Chapter 23

Doppler ultrasound of renal vessels

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Content

Introduction

Ultrasound is the most frequently used method of imaging in diagnosis of pathological changes of urinary system. B-mode ultrasound allows the evaluation of morphology and kidney anatomy and position, measurement of thickness and assessment of echogenicity of parenchyma and dilatation of the collecting system.

Colour duplex Doppler and power Doppler ultrasound of the renal and intrarenal vessels also provide data on renal function, i.e. blood flow in renal and intrarenal arteries, in veins and evaluation of renal vascular resistance.

Doppler examination technique for renal vessels

Duplex Doppler is used to analyse the flow in renal arteries and renal veins, as well as in intrarenal segmental, interlobar and arcuate arteries and veins. It allows the simultaneous evaluation of kidney morphology and blood flow in vessels, with spectral waveform analysis and quantification of flow [1,2].

Doppler examination of the main renal artery and renal vein is initially performed with the patient in a supine position. In an axial section, the right renal artery origin (from the aorta) is positioned anterolaterally, and the left renal artery origin is positioned posterolaterally (Figure 1).

Figure 1   *Transverse scan of the origin of the right renal artery from the aorta, originating anterolaterally. Colour Doppler demonstrates flow away from the transducer, seen in red in the initial, short segment of the artery, courses anteriorly, while the major part of artery is shown in blue, in which the flow is directed away from the transducer, posterolaterally, towards the right kidney.*

The right renal artery is easily seen behind the inferior vena cava (IVC), serving as the acoustic window. The IVC should be scanned in longitudinal section, and the retrocavaly located right renal vein is than seen in transverse section as a round structure. The transducer has to be slowly rotated so that the right renal artery is finally seen in longitudinal section. Multiple renal arteries (Figure 2) and early branching of renal artery (Figure 3) can be detected in this fashion.

Figure 2 *Longitudinal scan through the IVC. Two right renal arteries are visible behind IVC, in transverse section. The wider renal artery (RA) is superior to the narrow accessory inferior artery.*


Figure 3 *Early branching of the right renal artery on segmental branches. The artery is easily seen behind the inferior vena cava.*

The left renal artery is easily demonstrated behind the left renal vein. Veins are normally positioned anterior to arteries. It is important to use the smallest possible insonation angle, and perform an angle correction to obtain adequate velocities values. In 3–4% of people the right renal artery is positioned anterior to IVC (Figure 4).

Figure 4 *Longitudinal scan through the inferior vena cava (flow seen in blue). Right renal artery (transverse section, flow seen in red) is positioned anterior to IVC (a). In the same patient, the longitudinal section through the anterocavally positioned right renal artery. Spectral waveform confirms arterial flow (b).*

a *b*
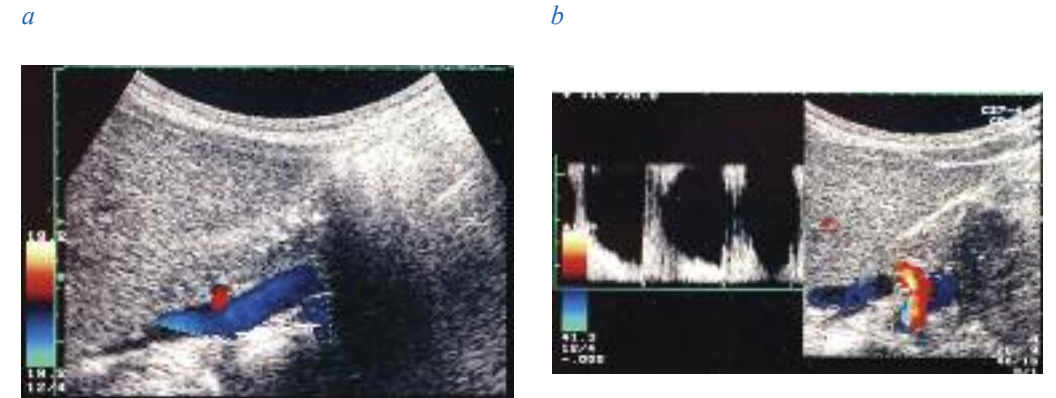
It is also quite common to observe retroaortic position of the left renal vein (Figure 5).

Figure 5 *Retroaortic position of the left renal vein.*

The left renal vein normally passes between the aorta and superior mesenteric artery. If the left renal vein is compressed in this narrow space the distal part of left renal vein can be dilated, which can typically cause loin pain and haematuria (known as, loin pain haematuria syndrome), especially in young, slim patients ("nutcracker" syndrome)[3].

Doppler spectra in renal and intrarenal arteries have high, continuous, antegrade diastolic flow, short acceleration time and a filled systolic window (Figure 6).

Figure 6   Normal spectral display of flow in the right renal artery. Low-resistance type spectrum is above the baseline, with PSV of 80 cm/s. Angle correction is performed. Physiological spectral broadening is visible.
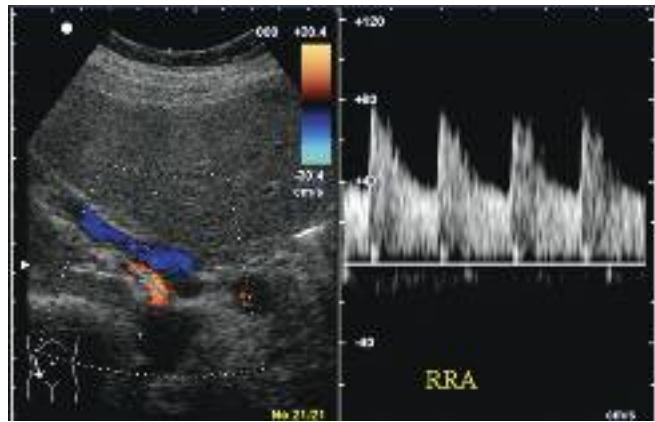
The renal vein flows in an opposite direction to the renal artery, which is easily visible with colour duplex Doppler. Venous spectra are continuous, with slight respiratory variations [1,2].

Doppler examination of intrarenal vessels should be performed in the lateral decubitus position. Segmental, interlobar and arcuate arteries and veins should be evaluated (Figure 7 and Figure 8) [1,2].

Figure 7   Normal intrarenal vessels demonstrated with colour Doppler. Arteries are seen in red and veins in blue.
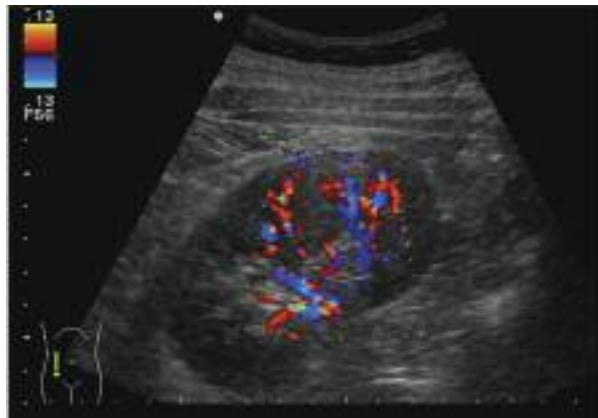

Figure 8   Normal intrarenal flow demonstrated with e-flow.


Power-Doppler is very sensitive for visualising slow flow in small vessels, and therefore allows the visualisation of flow as far as the renal capsule, and visualisation of the interlobular arteries.

Arteries are insonated at typical points: segmental in the sinus, interlobar on corticocentral junction and corticomedullary borders, and arcuate at the base of the medullary pyramids. Velocities decrease distally. To perform optimal spectral analysis and accurate measurements the wall-filter should be adjusted to the smallest possible values so as not to erase low diastolic flow. The lowest pulse repetition frequency should be used so that aliasing does not occur [1,2,4,5]. The most common use of Doppler spectra is to measure resistance index (RI), which reflects renal vascular resistance (RVR). RI is calculated as:

(maximum systolic velocity - minimum diastolic velocity) / maximum systolic velocity

Acceleration time (time from the beginning of systole to the early systolic peak) should also be measured, as well as acceleration index, reflecting steepness of the early systolic part of the spectrum. The systolic window is filled due to spectral broadening, which is a normal finding in such narrow vessels (Figure 9) [1,2,4].

Figure 9   Normal Doppler spectrum in interlobar artery with RI=0.56. Below the baseline continuous spectrum from interlobar vein is visible.
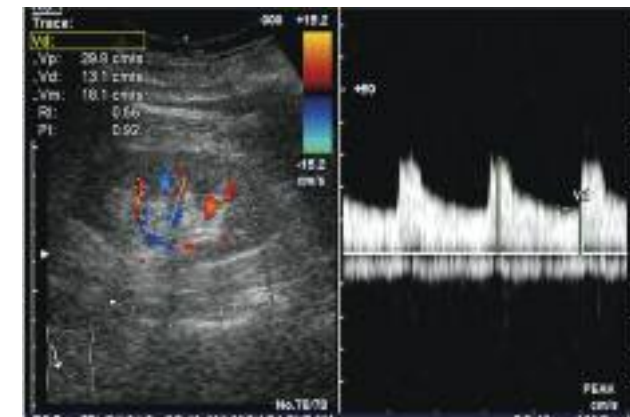
Peak systolic velocity (PSV) in the main renal artery is approximately 1 m/s, and values below 1.5 m/s are still within the normal range. Normal values of RI in most studies are in the range of 0.58–0.64 [5–8]. We observed normal RI values in adults of 0.60±0.03 [8]. Aging renal vasculature is associated with increase in resistance, which is physiological phenomenon and this increase is not accompanied with changes of serum creatinine or creatinine clearance. Therefore older people have 10–15% higher values of RI compared with younger adults. In children values of RI are higher in the first 2 years of life, and between 2 and 6 years of age gradually become similar to adult values [6,7].

For adults, a threshold RI value of 0.70 is an indicator of normal RVR, and all values above 0.70 indicate increased RVR, which is important in evaluation of many pathological conditions, particularly renal parenchymal diseases [2,4]. In children below the age of 6 years threshold value of RI should not be used (Figure 10) [6].

Figure 10 Normal Doppler spectrum in interlobar artery of a 16-month-old child with RI of 0.74, which is a normal value for this age.

Renal vascular diseases and renovascular hypertension

Renal vascular diseases include: renovascular hypertension, nephroangiosclerosis, vasculitis (poliarteritis nodosa, Wegener disease, etc), thrombotic microangiopathies (haemolytic-uraemic syndrome, thrombotic thrombocytopenic purpura), scleroderma, renal infarcts, cortical necrosis, toxaemia of pregnancy [9,10].

Renovascular hypertension (RVHT) is a consequence of renal artery stenosis (RAS); it is potentially curable if arterial patency is reconstituted. RAS causes increased production of renin, angiotensin II and aldosterone. An ischaemic kidney retains sodium and fluid, and longstanding hypertension damages intrarenal vessels of an unprotected kidney. Hypertension and renal failure may persist after the removal of the stenotic kidney [9–11].

In 90–95% of cases RVHT is caused by atherosclerotic stenosis of the renal artery and is primarily seen in older patients, over 55 years of age, and is more common in men. Fibromuscular dysplasia is more common in women and younger patients (average age, 35 years). The most common type is media fibrosis of distal two-thirds of the renal artery and of the main branches [10,11].

RVHT is clinically significant, but the prevalence of RVHT in the general population of hyper-

tensive patients is very low, only 2–6%. Clinical signs that suggest RVTH should be investigated with imaging are uncontrolled hypertension on medications, sudden onset of diastolic hypertension, hypertension with coronary artery disease, and so on [11–13]. A very important finding is asymmetry of kidney dimensions on ultrasound, CT or MRI [9,10]. Just the presence of RAS does not imply that the patient has RVTH; asymptomatic RAS is common and more than 50% of normotensive people have a certain degree of RAS. It is considered that RAS that reduces the diameter of artery more than 60–70% causes RVHT. If revascularisation leads to amelioration of the disease, a diagnosis of RVHT can be made retrospectively [9–11].

The main goal of imaging in diagnosis of RAS is to detect a potentially curable lesion in a normal-sized kidney. Doppler ultrasound is established as the initial imaging method for screening, diagnosis and follow-up after treatment of renal artery stenosis.

Doppler should be used to analyse the main renal artery and intrarenal arteries. Obesity and excessive air in the bowel may hinder visualisation of the main renal artery. More than 25% of people have more than one renal artery on one or both sides [1,2].

The most important finding of RAS is focal elevation of PSV at the site of stenosis. The usual threshold value for diagnosis is PSV of more than 1.8–2 m/s. It is also important to evaluate the renal aortic ratio, a ratio of PSV at the site of stenosis and in the aorta proximal to renal artery branching; RAR >2.5 is considered to be diagnostic for RAS (Figure 11 and 12) [2,14].

Figure 11 Spectrum at the site of ostial, high degree stenosis of the right renal artery with peak systolic velocity of 4.1 m/s, end-diastolic velocity of 1 m/s and an elevation of velocity compared with aorta of five times the size.
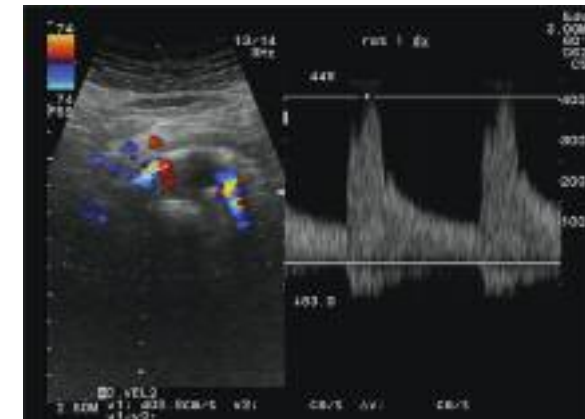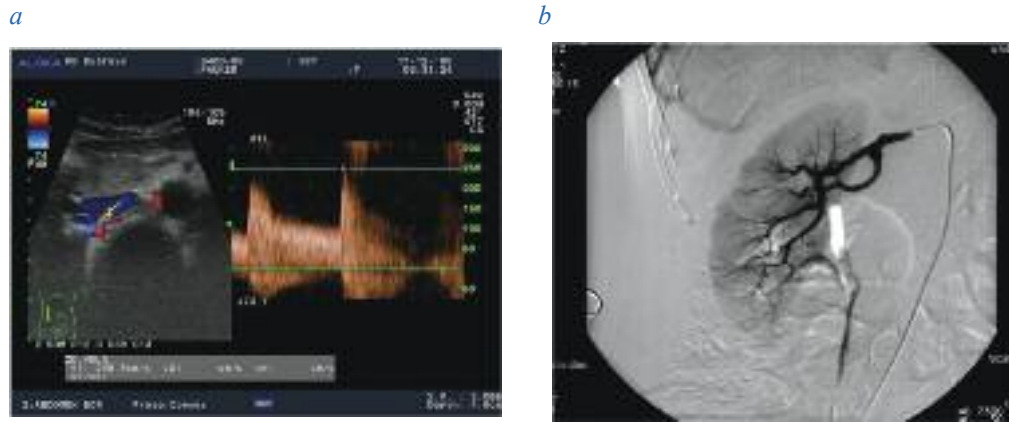
Figure 12 Doppler spectrum at the site of stenosis in the middle segment of the right renal artery in 36-year-old female with fibromuscular dysplasia of renal artery. PSV = 2.5 m/s (a). The same patient, typical finding of FMD of the right renal artery with digital subtraction angiography (b).

a   *b*

Demonstration of intrarenal arteries is technically much easier compared with the main arteries, and can usually be performed even in very obese patients. Stavros et al [15] has described parvustardus spectra in intrarenal arteries in the case of significant renal artery stenosis. These spectra have prolonged acceleration time (over 0.07 s) and increased diastolic flow (Figure 13). Comparison of Doppler and angiographc findings has demonstrated that parvus-tardus spectra are seen in high-degree stenosis, above 70% or 80% [14].

Figure 13 Post-stenotic parvus-tardus spectra in interlobar intrarenal artery in a case of high-degree stenosis of the main renal artery
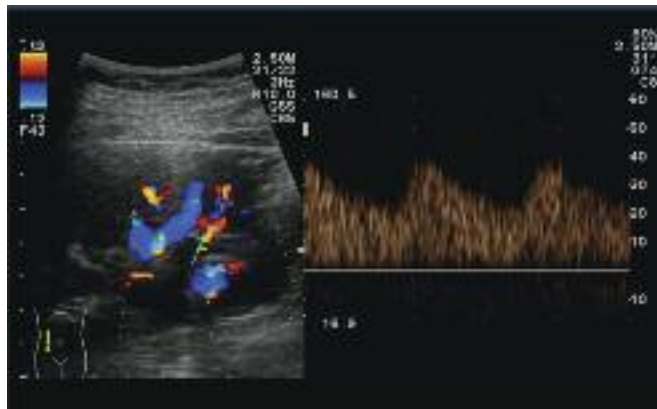
Disappearance of parvus-tardus spectra is observed after successful percutaneous transluminal angioplasty (PTA) or stenting of renal arteries or both [16]. Parvus-tardus spectra may not be present in cases of severely reduced compliance of the blood vessel, even in high-degree RAS.

If parvus-tardus spectra are visible before angioplasty or stenting (Figure 14a) and they disappear after the procedure (Figure 14b) then these Doppler findings indicate that the procedure was successful.

Figure 14 Intrarenal interlobar post-stenotic parvus-tardus spectrum in 33-year-old patient with fibromuscular dysplasia and high-degree stenosis of the renal artery; prolonged acceleration time of $\Delta t = 0.16$ s is seen (normal, <0.07 s) (a). Intrarenal interlobar spectrum in the same patient after the successful percutaneous transluminal angioplasty of renal artery stenosis; spectrum morphology is completely normal after the procedure (b)

a   *b*
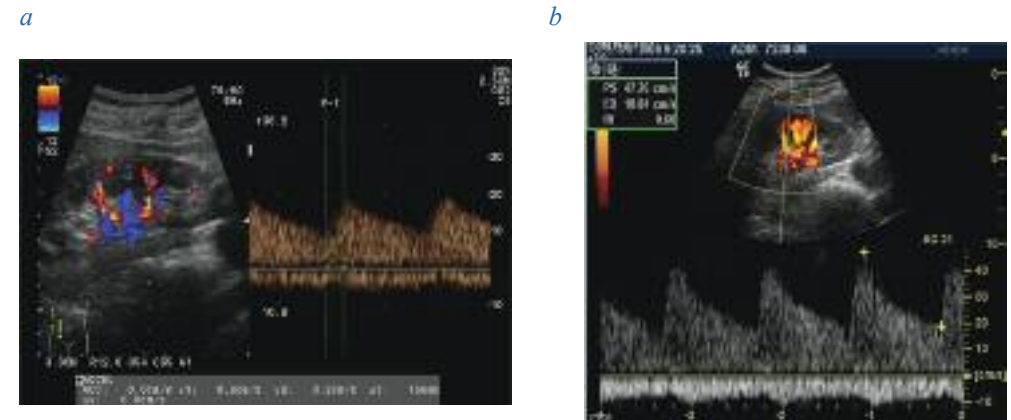
If intrarenal RI is above 0.80, endovascular recanalisation is usually not successful due to irreversible changes of the kidney vasculature [17,18]. If flow cannot be demonstrated in the main RA intravenous ultrasound contrast media may allow the visualisation of the flow.

Accuracy of duplex Doppler ultrasound in RAS is 80–90%, which depends on the experience of the examiner and the quality of the equipment [14]. Although the stenosis of the accessory renal artery is considered important, it has been shown that the prevalence of isolated significant stenosis of the accessory artery is only 1.5%, and it does not decrease the use of Doppler in detection of RAS [19].

CT angiography has a very high negative predictive value (<95%) in diagnosis of RAS, but it has negative side effects, such as the risk of contrast-induced nephropathy, high radiation dose and high cost [20]. Contrast-enhanced MR angiography has many advantages and high diagnostic accuracy, but it has relatively low specificity and tends to overestimate moderate stenosis. There is also a risk of nephrogenic systemic fibrosis in patients with pre-existing azothaemia [21,22].

The American College of Cardiology recommends duplex Doppler as the initial imaging method to diagnose RAS (class I, level of evidence B). CTA or MRA may be indicated after Doppler [23].

Doppler is important to evaluate successfulness of endovascular therapy and in follow-up to diagnose restenosis after PTA or stenting or both of the renal artery (Figure 15). High in-stent PSV, >2 m/s indicates high-risk of impaired stent patency and loss of renal function [24].

Figure 15 Flow through the stent in the left renal artery with colour Doppler and spectrum that demonstrates normal velocity (PSV = 71 cm/s).
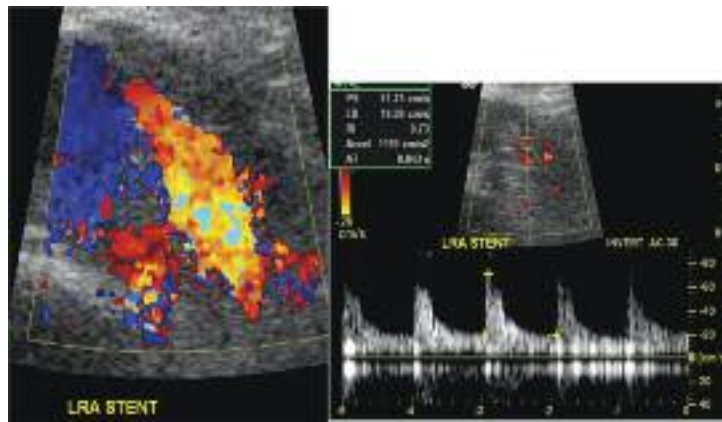
Clinical scenario

The analysis of the natural history of untreated atherosclerotic RAS has established that 42–49% of stenotic renal artery progress during 6–24 months, and angiographic or ultrasound follow-up has shown that 11–14% of RAS progress to occlusion [25,26]. Patients surviving 15 years with end-stage renal disease because of RAS is 0%, but 32% in patients with end-stage renal disease for other reasons (e.g. autosomal dominant polycystic kidney disease) [27].

Patients can be treated with medical therapy (ACE inhibitors, β-blockers, calcium channel blockers, AT II receptor blockers), with surgical revasularisation and with endovascular revascularisation. More than 80% of patients have good blood pressure control with medical therapy. Surgical revascularisation has relatively high mortality and post-operative complication rate [28]. Regarding endovascular revascularisation, percutaneous transluminal angioplasty is an excellent method for the treatment of fibromuscular dysplasia, where results are much better than in atherosclerotic disease. The best treatment for atherosclerotic RAS is controversial, and conflicting data have been published regarding indications, benefits, complications and advantages of PTA/stent over medical therapy [28–32]. Although 25–30% of patients with impaired renal function can recover glomerular filtration after endovascular revascularisation, many have no apparent change in renal function, and 19–25% experience a significant loss of kidney function, some as a result of atheroemboli [31]. A review of RAS treatment in 2006 for the Agency for Healthcare Research and Quality concluded that there is insufficient evidence to suggest a clear advantage of renal revascularisation over maximal medical therapy [27].

A newly published study comparing percutaneous revascularisation vs. medical therapy for renal-artery stenosis is the ASTRAL study [33]. 806 patients with atherosclerotic high-degree RAS were randomised into groups that underwent revascularisation in addition to receiving medical therapy, and into a group receiving medical therapy alone. The primary outcome was renal function and the secondary outcomes were blood pressure, time to renal and major cardiovascular events, and mortality. During a mean follow-up of 34 months there was no evidence of a worthwhile clinical benefit from revascularisation in patients with atherosclerotic renovascular disease, while serious complications associated with revascularisation occurred in 23 of 403 treated patients.

In conclusion, when medical therapy fails RAS may be treated with PTA/stenting, specifically in cases with accelerated, resistant or malignant hypertension, hypertension with unilateral small kidney, hypertension with medication intolerance, in chronic renal insufficiency with bilateral RAS or RAS supplying solitary functioning kidney and in cases of unstable angina probably due to RAS. Doppler ultrasound should be the first imaging modality to diagnose the disease, and meticulous evaluation of intrarenal spectra should be performed to identify those patients that may not benefit from revascularisation. If ultrasound findings are equivocal, CT angiography can be performed; and it has very high negative predictive value. Extensive calcifications do not allow an accurate diagnosis, and risks of contrast-induced nephropathy have to be minimised. Contrast-enhanced MR angiography has a high diagnostic accuracy, but it has relatively low specificity and tends to overestimate moderate stenosis. In patients with pre-existent renal functional impairment the risk of nephrogenic systemic fibrosis is present.

Renal vein thrombosis

Doppler is very accurate in the diagnosis of renal vein thrombosis. Colour Doppler can directly visualise a distended vein, filled with the thrombus, without flow. In adults renal vein thrombosis is most commonly seen in patients with kidney cancer that commonly infiltrates the renal vein and inferior vena cava. In these patients, malignant venous thrombus may demonstrate vascularisation on colour Doppler.

Indirect signs of RVT may be an alteration of intrarenal arterial spectra, with extreme elevation of RI due to intrarenal oedema caused by impaired venous drainage [34]. RVT that is not caused by a malignant tumour is more common on the left side, and left renal vein is much longer than the right one. In adults RVT may be caused by nephritic syndrome, hypercoagulable conditions, oral contraceptive intake, trauma, retroperitoneal fibrosis and thrombophlebitis migrans. In children more common causes are dehydration and trauma. Early diagnosis is important because to ensure adequate therapy. Venous recanalisation after successful treatment is evaluated by colour duplex Doppler.

Cases of right renal vein thrombosis in young women taking oral contraceptives is demonstrated in Figure 16a–c.

Figure 16 Echogenic thrombus that protrudes from the right renal artery into the inferior vena cava (a). Intrarenal arterial spectrum from the right kidney demonstrates very high resistance due to the right renal vein thrombosis; intrarenal arterial resistance is elevated due to oedema caused by the impaired venous drainage (b). (c). After the successful recanalisation of right renal vein thrombosis normal spectra are visible in intrarenal arteries, with normal resistance and RI = 0.61.

a

b

c
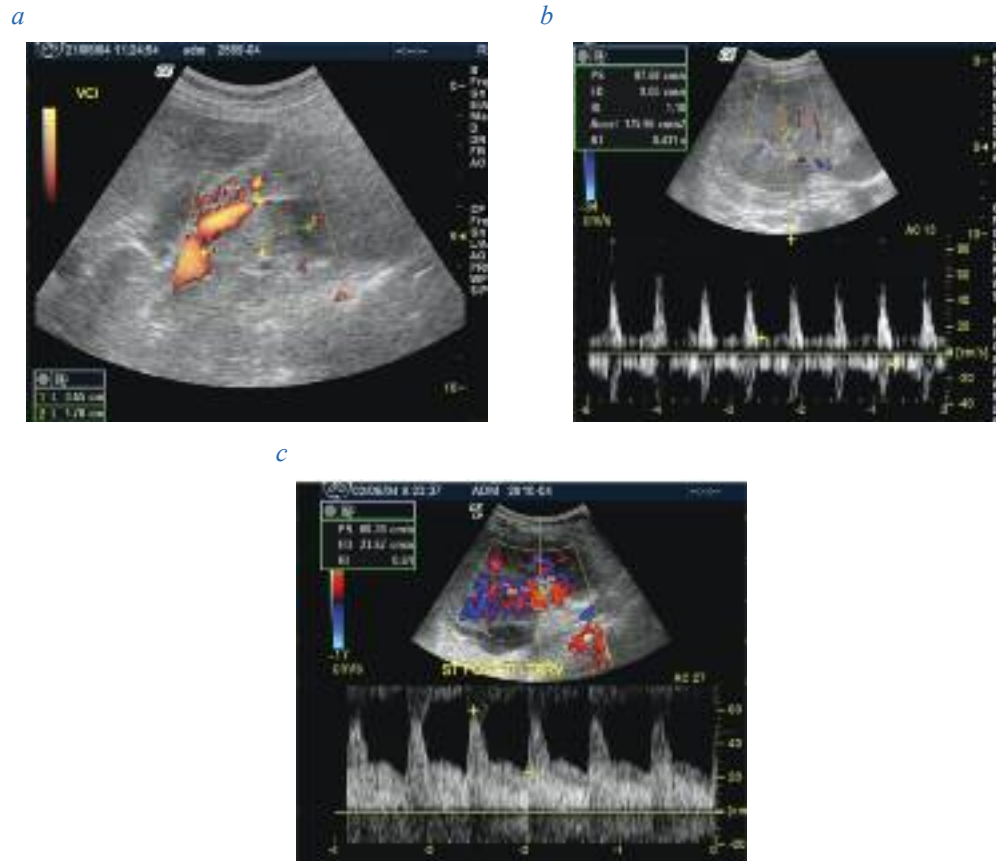
Doppler in diagnosis of other renal diseases

Colour Doppler is useful to diagnose small renal stones due to "twinkling" artefacts; these are irregular Doppler shifts in stone shadow that depend on the irregularities of the stone surface (Figure 17). This artefact is usually not seen in stones composed of calcium-oxalate [35].

Figure 17 Twinkling artefact behind a renal stone that does not cause collecting system dilatation.
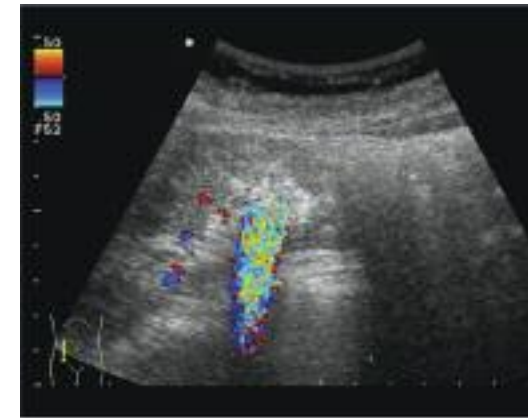
Conventional ultrasound cannot differentiate obstructive and non-obstructive renal collecting system dilatation. Doppler can demonstrate elevated renal vascular resistance in significant obstruction of the collecting system. RVR is increased due to several vasoconstrictor substances, principally thromboxane A-2.

It is important to measure RI in intrarenal arteries of both kidneys and a difference in RI of 0.08 or more is indicative of significant unilateral obstruction (Figure 18a,b) [36,37]. RI is usually elevated within 6–48 h after the onset of obstruction.

Figure 18 Elevated renal vascular resistance in the obstructed right kidney due to the ureteric stone. RI= 0.74. Normal RI in a non-obstructed left kidney of the same patient. RI= 0.60, dRI= 0.14 (b).

a

b
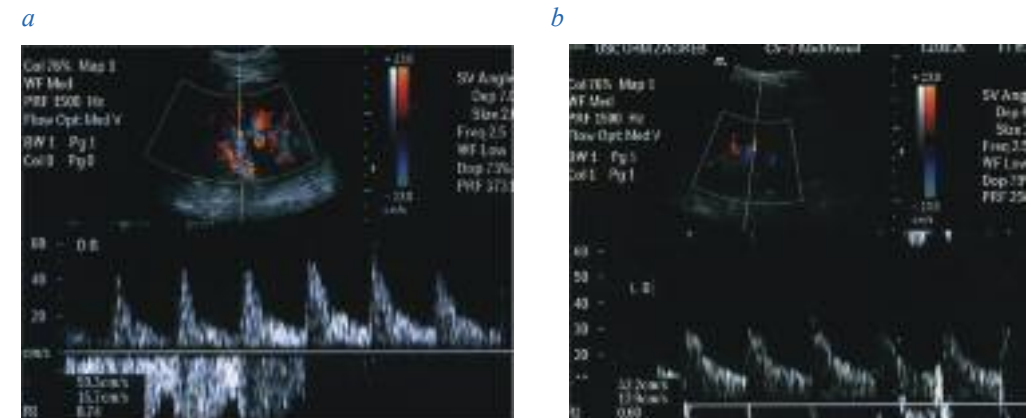
One might also analyse ureteric jets with colour Doppler (Figure 19); these are short-lasting jets of urine entering the bladder from the ureters that indicates patent ureter [38].

Figure 19 Ureteral jets visible from both vesicoureteric orifices. They are helpful to locate orifices and measure their distance to the midline of the bladder.

Renal vascular resistance and intrarenal RIs are elevated in acute renal failure and in several renal parenchymal diseases, particularly those with pathological changes in tubules, renal interstitium and blood vessels, while patients with isolated glomerular lesions usually have normal RIs [1,39].

Haemolitic-uraemic syndrome causes acute renal failure in children. Its main feature is thrombotic microangiopathy and pronounced intrarenal vasoconstriction, with subsequent elevation of RVR. Children with HUS have elevated renal RIs. Restitution of renal function may be expected if RI values normalise in the diuretic phase of the disease, and changes in RI occur before changes in laboratory or radionuclide findings and clinical signs of improvement. Doppler can therefore be used to stop haemodialysis treatment [40].

Acute renal failure (ARF) is caused by many diseases that need to be differentiated to ensure adequate treatment. Doppler may be useful to differentiate two of the most common causes of ARF: acute pre-renal failure and acute tubular necrosis (ATN). In ATN, RI above 0.75 is observed in more than 90% of patients, while in the acute pre-renal failure RI values are usually normal [40,41]. An example of very elevated resistance in patients with ARF caused by ATN is demonstrated in (Figure 20).

Figure 20 High intrarenal arterial resistance (RI=0.81) in patients with the acute renal failure due to the acute tubular necrosis

Diabetic nephropathy is very common and the leading cause of chronic renal failure. Histopathological changes in the diabetic kidney affect mostly blood vessels, and are manifested as increased RVR and increased RI. An increase in RI is proportional to the progression of diabetic nephropathy, but RI values over 0.70 are seen only in stages of azothaemia and clinically manifested disease; while in early stages, especially in the stage of microalbuminuria RIs are not increased [8]. Doppler changes are seen before conventional ultrasound changes in diabetic nephropathy [42]. Examples of increased RI in diabetic nephropathy are demonstrated in (Figure 21).

Figure 21 Elevated intrarenal arterial resistance (RI=0.73) in patients with diabetic nephropathy and non-insulin dependant diabetes mellitus.

Hepatorenal syndrome marks impairment of renal function in patients with chronic liver disease. These patients have intense intrarenal vasoconstirction and increased renal RI values. Elevation of RI is observed before elevation of serum creatinine, e.g. before clinically proven HRS [43].

In patients with autosomal dominant polycystic kidney disease renal RI elevation correlates well with renal functional impairment and the degree of morphological kidney changes on conventional ultrasound [44]. Colour duplex Doppler is useful to evaluate vascularisation of solid renal tumours, although it does not have an important role in differentiation of various tumour types. Colour duplex Doppler is also useful to guide the needle path during kidney biopsy and to detect complications of biopsy such as pseudoaneurysms (Figure 22a,b) and AV fistulas (Figure 23). Post-biopsy AVF is usually much smaller than congenital AV malformation in the kidney [1].

Figure 22 Colour Doppler of the part of the kidney after biopsy. Iatrogenic pseudoaneurysm with colour-coded flow in both directions (a). Spectral display of the same pseudoaneurysm with the flow above and below the baseline (b).
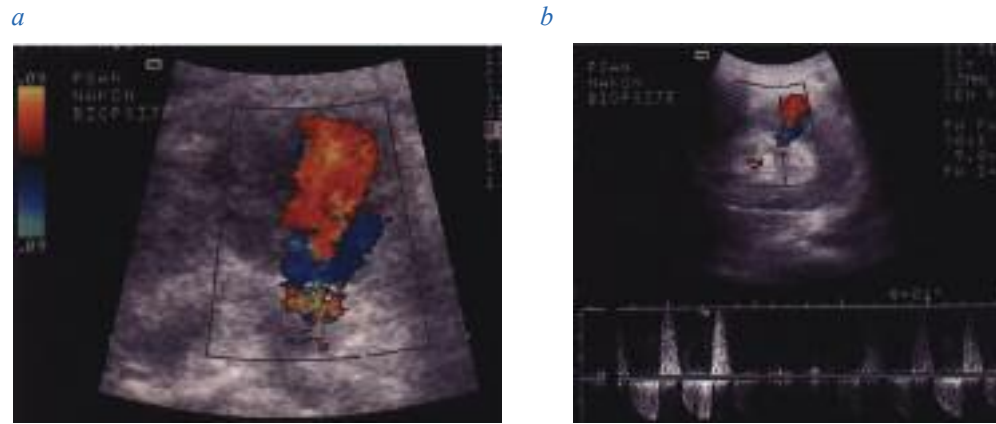
a   b

Figure 23 High systolic and high diastolic flow Doppler spectrum from iatrogenic arteriovenous fistula in the kidney, which is a complication of kidney biopsy.


Colour and power Doppler are useful in acute pyelonephritis, especially in children, in which focal area of hypovascularisation can be demonstrated with high accuracy of 80–90%, and methods that expose children to ionizing radiation, such as dynamic scintigraphy and CT can be avoided [45].

Figure 24 Colour duplex Doppler of elevated renal vascular resistance in a 60-year-old female patient with autosomal dominant polycystic kidney disease; RI is 0.76.

Figure 25 Nutcracker syndrome. B-mode (a) and Power Doppler (b). The left renal vein (VRS) is between the aorta (AO) and superior mesenteric artery (AMS). The vertebral spine is also indicated (WS). VCI: inferior vena cava. Niere: kidney.

a   b

c
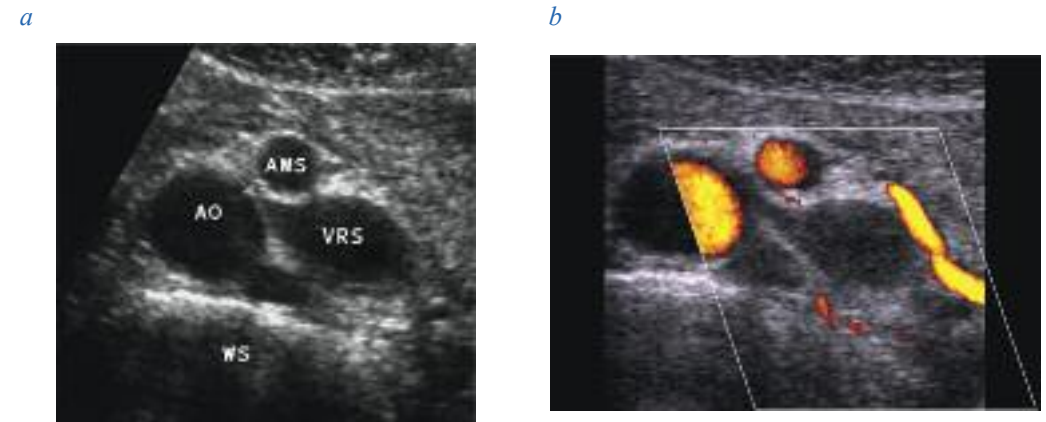
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