Ultrasound imaging of the kidneys

Introduction

A wide range of disorders affect the kidneys and ultrasonography is often the modality of choice in the initial assessment. This article reviews the ultrasound appearances of some common adult kidney disorders encountered in daily practice.

Technique and normal appearances

The mainstay for ultrasound examination of the kidneys is provided by real-time, gray-scale, B-mode imaging using a 3–5 MHz transducer.

Ultrasound produces two-dimensional images and is non-invasive, quick, portable (for intensive care patients) and inexpensive without using ionizing radiation.

The normal renal outline appears smooth with an echogenic (bright) central renal sinus (made up of the pelvicalyceal system, vessels and fat). The renal cortex is seen as a uniform zone of relatively low echogenicity. The medullary pyramids are identified as triangular areas of lower echogenicity than the cortex (*Figure 1*). The kidneys can be accurately measured and cortical thickness assessed. The ureters are not usually visualized. The bladder should be imaged full, to allow optimal assessment of wall thickness, masses and calculi. Pre- and post-micturition volumes can be measured.

Doppler ultrasound can be used to assess vessel patency, direction of flow and degree of stenosis, e.g. renal artery stenosis. The technique is based on the principle that when incident sound waves are reflected from a moving structure, the frequency is shifted by an amount proportional to the velocity of the reflector (e.g. red blood cell), and this can be quantified and displayed as a spectral Doppler or a colour overlay (colour Doppler) (*Figure 2a*). Flow towards the transducer is conventionally red and away blue. Spectral Doppler interrogation of a vessel gives a time-dependent velocity profile useful in assessing vascular stenoses (*Figure 2b*). Power Doppler shows the intensity of the Doppler shift as a colour display; directional and flow information is lost but sensitivity may be increased (*Figure 2c*). The normal adult renal vasculature is of low resistance meaning that the arterial signal is fast with an almost vertical systolic upstroke and continuous forward end diastolic flow. The resistive index in the renal arteries is thus relatively low with normal values ranging from 0.58–0.64.

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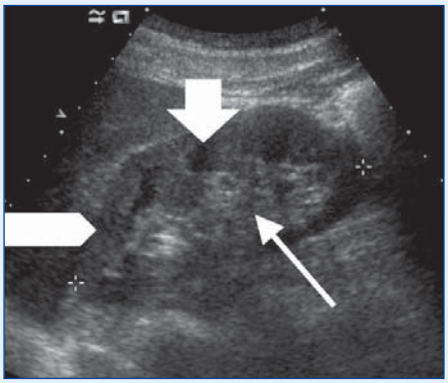


Figure 1. Longitudinal ultrasound scan of a normal kidney showing renal cortex (chevron), echogenic central renal sinus (straight arrow) and pyramid (thick arrow).

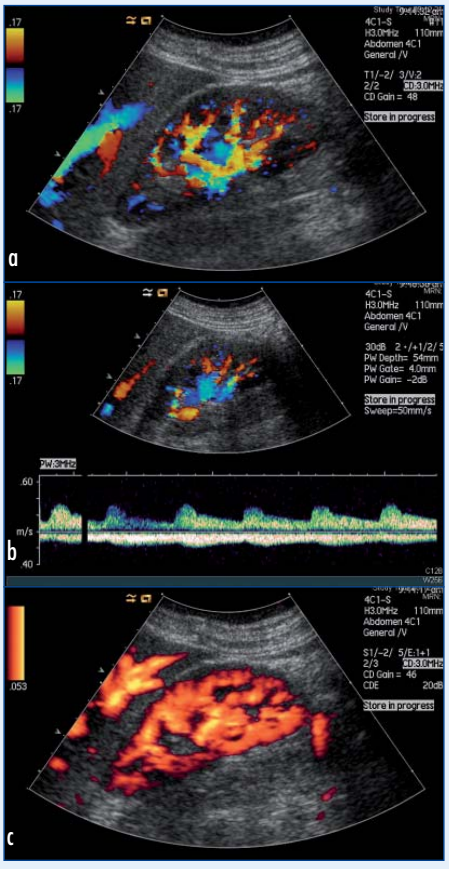


Figure 2. Doppler ultrasound study of a normal kidney. a. Colour Doppler with red indicating flow towards the transducer. b. Colour and spectral Doppler with the spectral Doppler cursor positioned over an artery and vein. The arterial trace is seen above the baseline (indicating flow towards the transducer) and the venous trace below. c. Power Doppler demonstrating peripheral cortical flow.

Indications

There are many indications for renal ultrasonography and recommendations for the investigation of common problems, based on the Royal College of Radiologists (2007) guidelines, are given in *Table 1*. While one of the commonest indications is the assessment of acute or chronic renal impairment, ultrasound is also excellent for the assessment of renal masses and is very sensitive to obstruction. The real-time nature of ultrasound imaging is highly suited to renal biopsy and guides interventions such as nephrostomy placement.

Cystic disease

Simple cysts

A simple cyst is the most common focal renal lesion and is a common incidental finding with increasing age. Simple cysts may be solitary or multiple and generally are asymptomatic unless they become infected, haemorrhagic or cause obstruction. They can vary in size considerably ranging from a few millimetres to several centimetres when they can present as an abdominal mass. Most simple cysts are cortical but occasionally are seen within the medulla. They are sharply defined, round or ovoid, thin smooth-walled, anechoic masses which exhibit posterior acoustic enhancement.

Adult polycystic disease

Adult polycystic disease is an autosomal dominant disease with an incidence of 1 in 1000. Around 50% of patients also have cysts in the liver, spleen and pancreas. Ultrasound features include bilaterally enlarged kidneys with multiple, varying sized asymmetrical cysts (*Figure 3*), with lit-

Table 1. Indications for renal ultrasonography

Renal failure	Obstruction – pelvicalyceal dilatation
	Renal size, cortical thickness and scars
Renal masses	Differentiation of simple cystic, solid lesions and abscesses
	Tumour extension into vein
Calculi	Detection of radiolucent stones
	Demonstration of site of stone impaction
Renal transplantation	Complications – obstruction and vascular patency
	Perinephric collections
Renal Doppler	Renal artery stenosis
	Venous patency
	Vascularity of renal masses
Intervention	Renal biopsy
	Nephrostomy
	Cyst aspiration
	Drain insertion

tle intervening normal renal tissue. Haemorrhage or infection can cause internal echoes.

Complex cysts

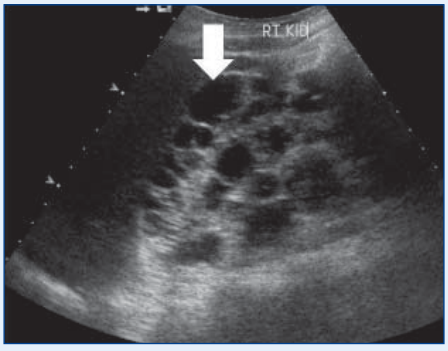
These are cystic lesions with additional features such as internal echoes, septation (*Figure 4*), wall thickening, calcification and hypervascularity. These may be seen in infection, haemorrhage and cystic tumours.

Benign renal tumours

Oncocytoma

This tumour arises from proximal tubular cells and is usually well encapsulated. The mean size at diagnosis is 6 cm. There is a central stellate scar in 30% as a result of necrosis. A spoke-wheel distribution of vessels is characteristic. The latter two features are only seen in large tumours. Percutaneous biopsy is unreliable in making the diagnosis as a well-differentiated renal cell carcinoma may have oncocytic features.

Figure 3. Adult polycystic kidney disease. The kidney is almost completely replaced by anechoic cysts (arrow).



Angiomyolipoma

This is a benign tumour containing blood vessels, smooth muscle and fat. Solitary lesions occur most commonly in women over 40 years of age. Multiple and bilateral angiomyolipomas are a feature of tuberous sclerosis. The tumour may be within the parenchyma or exophytic. Owing to the high fat content, angiomyolipomas are characteristically highly echogenic (*Figure 5*) and are isoechoic to the renal sinus. Diagnosis must be confirmed by further imaging as there is an overlap in appearances with renal cell carcinoma, especially in small lesions (Yamashita et al, 1992). These lesions contain aneursymal vessels with an increased risk of haemorrhage in angiomyolipomas >4 cm in size. Diagnosis can be difficult if there has been haemorrhage into the tumour or the perinephric space.

Malignant renal tumours

Renal cell carcinoma

Renal cell carcinoma is the commonest type of renal malignancy (*Figures 6a* and *b*). Typically renal cell carcinoma is a solid lesion which can either have an irregular or a smooth margin and can be isoechoic (86%) or hypoechoic (10%) (Charboneau et al, 1983) to the surrounding parenchyma. Small renal cell carcinomas (<3 cm) tend to be hyperechoic and may mimic angiomyolipomas. The texture is generally heterogenous and the heterogenicity is further increased by haemorrhage or necrosis. The mass may also contain specks of calcification and be cystic in appearance. Typically they are very vascular. Doppler may demonstrate venous invasion. However, computed tomography (CT) remains the gold standard for detecting, characterizing and staging renal tumours.

Figure 4. Benign complex septated cyst (arrow) on colour Doppler. No vascularity of the septa is present.

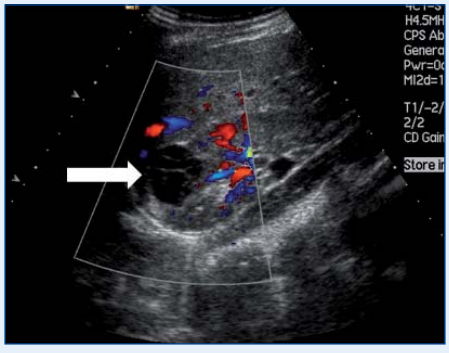
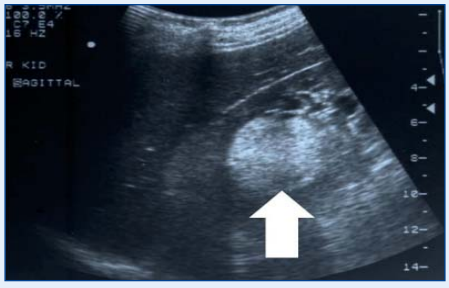


Figure 5. Renal angiomyolipoma (arrow).



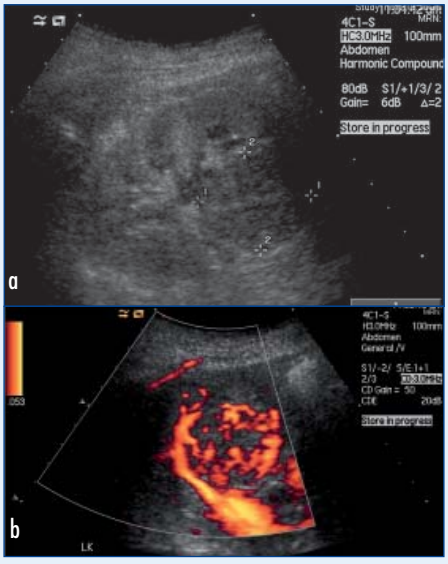
Lymphoma

Renal involvement by lymphoma is not uncommon. The appearances are variable. Most frequently there are multiple masses which are solid, homogenous and hypoechoic. As the masses enlarge they become increasingly hyperechoic and heterogenous.

Obstruction

Ultrasound is a very sensitive method for detecting pelvicalyceal dilatation of which there are many causes (*Figure 7*) (*Table 2*). If the obstruction is chronic it may cause atrophy of the renal cortex. In the majority of cases the exact level and cause are difficult to identify on ultrasound. The level is best demonstrated by intravenous urogra-

Figure 6. Renal cell carcinoma. a. The B mode shows an echopoor mass measured by calipers. b. The renal cell carcinoma is highly vascular on power Doppler.



phy (IVU) or CT IVU. Pelvicalyceal dilatation may be graded as mild (grade I), moderate (grade II) or severe (grade III). In mild pelvicalyceal dilatation there is a centrally positioned, echo-free area within the renal sinus. This collection communicates with the peripheral calyces in moderate dilatation and in marked pelvicalyceal dilatation or hydronephrosis the obstructed large calyces and sinus are easily recognized. The length of the kidney can be increased and the parenchyma is thinned when the hydronephrosis is marked. Both distal, dilated ureters can often be traced for a few centimetres until they are hidden behind bowel gas. Pyonephrosis may develop in a hydronephrotic kidney (*Figure 8*).

There are several important false-positives and negatives for obstruction on ultrasound (*Tables 3* and *4*).

Figure 7. Hydronephrotic kidney caused by an obstructing calculus (measured by calipers).

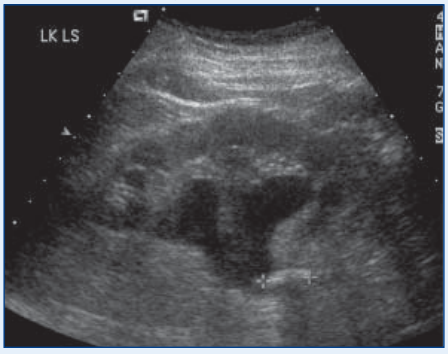


Table 2. Causes of renal tract obstruction

Intrinsic factors	Stones
	Tumour
	Blood clot
	Papillary necrosis
Infective	Stricture caused by chronic infection
	Tuberculosis
	Fungal balls
Congenital	Idiopathic pelviureteric junction obstruction
	Posterior urethral valves
	Ureterocele
Outflow obstruction	Prostatic hypertrophy (benign or malignant)
	Urethral stricture
Extrinsic pelvic mass	Endometriosis
	Lymphadenopathy
	Gynaecological masses
	Inflammatory bowel masses
Iatrogenic	Surgery
Trauma	Stricture
	Blood clot

Renal calculi

Ultrasound has a 96% sensitivity for renal stone detection which is slightly inferior to a combination of plain radiography with CT (Middleton et al, 1988). Stones greater than 5 mm are detected with 100% sensitivity (Middleton et al, 1988). Renal calculi are highly echogenic foci with well-defined posterior acoustic shadowing. The shadowing may be difficult to demonstrate, however, because of the proximity of the hyperechoic sinus echoes distal to the stone and if the calculus is smaller than the width of the ultrasound beam. Small stones may also be missed in the renal sinus because of the similar echogenicity of the renal sinus fat. For these reasons false-positive and false-negative studies are well recognized and the CT IVU is now known as the best and most reliable diagnostic test for calculi detection.

Figure 8. Focal pyelonephritis/abscess (arrow) shown as a defect on power Doppler.

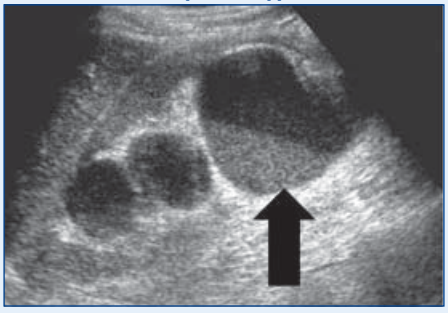


Table 3. Causes of pelvicalyceal dilatation without obstruction (false positives for obstruction)

Normal variants such as a 'baggy' renal pelvis, secondary to a full bladder or congenital megacalyces
Dilated pelvicalyceal system from pre-existing renal disease, e.g. post-obstructive dilatation or infection
Non-obstructed dilated calyces, e.g. reflux nephropathy, pregnancy, calyceal diverticula or papillary necrosis
Increased urine flow, e.g. overhydration, diuresis as a result of medications

Infection

Acute pyelonephritis

The kidneys usually appear normal. If abnormality is present the kidney may be swollen with reduced cortical echogenicity and loss of corticomedullary differentiation. Haemorrhagic necrosis is seen as areas of increased echogenicity (Rigsby et al, 1986). Doppler ultrasound often exhibits reduced blood flow as a result of oedema as opposed to hyperaemia which might be expected (*Figure 9*). Hyperaemia can be seen around focal areas of inflammation. In emphysematous pyelonephritis gas characteristically produces focal areas of increased echogenecity with poorly defined posterior acoustic shadowing.

Figure 9. Pyonephrosis. Obstructed kidney with sludge level (arrow) in a hydronephrotic collecting system.

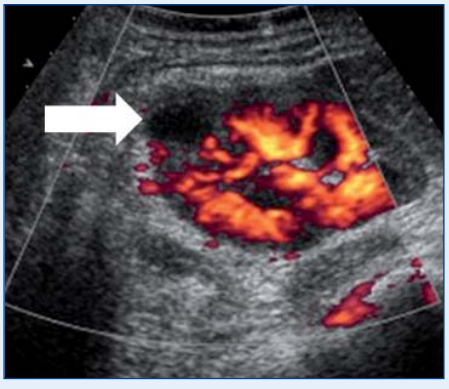


Table 4. Ultrasonography cannot exclude obstruction in the following situations (false negatives for obstruction)

Technical problems	When the kidneys are difficult to identify, e.g. small irregular kidneys with increased parenchymal echogenicity or obese patients.
Cystic disease	A dilated pelvicalyceal system is difficult to visualize in polycystic kidney disease, multiple simple cortical cysts and parapelvic cysts
Calculus disease	Large stones filling and distending the pelvicalyceal system
Failure of dilatation of an obstructed system	In severe parenchymal disease (e.g. acute tubular necrosis), dehydration, infiltrative processes such as retroperitoneal fibrosis or early in acute obstruction

Chronic pyelonephritis

Repeated bouts of infection result in chronic inflammation and scarring. The affected kidney is often small with an irregular contour. A scar is seen as an area of increased echogenicity with an associated dilated calyx and a hypertrophied adjacent parenchyma.

Diffuse renal disease

In a wide spectrum of medical renal diseases the ultrasound appearances are non-specific with renal size, cortical echogenicity or distinctness of the corticomedullary boundary unable to differentiate between pathologies. In acute parenchymal disorders the kidneys may be enlarged as a result of inflammation or oedema, whereas in chronic disease the kidneys are smaller and fibrotic. Typically the renal cortex shows increased reflectivity and may be seen in the presence of systemic sepsis, diabetes, connective tissue diseases, interstitial nephritis, glomerulonephritis, human immunodeficiency virus infection (*Figure 10*), nephrotic syndrome, amyloid and hepatorenal syndrome. Despite these limitations some conditions have characteristic, although not specific ultrasound findings. In acute tubular necrosis there may be increase in renal size and prominent swollen pyramids. In papillary necrosis the initial changes of papillary necrosis are not visualized on ultrasound but calcification may occur in the necrotized papilla tips and if these slough off small round or triangular cystic abnormalities may be seen on ultrasound.

Nephrocalcinosis

This is a group of conditions where calcium is deposited in the parenchyma, usually medulla or rarely cortex. Causes include hyperparathyroidism (*Figure 11*), medullary sponge kidney, renal tubular acidosis, and any cause of hypercalcaemia.

Renal trauma

Ultrasound generally has a secondary role to CT in blunt renal trauma (*Figure 12*). The severity of trauma to the kidney may vary significantly and therefore a range of findings can be seen with ultrasound. The Ferdle classification has been widely adopted (*Table 5*) (Kawashima et al, 2001).

The appearances of haemorrhage vary with its age. Acutely haematoma is hypoechoic and subsequently develops echogenic foci within it as it clots. The haematoma liquefies over several weeks and regains an echo-poor appearance. Lacerations are seen as linear defects in the parenchyma which radiates from the hilum to the periphery. The laceration is inevitably filled with haematoma. Colour and pulsed wave Doppler assessment can help identify vascular pedicle disruption. BJHM

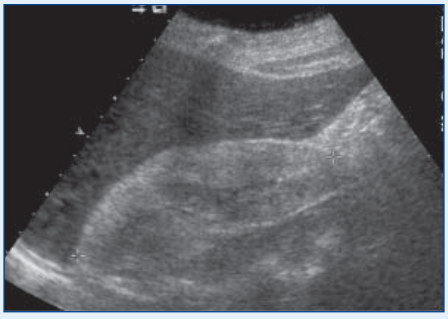


Figure 10. Diffuse renal cortical echogenicity in a case of human immunodeficiency virus infection.

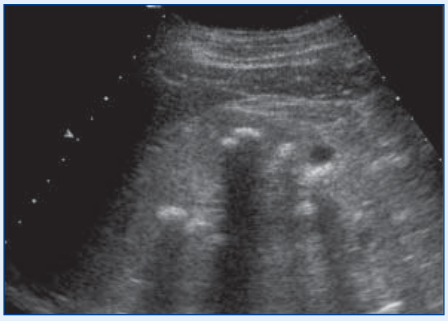


Figure 11. Nephrocalcinosis in case of hyperparathyroidism.

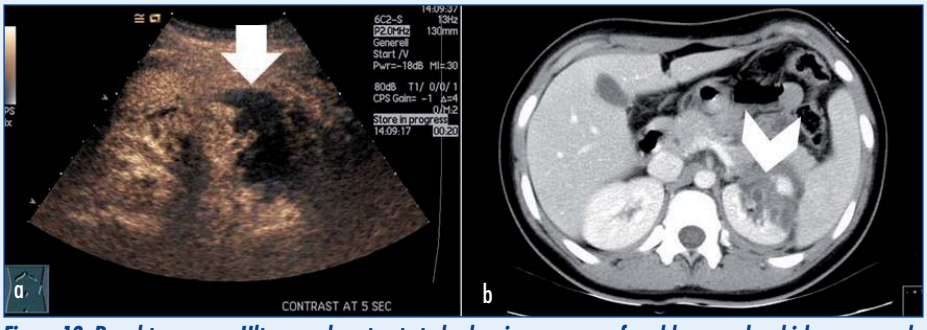


Figure 12. Renal trauma. a. Ultrasound contrast study showing a non-perfused lower pole which corresponds to (b) the unenhanced region (chevron) seen on the computed tomography scan.

Table 5. Ferdle classification of renal trauma

Category I	Minor injuries (75–85%)	Contusion
		Superficial laceration
		Subcapsular haematoma
Category II	Major injuries (10%)	Deep laceration with or without involvement of the pelvicalyceal system
Category III	Catastrophic injuries (5%)	Shattered kidneys and/or renal pedicle injury
Category IV	(Rare)	Pelvi-ureteric junction injuries

From Kawashima et al (2001)

Conflict of interest: none.

Charboneau JW, Hattery RR, Ernst EC et al (1983) Spectrum of sonographic findings in 125 renal masses other than benign simple cyst. *AJR* **140:** 87–94

Kawashima A, Sandler CM, Corl FM et al (2001) Imaging of renal trauma: A comprehensive review. *Radiographics* **21:** 557–74

Middleton WD, Dodds WJ, Lawson TL et al (1988) Renal calculi: sensitivity for detection with US. *Radiology* **167:** 239–44

Rigsby CM, Rosenfield AT, Glickman MG, Hodson J (1986) Haemorrhagic focal bacterial nephritis: findings on gray scale sonography and CT. *AJR* **146:** 1173–7

Royal College of Radiologists (2007) *Making the Best Use of Clinical Radiology Services.* 6th edn. Royal College of Radiologists, London

Yamashita Y, Takahashi M, Watanabe O et al (1992) Small renal cell carcinoma: pathologic and radiologic correlation. *Radiology* **184:** 493–8

KEY POINTS

- Ultrasound is the modality of choice in the initial assessment of renal disease.
- Ultrasound is highly sensitive in the detection of renal obstruction. However, there are important false negatives and positives for obstruction on ultrasound.
- Ultrasound is excellent at differentiating and characterizing renal masses and cysts
- The real-time nature of ultrasound imaging is highly suited to renal biopsy and guides interventions such as nephrostomy placement.