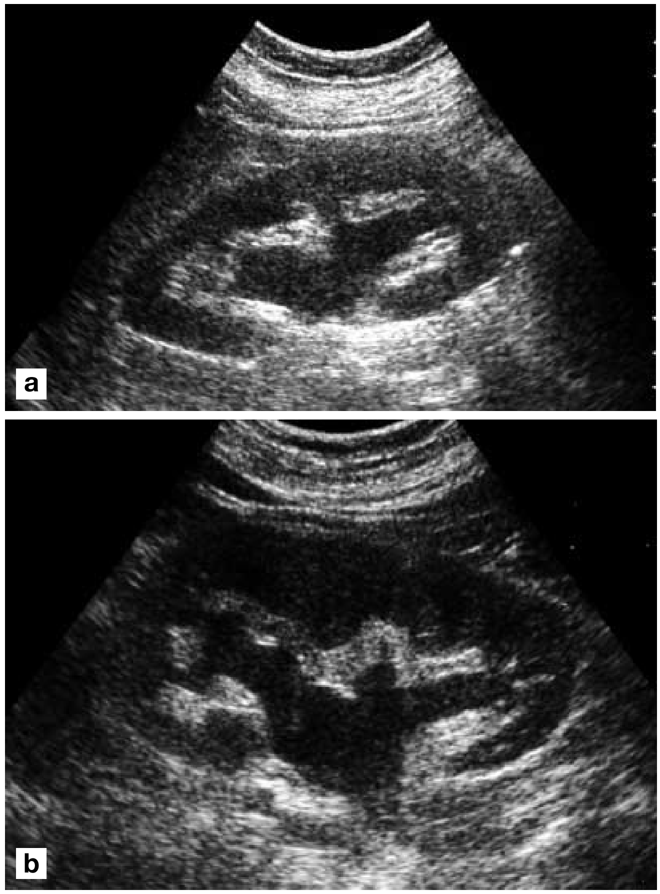


Fig. 1 a, b A 55-year-old woman with advanced cervical carcinoma (not shown). Longitudinal US scan of the **a** right and **b** left kidney. Dilatation of the pelvicalyceal system, but normal renal parenchyma. Bilateral hydronephrosis grade 2 due to obstruction of the ureters by cervical carcinoma

Regarding the first question, conventional real-time US is not the method of choice to provide further information for the differential diagnosis [1, 2].

Regarding the second question, the kidney and the ureter should be searched for possible calculi and other pathologic structures responsible for obstruction (Table 1); however, visualization of the entire ureter may be difficult due to overlying bowel gas, but US interrogation of the distal ureter using the fluid-filled urinary bladder as acoustic window is mandatory. This extra effort is well worth making since stone visualization is often possible (Figs. 2, 3, 4, 5, 6) [1]. Endovaginal or endorectal US imaging permits excellent visualization of the distal ureter, if available, and avoids a diagnostic delay if the bladder is empty at the time of percutaneous US, as full bladder distension is mandatory for percutaneous US in this case with only few exceptions.

Whereas US has an excellent sensitivity for diagnosing a dilatation of the collecting system, sensitivity and specificity for the diagnosis of obstruction are less convincing [1, 2]. Table 2 lists various causes for potential false-positive and false-negative real-time US findings for obstruction.

Most often, false-positive diagnoses are due to minimal dilatation [1]. A dilated extrarenal pelvis might be diagnosed if the dilatation disappears when US is repeated several minutes after the patient changed to the standing position. Ultrasound performed some minutes after voiding might demonstrate normal findings in patients where both, bilateral grade-1 dilatation and a full bladder, were present initially. Especially in slim patients and more within the left kidney (probably due to compression of the left renal vein between abdominal aorta and mesenteric vessels) prominent vessels in the renal sinus may have the appearance of grade-1 [13] or even grade-2 hydronephrosis. Color duplex Doppler sonography readily clarifies this situation and reveals this “hydronephrosis” usually as veins (Fig. 7).

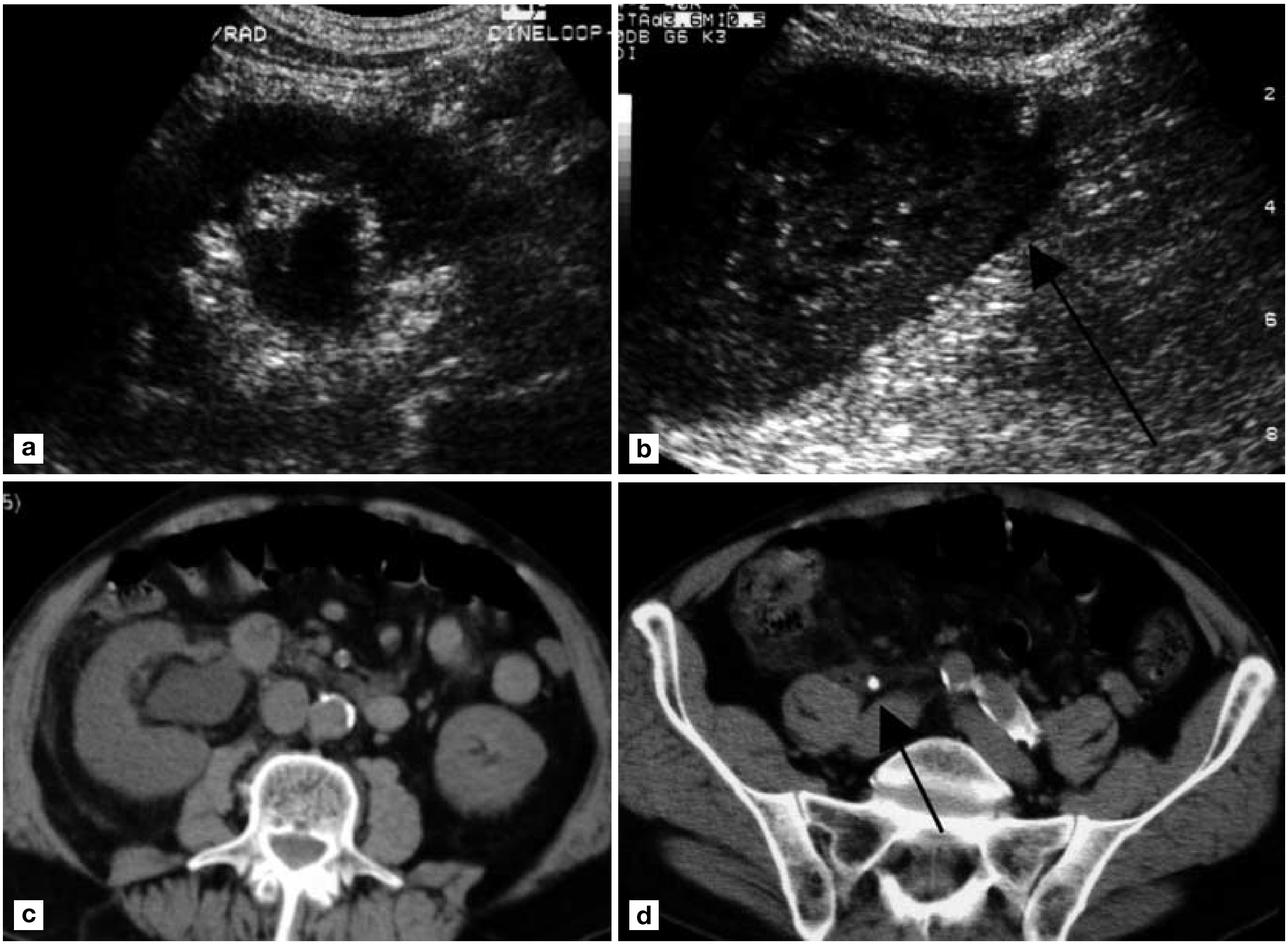


Fig. 2 a–d A 45-year-old man 6 h after sudden onset of typical right-sided renal colic. **a** Longitudinal US scan of the right kidney showing dilatation of the collecting system, grade 2. **b** Oblique US scan of the right kidney demonstrating small amount of perirenal fluid near the lower pole *(arrow)* suspicious for calyceal rupture. Distal ureter (not shown) behind the urinary bladder was normal, but proximal and mid portions of the ureter were not seen by US due to overlying bowel gas. Spiral CT without contrast material (slice thickness 5 mm, table feed 8 mm, reconstruction interval 4 mm) showing **c** dilatation of the collecting system and perirenal fluid, and **d** calcified ureter calculus *(arrow)* at the level of the iliac vessels not demonstrated by US

Renal sinus cysts may resemble hydronephrosis even for the experienced sonographer. Whereas dilated calyces show some continuity toward the renal pelvis, cysts are separated from each other, but excretory urography may be necessary to reliably exclude dilatation with/without obstruction (Fig. 8).

False-negative examinations are less common, but one should be familiar with the fact that in very early, acute obstruction the collecting system might not have had time to dilate, especially if other factors, such as hypovolemia or dehydration, are present [2]. In clinical practice, this problem is rare; however, distinction between obstructive and nonobstructive hydronephrosis remains a problem using conventional gray-scale US.

Color- and duplex Doppler US

Whereas state-of-the-art color Doppler techniques, such as amplitude-coded Doppler sonography, are useful in assessing focal renal abnormalities such as focal pyelonephritis, abscess, infarction, or tumor [14, 15, 16], assessment of intrarenal resistance by interrogating intrarenal arteries by pulsed Doppler US available since the 1980s is mandatory for the diagnosis of obstruction. Color Doppler might be useful in guiding the duplex Doppler sample volume to intrarenal arteries, thus possibly shortening the examination time; however, at times this examination may still be time-consuming even using state-of-the-art US equipment and requires high technical experience [2]. For optimal results, sampling

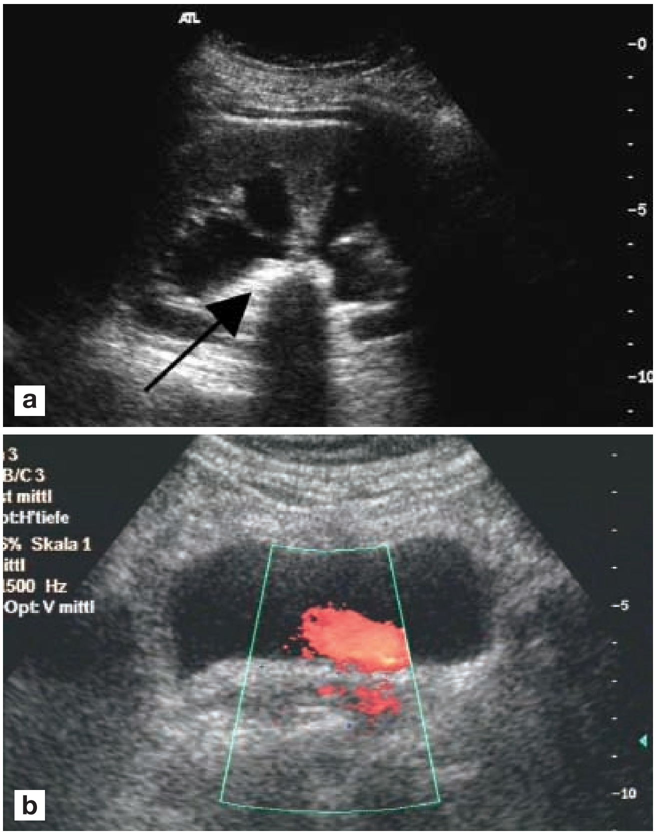


Fig. 3 a, b A 68-year-old asymptomatic woman with microhematuria. **a** Longitudinal US scan of the left kidney demonstrating dilatation of the collecting system, grade 2, and large stone in the renal pelvis *(arrow)*. **b** Left ureteral jet in the bladder is present indicating incomplete obstruction due to the pelvic calculus

Table 2 Causes of false-positive and false-negative real-time US in obstruction. (Adapted from [1], [2], and [6])

US false positive
• Normal variants
Extrarenal pelvis
Full urinary bladder
Blood vessels (vein) in renal sinus
• Increased flow of urine
• Cystic disease
Renal sinus (parapelvic) cysts
Adult polycystic disease
Simple cysts, but multiple
• Miscellaneous
Dilatation without obstruction
Vesicoureteral reflux
Congenital megacalyces
US false negative
Very early acute obstruction
Hypovolemia, dehydration
Retroperitoneal fibrosis, retroperitoneal tumors invading the kidney

the Doppler spectrum of the intrarenal arteries requires optimal settings of the US unit (low wall filter, optimal – preferably low – pulse repetition frequency in order to obtain a Doppler spectrum of good size, but without aliasing, appropriate gain settings) and a cooperative patient. For the characterization of the intrarenal Doppler spectrum commonly the resistive index (RI) is used, as easily calculated by the software of most US units as peak systolic frequency shift minus end-diastolic frequency shift divided by peak systolic frequency shift. The RI is independent of the angle between US beam and blood flow, thus not requiring Doppler angle adjustments.

An increase in intrarenal vascular resistance is reflected by a reduction in diastolic flow velocity within the intrarenal arteries and a consecutive increase of the RI. As renal vasoconstriction is the key factor in the pathophysiologic course of acute and chronic obstruction [7, 8, 9, 10, 11], application of RI measurements for the diagnosis of obstruction seems reasonable. Accordingly, many studies have established normal intrarenal RI values and evaluated the role of RI measurements in US imaging of urinary obstruction [4, 5, 17, 18, 19]. These studies clearly demonstrate that obstruction leads to an elevated RI [4, 5, 17, 18, 19]. To quantify these findings, various criteria have been suggested; these include elevation of the RI above the "normal" threshold of an RI of 0.7 and an interrenal difference in RI between normal and obstructed kidney (RI difference 0.05–0.1) [4, 5, 17, 18, 19]. An additional idea to further improve Doppler results in the differentiation of obstructive to nonobstructive hydronephrosis is to add a diuretic challenge to the intrarenal RI evaluation [5, 20]. In the adult population Mallek et al. prospectively investigated 48 kidneys in 26 patients with suspected renal obstruction by diuresis duplex Doppler sonography (furosemide 0.5 mg/kg body weight) and compared the results of baseline and diuresis RI measurements to the results of diuresis renography [5]. The baseline RI in normal ($n = 19$) and nonobstructed but dilated ($n = 12$) kidneys was normal (0.64 ± 0.06 and 0.62 ± 0.04, respectively) and was not changed by the diuretic challenge [5]; however, the RI in obstructed [$n = 8$, as defined by an elimination rate (E_{max}) < 6 %/min] and indeterminate ($n = 9$, as defined by 6 %/min < E_{max} < 14 %/min] was elevated in the baseline US Doppler examination and increased further with diuretic challenge (obstruction: 0.71 ± 0.04 to 0.77 ± 0.03, indeterminate 0.72 ± 0.11 to 0.78 ± 0.09) [5]. In this study the threshold RI for baseline RI measurements of 0.69 yielded an accuracy of 90 % for the diagnosis of obstruction, which was increased to 95 % (sensitivity 88 %, specificity 97 %) when using a threshold RI of 0.75 after furosemide application [5].

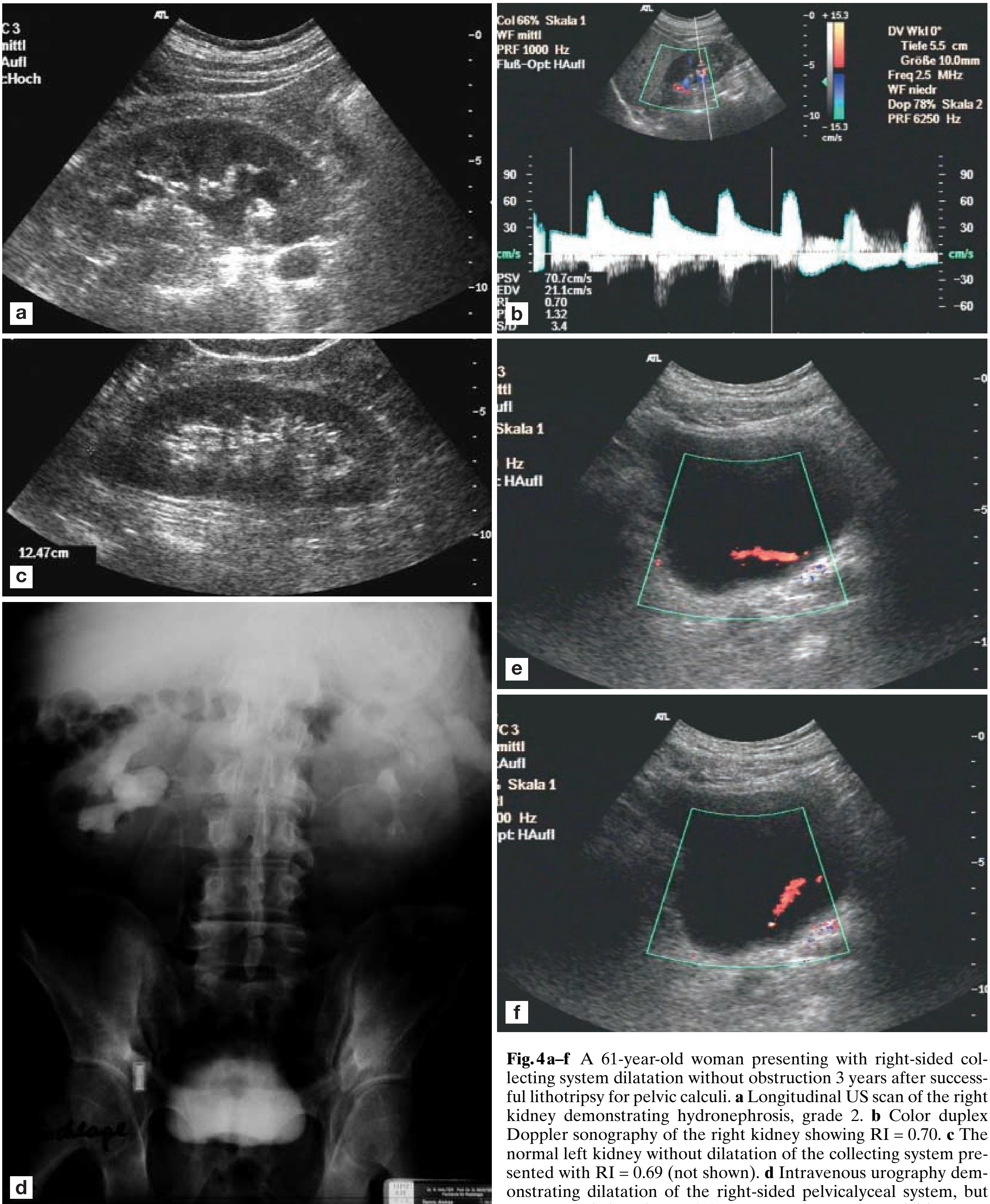


Fig. 4 a–f A 61-year-old woman presenting with right-sided collecting system dilatation without obstruction 3 years after successful lithotripsy for pelvic calculi. **a** Longitudinal US scan of the right kidney demonstrating hydronephrosis, grade 2. **b** Color duplex Doppler sonography of the right kidney showing RI = 0.70. **c** The normal left kidney without dilatation of the collecting system presented with RI = 0.69 (not shown). **d** Intravenous urography demonstrating dilatation of the right-sided pelvicalyceal system, but ureteropelvic junction and the ureter are normal. In addition, ureteral jets of the **e** left and **f** right ureter are identical in shape

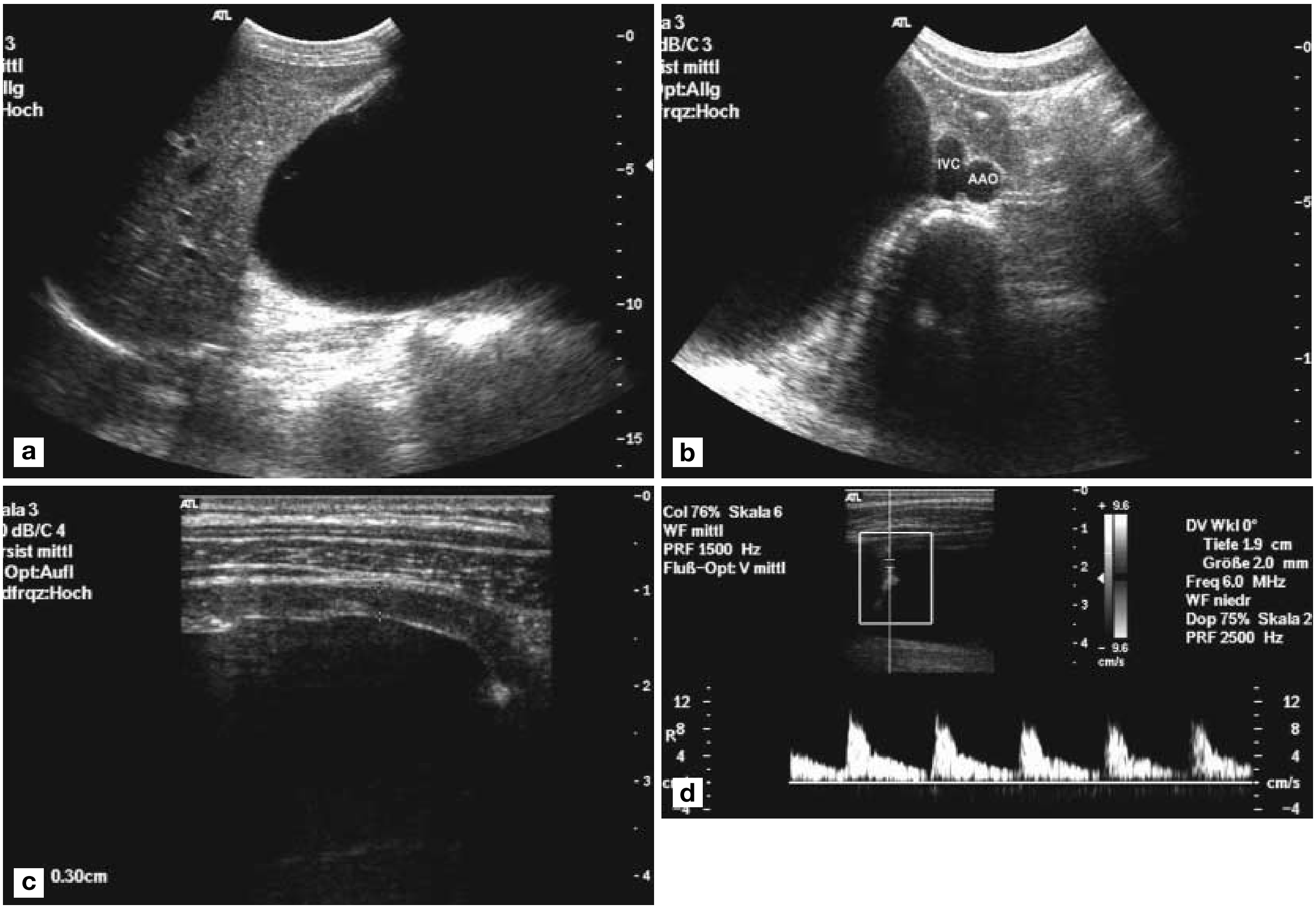
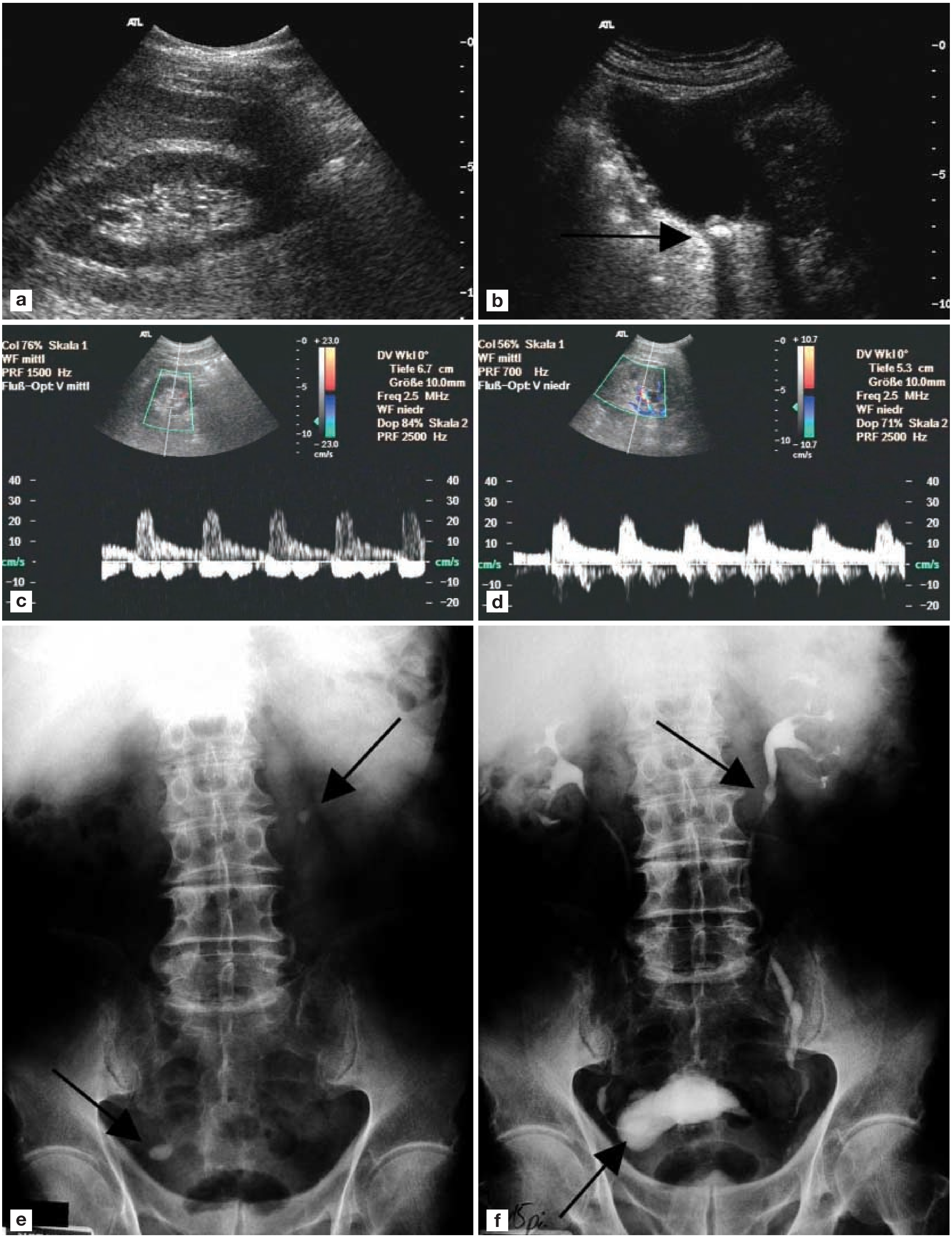


Fig. 5 a–d A 24-year-old woman presenting with a palpable mass in the right abdomen present at least for months and confirmed as hydronephrosis grade 3 due to ureteropelvic junction stenosis. **a** Longitudinal and **b** transverse US scans of the right upper abdomen using standard US equipment demonstrate a large "cyst" measuring 15 cm in longest diameter (*AAO* abdominal aorta; *IVC* inferior vena cava). High-resolution US (10- to 12-MHz scanhead) showing 3-mm wall of the **c** "cyst" and **d** "septae" with arterial perfusion. Doppler spectrum (**d**) shows typical renal arterial Doppler curve; however, RI is increased to 0.87

As results of RI measurements to diagnose complete obstruction are excellent, partial obstruction is not as well investigated, probably because well-established noninvasive standards for diagnosis are missing [2, 5]. As Platt mentioned, a normal RI in the setting of partial obstruction reflects the fact that this obstruction is not severe enough to induce renal vasoconstriction; however, there might be morphologic criteria for narrowing of the collecting system [2] (Figs. 4, 6).

It has been stated that assessing the RI is a separate and distinct parameter from collecting system dilatation in suspected obstruction [2]; thus, it seems mandatory to analyze Doppler derived RI together with real-time US information of the collecting system; however, intrarenal RI measurements are not free of error and variability [21, 22, 23]. Conditions other than renal disease might affect the RI, as very high or very low heart rates [23]. Another factor of variability is the age of the patient [22]. It has been demonstrated that unspecific histologic, especially nonspecific, vascular findings, such as arteriosclerosis and arteriolosclerosis,

Fig. 6 a–f A 90-year-old man with lower back pain referred for renal US. Bilateral nonobstructive ureteral calculi confirmed by IVU. **a** Longitudinal US scan of the right kidney without collecting system dilatation. **b** Longitudinal scan of the urinary bladder showing calculus within the distal right ureter *(arrow)*. Note massive enlargement of the prostate and trabeculation of the bladder. Color duplex Doppler sonography of the **c** right and **d** left kidney demonstrating identical intrarenal Doppler spectra with RI = 0.78 of the right and RI = 0.79 of the left kidney, respectively. Intravenous urography (**e** native and **f** 15 min after contrast administration) confirms calcified stone in the distal right ureter *(arrows)* and demonstrates additional calcified stone in the proximal left ureter *(arrows)* not recognized on the initial US examination; however, signs of urinary tract dilatation are missing on both sides. Bilateral increased RI probably due to the advanced age of the patient ▶



a
b
c
d
e
f
ATL
Col 76% Skala 1
WF mittl
PRF 1500 Hz
Fluß-Opt: V mittl
DV Wkl 0°
Tiefe 6.7 cm
Größe 10.0mm
Freq 2.5 MHz
WF niedr
Dop 84% Skala 2
PRF 2500 Hz
Col 56% Skala 1
WF mittl
PRF 700 Hz
Fluß-Opt: V niedr
DV Wkl 0°
Tiefe 5.3 cm
Größe 10.0mm
Freq 2.5 MHz
WF niedr
Dop 71% Skala 2
PRF 2500 Hz
cm/s

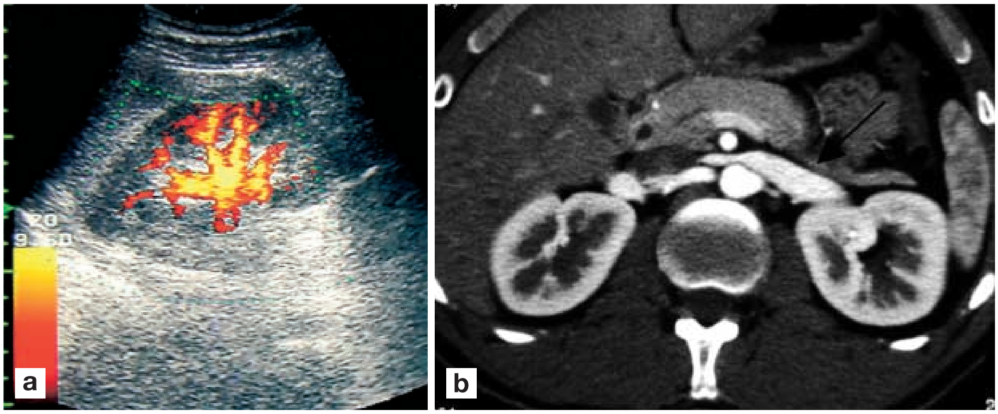


Fig. 7 **a** Prominent left intrarenal veins demonstrated by amplitude-encoded color Doppler sonography in a 24-year-old man. **b** Spiral CT after intravenous contrast (performed for other reasons) demonstrating proximal left renal vein compressed between aorta and superior mesenteric artery with distal dilatation *(arrow)*

influence the RI [22]. As these changes predominate with age, an increase of the RI with increasing age has been demonstrated (Fig. 6) [22]. Nevertheless, in experienced hands interobserver variability of intrarenal RI measurements is surprisingly low and in the range of 3 % [5].

Ureteral jet

Another, although not very common, application of CCDS in the assessment of urinary tract obstruction is imaging of the ureterovesical junction for the presence or absence of ureteral jets [24]. Patent ureters and protrusion of urine into the bladder produce a jet near the ureterovesical junction [24]. This jet is easily detected by CCDS and missing in complete obstruction [24]. Partial obstruction of one ureter can result in asymmetry of the jets, with the low-level jet at the side of partial obstruction (Figs. 3, 4) [24]; however, appropriate CCDS settings are necessary for comparable results and the examination may be extremely time-consuming especially if the patient is dehydrated.

Hydronephrosis in pregnancy

During the third trimester of pregnancy physiologic dilatation of the collecting system is found in up to 90 % of pregnant women [25, 26]; thus, differentiation between physiologic dilatation and obstruction, e.g., due to passing kidney stone, is challenging. In this setting, as physiologic dilatation during pregnancy does not alter the RI, evaluation of intrarenal Doppler spectra and assessment of ureteral jets might be helpful diagnostic tools without any ionizing radiation [26].

The patient with suspected urinary obstruction: role of US

Over the past decades many paradigm shifts changed imaging strategies of the patient with acute obstruction, i.e., with clinical symptoms such as renal colic or flank pain. In this setting US imaging is challenged by the old gold standard intravenous urography (IVU) and the new technique spiral CT (SCT). Together with the plain film of the abdomen, these four modalities, or a combination of these, form the diagnostic armamentarium to be applied in a cost-effective way [27, 28]. In this clinical situation US has a high sensitivity in the detection of possible dilatation of the collecting system, but only low sensitivity (ranging from 10 to 50 %) for stone detection [28]. Conversely, SCT sensitivities and specificities for stone detection are both in the range of 95 %, respectively [28]. In an approach for cost-effective imaging these modalities were arranged into four groups representing different imaging strategies: (a) plain SCT; (b) plain film+US+IVU (in 28 % of cases); (c) plain film+US+SCT with intravenous contrast (in 28 % of cases); and (d) IVU [28]. Full costs were 74 Euro for (a), 67 Euro for (b), 65 Euro for (c), and 81 Euro for (d), respectively [28]. These authors conclude that both protocols including IVU should be ruled out. Either using plain SCT alone or SCT in the combination of group (c) seems advisable; however, as SCT is not yet widely available in Europe, the combination of US and plain film may continue as a cost-effective and noninvasive imaging strategy in the majority of patients with this clinical question.

Renal medical disease

Since the early days of US there is general agreement that in patients with renal parenchymal disease, assessment of gray-scale US criteria, such as renal length, renal cortical echogenicity, or distinctness of the cortico-

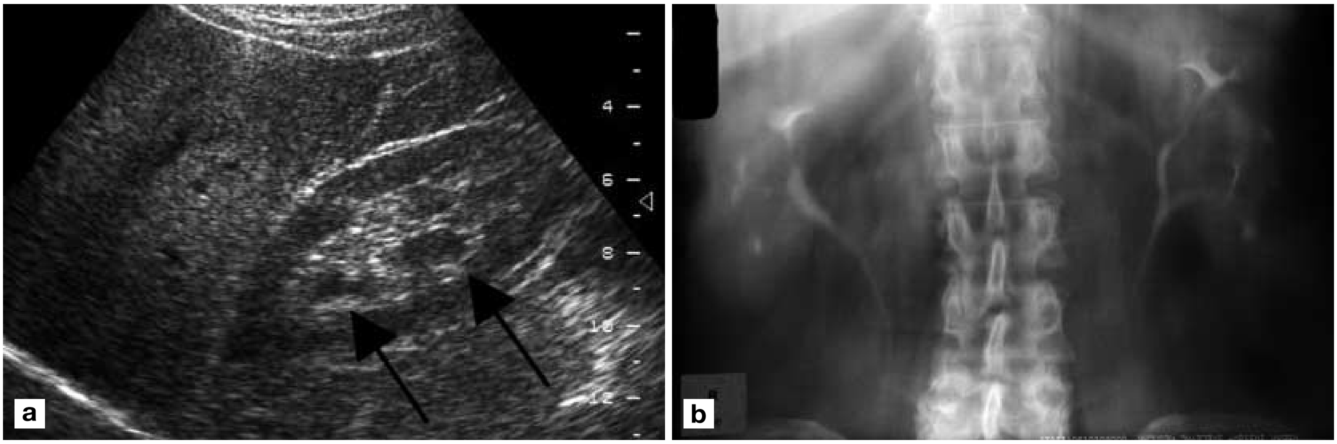


Fig. 8 a, b Bilateral renal sinus cysts in a 55-year-old man. **a** Longitudinal US scan of the right kidney remaining unclear whether cystic structures within the renal sinus *(arrows)* are cysts or represent dilatation of the collecting system. **b** Intravenous urography (tomography) rules out obstruction of the collecting system and confirms renal sinus cysts

Fig. 9 End-stage renal failure due to glomerulonephritis: longitudinal US scan of the right kidney showing increased cortical echogenicity

medullary boundary, does not allow us to distinguish specific types of renal medical disorders [29, 30]. There is no convincing evidence that modern US techniques have changed this opinion; thus, it can be said that generally in acute parenchymal disorders renal size is increased, due to inflammation and edema, compared with chronic disease, where the kidney tends to contract as fibrotic changes occur [12, 31].

Real-time US

Various efforts have been undertaken to get more insight into gray-scale US changes in renal parenchymal diseases [22, 29, 30, 31]. In the study by Hricak et al. on 129 patients with renal biopsy [29], there was overall no correlation between the specific sonographic appearance of a kidney and the type of renal disease. There was a significant correlation between renal length and the prevalence of global sclerosis, focal tubular atrophy, and hyaline casts per glomerulus, whereas cortical echogenicity was positively correlated to the severity of global sclerosis and focal tubular atrophy [29]; however, as stated by Platt et al. as early as in 1988, accepted sonographic criteria for abnormal renal echogenicity (kidney echogenicity = liver) are neither sensitive (62 %) nor specific (58 %) for renal parenchymal disease. In another real-time US study performed in the late 1980s in 63 patients with end-stage renal parenchymal disease, renal length was significantly larger in glomerulonephritis and diabetic nephropathy as compared with analgesic nephropathy and pyelonephritis, where kidneys measured 6–7 cm in length [32]. In addition, cortical echogenicity as compared with liver echogenicity was increasing from diabetic nephropathy to glomerulonephritis to analgesic nephropathy to pyelonephritis [32]; however, as there was overlap of these parameters between the different entities, etiologic information was limited [32]. But there is evidence that in diabetes the kidney in early stages instead increases in size and represents with normal cortical echogenicity [12]. In another histologically correlated study analyzing US findings in renal parenchymal disease, there was a significant positive correlation between renal length and the amount of edema and a significant negative correlation to the severity of arteriosclerosis [22]; thus, unspecific histologic findings influence kidney morphology in renal parenchymal diseases (Fig. 9).

Fig. 10 Marked increase in cortical echogenicity of the right kidney in a 24-year-old woman with AIDS and decreased renal function

Color- and duplex Doppler US

In renal parenchymal diseases, there is loss of diastolic flow indicating an increase in vascular resistance or increase in parenchymal pressure within the kidney resulting in an increased RI obtained from intrarenal Doppler spectra [22]. There is a significant positive correlation between the RI and the severity of arteriolosclerosis, arteriosclerosis, glomerular sclerosis, edema, and focal fibrosis [22]. Again, these findings are nonspecific, and the RI does not allow to distinguish different forms of renal medical disorders [22].

Pathologic entities

Despite these limitations, there are some renal medical diseases with somewhat characteristic, although not specific, US findings [6, 12]. In acute tubular necrosis (ATN), US shows an increase in renal size and prominent pyramids.

In nephrocalcinosis, there are areas of high echogenicity in the pyramids due to the deposition of calcification.

In acquired immunodeficiency syndrome (AIDS), there is a marked increase in cortical echogenicity if renal failure occurs. This may be due to a particular form of AIDS-related glomerulonephritis and/or nephrotoxic drugs (Fig. 10).

In analgesic nephropathy, as well in other diseases (sickle cell anemia, diabetes, VUR), renal papillary necrosis may be present. The necrotic papillary tips may present as tiny cysts and as small calcifications.

Patients with renal insufficiency

Ultrasound of the patient with renal insufficiency is essentially the summary of this review, as both entities, obstruction and renal medical diseases, are the major causes of diminished or absent renal function. In clinical practice usually there is no stringent information as to whether this renal insufficiency is acute or chronic, or if this is "acute on chronic renal failure." In short, the first step is to clarify if dilatation of the collecting system is present or not. If dilatation is absent, differential diagnosis by US criteria relies on the assessment of renal size (normal, increased or decreased; unilateral or bilateral). As indicated previously, in acute parenchymal disorders renal size is increased and cortical echogenicity may be decreased, due to inflammation and edema, compared with chronic disease, where the kidneys tend to decrease in size and increase in echogenicity, as fibrotic changes occur [12, 31].

References

1. Cronan JJ (1994) Acute urinary tract obstruction in the adult. RSNA Categorial Course in Genitourinary Radiology, pp 103–108
2. Platt JF (1996) Urinary obstruction. Radiol Clin North Am 34: 1113–1129
3. Whitaker R (1979) Clinical application of upper urinary tract dynamics. Urol Clin North Am 6: 137–141
4. Platt JF, Rubin JM, Ellis JH, Pietro MA di (1989) Duplex Doppler US of the kidney: differentiation of obstructive from nonobstructive dilatation. Radiology 171: 515–517
5. Mallek M, Bankier AA, Etele-Heinz A, Kletter K, Mostbeck GM (1996) Distinction between obstructive and nonobstructive hydronephrosis: value of diuresis duplex Doppler sonography. AJR 166: 113–117
6. Koeppen-Hagemann I, Ritz E (1992) Nierensonographie. Ein Leitfaden zur nephrologischen Diagnostik. Thieme, Stuttgart
7. Klahr S, Buerkert J, Purkerson ML (1977) The kidney in obstructive uropathy. Contrib Nephrol 7: 220–249
8. Walker RD, Richard GA, Bueschen AJ et al. (1980) Pathophysiology and recoverability of function and structure in obstructed kidneys. Urol Clin North Am 7: 291–311
9. Moody TE, Vaughan ED Jr, Gillenwater JY (1975) Relationship between renal blood flow and ureteral pressure during 18 hours of total unilateral ureteral occlusion. Implications for changing sites of increased renal resistance. Invest Urol 13: 246–251
10. Klahr S (1991) Pathophysiology of obstructive nephropathy: a 1991 update. Semin Nephrol 11: 156–168

11. Vaughan ED Jr, Sorenson EJ, Gillenwater JY (1970) The renal hemodynamic response to chronic unilateral complete ureteral occlusion. Invest Urol 8: 78–90
12. Bossi MC (1996) The kidney and adrenal glands. In: Goldberg B, Pettersson H (eds) The NICER year book 1996 ultrasonography. The NICER Institute, Oslo, pp 187–220
13. Scola FH, Cronan JJ, Schepps B (1989) Grade 1 hydronephrosis: pulsed Doppler US evaluation. Radiology 171: 519–520
14. Martinoli C, Derchi LE, Rizzatto G, Solbiati L (1998) Power Doppler sonography: general principles, clinical applications, and future prospects. Eur Radiol 8: 1224–1235
15. Kollmann C, Turetschek K, Mostbeck G (1998) Amplitude-coded colour Doppler sonography: physical principles and technique. Eur Radiol 8: 649–656
16. Turetschek K, Kollmann C, Dorffner R, Wunderbaldinger P, Mostbeck G (1999) Amplitude-coded color Doppler: clinical applications. Eur Radiol 9: 115–121
17. Fung LC, Steckler RE, Khoury AE, McLorie GA, Chait PG, Churchill BM (1994) Intrarenal resistive index correlates with renal pelvis pressure. J Urol 152: 607–611
18. Platt JF (1992) Duplex Doppler evaluation of native kidney dysfunction: obstructive and nonobstructive disease. AJR 158: 1035–1042
19. Platt JF, Ellis JH, Rubin JM (1995) Role of renal Dopler imaging in the evaluation of acute renal obstruction. AJR 164: 379–380
20. Renowden SA, Cochlin DL (1992) The potential use of diuresis Doppler sonography in UPJ obstruction. Clin Radiol 46: 94–96
21. Pozniak MA, Kelcz F, Stratta RJ, Oberley TD (1988) Extraneous factors affecting resistive index. Invest Radiol 23: 899–904
22. Mostbeck GH, Kain R, Mallek R, Derfler K, Walter R, Havelec L, Tscholakoff D (1991) Duplex Doppler in renal parenchymal disease. Histopathologic correlation. J Ultrasound Med 10: 189–194
23. Mostbeck GH, Gössinger H, Mallek R, Siostrzonek P, Schneider B, Tscholakoff D (1990) Effect of heart rate on Doppler measurements of resistive index in renal arteries. Radiology 175: 511–513
24. Burge HJ, Middleton WD, McClennan BL, Hildebolt CF (1991) Ureteral jets in healthy subjects and in patients with unilateral calculi: comparison with color Doppler ultrasound. Radiology 180: 437–442
25. Hertzberg BS, Carroll BA, Bowie JD, Paine SS, Kliewer MA, Paulson EK, Weber TM, Gimenez EI (1993) Doppler US assessment of maternal kidneys: analysis of intrarenal resistivity indexes in normal pregnancy and physiologic pelvicaliectasis. Radiology 186: 689–692
26. Grenier N, Pariente JL, Trillaud H, Soussotte C, Douws C (2000) Dilatation of the collecting system during pregnancy: physiologic vs obstructive dilatation. Eur Radiol 10: 271–279
27. Dalla Palma L, Pozzi-Mucelli R, Stacul F (2001) Present-day imaging of patients with renal colic. Eur Radiol 11: 4–17
28. Grisi G, Stacul F, Cuttin R, Rimondini A, Meduri S, Dalla Palma L (2000) Cost analysis of different protocols for imaging a patient with acute flank pain. Eur Radiol 10: 1620–1627
29. Hricak H, Cruz C, Romanski R, Uniewski MH, Levin NW, Madrazo BL, Sandler MA, Eyler WR (1982) Renal parenchymal disease: sonographic–histologic correlation. Radiology 144: 141–147
30. Rosenfield AT, Siegel NJ (1981) Renal parenchymal disease: histopathologic–sonographic correlation. AJR 137: 793–798
31. Platt JF, Rubin JM, Bowermann RA, Marn CS (1988) The inability to detect kidney disease on the basis of echogenicity. AJR 151: 317–319
32. Mostbeck G, Derfler K, Walter R, Herold C, Mallek R, Tscholakoff D (1988) Sonography in end-stage renal insufficiency: aetiological information. Ultraschall 9: 250–254