peak incidence before 5 years of age. It occurs in various sites throughout the body.

**Other causes of focal liver lesions**

Liver metastases may occur from most paediatric malignancies, particularly neuroblastoma, rhabdomyosarcoma and Wilms’ tumour (p. 229). Leukaemia and lymphoma may also cause focal defects in the liver. Liver involvement may be manifested by hepatomegaly with normal liver texture, a non-specific sign, or by diffuse coarsened liver texture with or without hepatomegaly.

**Haemangioendothelioma**

Vascular tumours account for most benign liver tumours in childhood, with haemangioendotheliomas being seen more frequently than cavernous haemangiomas. Although haemangioendothelioma may be asymptomatic, infants generally present before the age of 6 months with an abdominal mass, respiratory distress, anaemia and cardiac failure, caused by the shunting of blood from the aorta through the tumour. Large tumours may bleed spontaneously, resulting in haemoperitoneum. They may present with jaundice and increased transaminase levels and 50% of children also have cutaneous haemangioma.10

These tumours are generally multiple, of varying echogenicity and may have a complex echotexture due to thrombus, calcifications and internal septations (Fig. 9.3B). The vascular nature of these lesions is demonstrated by a large coeliac axis and marked decrease in the size of the aorta below the origin of the coeliac axis. The main differential diagnosis of multiple haemangioendothelioma is from metastatic liver disease, particularly from disseminated neuroblastoma.

Although most asymptomatic paediatric haemangioendotheliomas regress spontaneously, those complicated by cardiac failure require active treatment. Steroids may be administered and serial ultrasound scans may be used to monitor the gradual resolution of the lesion. Angiographic embolization or surgical ligation of the major feeding vessels of the hepatic artery may be necessary in severe cases that fail to respond to steroid therapy.

**PANCREAS**

**Normal appearances**

The acoustic characteristics of the pancreas vary with age. Pancreatic echogenicity is quite variable and is occasionally hypoechoic in neonates compared with the adult gland. In older children echogenicity is equal to or slightly greater than that of the liver. The pancreas is relatively larger in young children than in adults, gradually increasing with age, reaching adult size in late teens.11 The pancreatic duct is often visualized but should not be greater than 2 mm in width. The relative hypoechoogenicity and relatively larger size of the normal pancreas in childhood should not be misinterpreted as a sign of probable pancreatitis when scanning a child with abdominal pain (Fig. 9.4).

**Pathology of the pancreas**

Pancreatic abnormalities are relatively uncommon in childhood. Most ultrasound abnormalities are the result of infiltrative processes associated with other syndromes or diseases (Table 9.1). Focal pancreatic lesions are rare.

Ultrasound is an ideal investigation for evaluating the paediatric pancreas, as a high-frequency
probe demonstrates excellent detail. A water-based drink may be given to provide an acoustic window. In cases of blunt injury to the abdomen with suspected pancreatic damage, CT is the imaging modality of choice in the acute situation, although sonography should be used during follow-up to detect the presence of a pseudocyst.

**URINARY TRACT**

Ultrasound is the first line of investigation in both antenatally detected abnormalities and in symptomatic children.

- The bladder should be scanned first, as voiding may often occur during the examination.
- Measurements of both kidneys, either length or renal volume, should be taken to highlight any difference in size and to provide a baseline for further growth comparison.
- A variety of planes can be used to view the kidneys in children. Often a posterior approach is best for obtaining an accurate bipolar length.
- Ensure that renal pelvic dilatation is not physiological, by rescanning postmicturition.
- Measure the anteroposterior diameter of any renal pelvic dilatation in transverse section through the renal hilum.
- Always scan the bladder immediately after micturition, paying attention to the ureteric orifice and looking for any ureteric or renal dilatation which may suggest reflux. Measure any residual volume.
- Colour Doppler may be helpful in identifying the ureteric orifice, by locating the jets of urine entering the bladder (Fig. 9.10D).

**Normal appearances**

After birth the renal cortex is relatively hyperechoic compared to the adult kidney, in strong contrast to the hypoechoic medullary pyramids. The outline of the kidney is often lobulated due to a persistent fetal lobulation. The renal pelvis is relatively hypoechoic, as the fat deposition seen in the adult is not yet present (Fig. 9.5A).

Gradually the cortex becomes less hyperechoic with age, the corticomedullary differentiation lessens and fat deposition in the renal sinus becomes more evident. The outline becomes smooth, although fetal lobulations do persist in some adult kidneys.

Normal postnatal growth of the kidneys, in terms of length and volume, is closely related to the height, weight and age of the child. Charts giving normal age- and weight-related values should routinely be referred to. Errors do occur in measurements of renal length with a potential error in the order of 1 year’s growth. Thus follow-up measurements for renal growth should not be undertaken at intervals of less than 1 year.

**Anatomical variants and pathology**

**The duplex system**

The duplex system is one of the more common congenital anomalies, occurring in up to 9% of referrals. It stems from aberrant budding of the Wolffian duct in utero, and can take a variety of forms, from complete duplication with two kidneys, each with a separate ureter, to a partial duplication involving the kidney only. Complete

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**Table 9.1 Paediatric pancreatic abnormalities**

<table>
<thead>
<tr>
<th>Increased echogenicity</th>
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<tbody>
<tr>
<td>Cystic fibrosis</td>
</tr>
<tr>
<td>— fatty replacement of the pancreas, calcifications, ectatic pancreatic duct, coarse texture, cysts</td>
</tr>
<tr>
<td>Pancreatitis</td>
</tr>
<tr>
<td>— hereditary</td>
</tr>
<tr>
<td>— trauma (physical abuse, road traffic accident)</td>
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<tr>
<td>— congenital anomaly, e.g. choledochal cyst</td>
</tr>
<tr>
<td>— drug toxicity</td>
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<tr>
<td>— viral and parasitic infection</td>
</tr>
<tr>
<td>Haemochromatosis</td>
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<tr>
<td>— pancreatic fibrosis, iron deposition in liver and pancreas</td>
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<tr>
<td><strong>Focal lesions</strong></td>
</tr>
<tr>
<td>Cysts</td>
</tr>
<tr>
<td>— isolated congenital cyst</td>
</tr>
<tr>
<td>— autosomal dominant polycystic disease</td>
</tr>
<tr>
<td>— von Hippel-Lindau disease</td>
</tr>
<tr>
<td>— Meckel–Gruber syndrome</td>
</tr>
<tr>
<td><strong>Solid lesions</strong></td>
</tr>
<tr>
<td>— primary pancreatic neoplasms are very rare in children</td>
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</table>
duplication predisposes to reflux, particularly into the lower moiety and subsequently to infection.

The upper pole moiety of a duplex kidney is more prone to obstruction either secondary to a ureterocele or, less commonly, with an obstructed ectopic ureter. In the former case the obstructed upper moiety may be associated with a dilated ureter which can be followed to the bladder where a ureterocele, that is, a cystic dilatation of the distal ureter, may be seen within the bladder at the ipsilateral vesicoureteric junction (Fig. 9.5 B, C and D). The ureterocele may extend into the urethra, causing bladder outlet obstruction which, if severe, may result in bilateral hydronephrosis.

In the absence of any dilatation, it may be difficult to demonstrate the duplex kidney on ultrasound. Generally, the kidney is longer than normal and two discrete, hyperechoic sinus echoes can be seen. Ectopic insertion of the upper pole ureter in a duplex system is a cause of urinary incontinence in girls. It may not be possible to follow an ectopic ureter to its distal end, even when dilated, but one may be able to demonstrate that the ureter is passing distally to the bladder.
When there is a strong clinical suspicion of an ectopic ureter an intravenous urogram or MR urogram will be required to identify a duplex kidney and site of ureteric insertion.

Renal fusion and ectopia

The horseshoe kidney is the most common form of renal fusion, in which the lower poles of the kidneys are fused with a central isthmus or ‘bridge’ across the front of the spine (Fig. 9.6). The isthmus frequently lies behind gas-filled bowel and can be difficult to detect. The sonographer should be suspicious of a horseshoe kidney when the lower poles of the kidneys cannot be clearly outlined, particularly when both kidneys look a little smaller than expected for age. Always ensure you see the outline of the lower poles clearly by turning the child prone or by scanning coronally through the side if necessary.

A dimercaptosuccinic acid (DMSA) scan may demonstrate the isthmus or bridge of renal tissue (when the ultrasound scan is equivocal) but only if it is functioning. In some cases the bridge is composed of non-functioning, fibrous tissue.

Fusion can take other forms, including an L shape, where one kidney lies horizontally across the midline; crossed ectopia, where both kidneys lie on the same side; H-shaped fusion of the hilar regions; and complete fusion to form a ‘cake’-shaped solitary kidney.

Ectopic kidneys occur most frequently in the pelvis (Fig. 9.7). In rare cases the kidney may be situated in the thorax.

Ectopic and horseshoe kidneys are often associated with a degree of malrotation of the kidney. This can be associated with a degree of obstruction at the pelviureteric junction, and predispose to the development of renal calculi.

Figure 9.6 (A) The lower pole of this right kidney (RK) could not be successfully demonstrated. Horseshoe kidney was suspected, and confirmed on coronal scanning planes. (B) Longitudinal section (LS) in the midline shows the renal isthmus of a horseshoe kidney anterior to the aorta. (C) Transverse section (TS) through the lower abdomen demonstrates the isthmus anterior to the spine.
Renal agenesis

The kidneys form from the ureteric bud, which arises from the pelvic area during the fifth to sixth week of gestation. The bud undergoes numerous divisions, forming the ureters, renal pelvis, calyces and renal tubules. Any interruption of this process may cause renal agenesis or ectopia.

Bilateral renal agenesis is lethal and is usually diagnosed prenatally. The incidence of unilateral renal agenesis is about 1:450 live births and is usually prenatally detected. Ultrasound is useful in confirming the prenatal diagnosis and excluding the presence of an ectopic kidney. A DMSA scan confirms the diagnosis. Renal agenesis is associated with VATER syndrome and with ipsilateral gynaecological anomalies in girls.

Multicystic dysplastic kidney (MCDK)

The MCDK is generally the result of complete, early ureteric obstruction in utero before 10 weeks, and is frequently diagnosed antenatally. The resulting kidney is non-functioning and contains cysts of varying sizes, separated by echogenic ‘dysplastic’ renal parenchyma. In general the cysts do not communicate but occasionally some communication can be seen, making differentiation from a severe hydronephrosis difficult.

MCDK is usually unilateral and is considered a benign condition, although there is a slight risk of malignancy and hypertension in later life. The kidney gradually involutes and often completely disappears (Fig. 9.8A, B). Surgical removal is unnecessary unless symptomatic due to its large size or is associated with repeated episodes of infection. Provided the contralateral kidney is normal, with good function, the prognosis is good. There is, however, an increased risk of associated urinary tract anomalies, such as ureterocelectasis, vesicoureteric reflux or contralateral pelviureteric junction obstruction, which may predispose to infection. These can be demonstrated with ultrasound and micturating cysto-urethrogram.

A DMSA scan differentiates MCDK, which is completely non-functioning, from a grossly hydronephrotic kidney, a distinction which may sometimes be difficult to make on ultrasound. Follow-up ultrasound scanning is generally advised in view of the slight increased risk of Wilms’ tumour and to monitor the growth of the contralateral kidney.

Polycystic disease of the kidneys

Autosomal recessive polycystic disease of the kidney (ARPCDK: infantile) may be diagnosed prenatally. Both kidneys are abnormal, being large and hyperechoic, with loss of corticomedullary differentiation (Fig. 9.8C). There is a spectrum of severity of disease and in some cases it may present later
in childhood with the milder, juvenile form of the disease. Prenatally the less severe forms appear normal on ultrasound. ARPCDK is associated with hepatic fibrosis and portal hypertension.

Autosomal dominant polycystic disease of the kidney (ADPCDK: adult) also has a wide spectrum of severity. Although it tends to present later in life, the more severe forms can present in childhood and can occasionally be diagnosed prenatally. Frank cysts can usually be demonstrated on ultrasound, but may not be detected until the second or third decade of life. The disease is also associated with cysts in the liver and pancreas, and with intracranial berry aneurysms.

Renal dilatation

Hydronephrosis is frequently detected antenatally, although the cause may be difficult to demonstrate. Dilatation is due either to obstructive uropathy, for example vesico- or pelviureteric junction obstruction, posterior urethral valves or obstructed upper moiety of a duplex kidney (Fig. 9.9), or it may be non-obstructive, for example due to reflux (Fig. 9.10).

Postnatal ultrasound scans should be performed when the infant is more than 4 days old, because there is commonly a period of dehydration immediately after birth. This may cause an obstructed or otherwise dilated kidney to appear normal for the first few days of life. If normal a follow-up scan is generally recommended at about the age of 6 weeks.

The presence of any calyceal dilatation or ureteric dilatation, as opposed to dilatation confined to the renal pelvis, is an important factor to note, indicating a greater degree of severity. A measurement of the anteroposterior diameter of the dilated intrarenal pelvis is a useful baseline from which to compare subsequent follow-up scans (Fig. 9.9D). It should be noted that slight separation of the renal pelvis is a normal finding in the newborn: an anteroposterior renal pelvis of 5 mm is the upper limit of normal.

The presence of a baggy, extrarenal pelvis, less than 10 mm, without pelvicalyceal system (PCS) dilatation is usually managed conservatively using ultrasound monitoring to demonstrate any increasing dilatation. PCS dilatation with a renal pelvic diameter of between 10 and 20 mm is more serious.
and likely to require an assessment of renal function with a MAG3 renogram. Conservative treatment is possible, but surgery may be required for very poor function.

The dilated renal tract is predisposed to infection due to ascending infection in reflux or haematogenous infection in an obstructed system, where a pyonephrosis requiring percutaneous nephrostomy may develop. As a consequence antibiotic prophylaxis is frequently advised in the neonate with significant renal tract dilatation.

Bilateral renal tract dilatation in boys may be due to posterior urethral valves with secondary dilatation of the upper tracts due to the urethral obstruction. The diagnosis is confirmed by fluoroscopic mic-turating cystography. This diagnosis may be suspected sonographically by the association of bilateral hydronephrosis with a distended and thick-walled bladder.

**Vesicoureteric reflux**

Vesicoureteric reflux, the retrograde passage of urine from the bladder up the ureter and into the kidney, predisposes the child to urinary tract infection and the development of reflux nephropathy. In the first year of life only, reflux is more common in boys than in girls and is usually more

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**Figure 9.9** Renal dilatation. (A) Dilatation of the pelvicalyceal system (PCS) due to pelviureteric junction obstruction. (B) TS of the same kidney. The ureter was not dilated. (C) Duplex RK with gross dilatation of the lower pole moiety containing echoes due to infection. The cortex is thin. The smaller upper pole moiety is also dilated. A ureteroceole was present at the right vesicoureteric junction (VUJ). (D) Mild dilatation of the LK. An anteroposterior (AP) measurement of the PCS provides a good baseline for follow-up.
severe. Conversely, after the first year of life reflux is more likely to present in girls and is often less severe. Vescoureteric reflux is a common cause of hydronephrosis antenatally, accounting for up to 38% of all prenatal urinary tract dilations, requiring ultrasound follow-up and antibiotic prophylaxis.

Reflux may either be due to a developmental anomaly at the vesicoureteric junction, or the result of a neurogenic bladder, partial outlet obstruction or foreign bodies such as calculi and the presence of a catheter.

Children who have had one or more episodes of urinary tract infection should be investigated to search for an underlying cause and to identify evidence of reflux nephropathy (Tables 9.2 and 9.3). Approximately 2% of boys and 8% of girls will develop at least one urinary tract infection by 10 years of age, requiring investigation, and in most centres will account for a substantial proportion of the paediatric sonography performed.

Reflux itself is not reliably diagnosed by ultrasound as it is possible to have intermittent reflux in the presence of a normal ultrasound scan, with a
There may be evidence of thickening of the uroepithelium of the renal pelvis due to intermittent renal pelvis distension. Uni- or bilateral dilatation may be present to a mild or severe degree and may involve the kidney and/or ureter (Fig. 9.10). It is important to scan the renal pelves and ureteric orifice immediately after micturition, when intermittent dilatation due to reflux may be demonstrated on an otherwise normal scan.

When dilatation is seen, the exact cause may be uncertain unless reflux is actually visualized, which is rare, and micturating cystography is required.

Although most commonly performed conventionally by fluoroscopy using iodinated contrast medium, radionuclide cystography and more recently contrast sonocystography have been used as an alternative, particularly in the older child.\textsuperscript{18}

The most common complication of reflux is infection and most children present with at least one episode of urinary tract infection. This can cause renal scarring. It is important to make the diagnosis of vesicoureteric reflux and renal scarring early in order to prescribe prophylactic antibiotics in an attempt to avoid the damaging complications caused by reflux of infected urine. The ultrasound appearances of scarring include a focal reduction in cortical thickness, irregular outline, interruption of or loss of the renal capsule echo or a disruption in the renal architecture. Colour flow and power Doppler may show triangular areas of decreased or absent blood flow (and occasionally increased flow) and can improve the detection rate of focal scarring on sonography.\textsuperscript{19} These signs can be difficult to demonstrate in young children’s kidneys, particularly when highly lobulated, and the most reliable method of scar detection is a DMSA scan (Fig. 9.10F).

Chronic reflux nephropathy leads to failure of renal growth, resulting in a shrivelled, poorly functioning kidney. Measurements of the maximum length of the kidneys should be routinely performed, and can be related to age, height and weight.\textsuperscript{12} A difference in renal length of more than 10% between

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**Table 9.2 Conditions associated with urinary tract infection (UTI)**

- Vesicoureteric reflux
- Obstruction
  - pelviureteric junction
  - vesicoureteric junction
  - posterior urethral valves
  - duplex kidney with obstructed moiety/ectopic ureter
  - ureterocoele
- Other structural anomalies
  - duplex and/or ectopic renal anatomy
  - multicystic dysplastic kidney
  - prune belly syndrome
- Calculi
- Neurogenic bladder

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![Figure 9.10 cont’d](E) Small, scarred RK, due to reflux. (F) DMSA scan showing bilateral renal scarring due to reflux. Note in particular two wedge-shaped scars in the RK.
the two kidneys should prompt further investigation into renal function with a DMSA scan.

**Fungal infection**

Candidiasis is a fungal infection which is most commonly seen in infants who are acutely ill or immunocompromised or in sick ventilated neonates. Fungal balls dilate and may obstruct the collecting system of the kidney (Fig. 9.11). Ultrasound is particularly useful in making the diagnosis by demonstrating the hyperechoic fungal balls within the dilated collecting system. Fungal infection may also undergo haematogenous spread to the spleen and liver, where it can result in multifocal abscess formation.

**Wilms’ tumour**

The most common paediatric renal malignancy, Wilms’ tumour usually presents before the age of 3 years. Although the lesion generally occurs in previously fit individuals, there are several known predisposing conditions, including hemihypertrophy, Beckwith–Wiedemann syndrome and sporadic aniridia, with an incidence of 30–40% in sporadic aniridia.
The tumours are large at presentation, presenting with a palpable abdominal mass, and, less frequently, pain, haematuria and fever. About 5% of these tumours are bilateral. The prognosis when unilateral is generally good.

The ultrasound appearances are of a relatively well-defined heterogeneous mass, predominantly solid but frequently with some necrotic or haemorrhagic areas, often almost completely replacing the kidney (Fig. 9.12). Small focal areas of calcification are seen very occasionally. A search should be made for tumour invasion of the renal vein and IVC which occurs in up to 10% of cases. Tumour invasion may extend into the right atrium. Occasionally a large, right-sided Wilms’ tumour may compress the IVC but not invade it; colour or power Doppler may be useful in the difficult distinction between compression and invasion on ultrasound. Ultrasound also identifies associated lymphadenopathy, particularly in the para-aortic and paracaval regions, and metastatic liver disease.

In a small percentage of cases, tumour may also be found in the contralateral kidney. This is usually much smaller than the mass on the presenting side and may be acoustically subtle. Up to 7% of contralateral tumours are missed on preoperative imaging due to their small size and the operator must be alert to the possibility of bilateral disease.

Occasionally a Wilms’ tumour may be found to be predominantly cystic, having the appearances of a large, multiloculated cystic mass. The main differential diagnosis would be of a mesonephric blastoma occurring during the first year of life and histology is required to establish the diagnosis.

In most cases, an ultrasound and chest radiograph are sufficient to diagnose correctly Wilms’ tumour but CT of the chest and abdomen is generally used for staging, and to exclude metastatic disease in the chest and liver. Percutaneous biopsy for confirmation of histological type is generally performed. CT or MRI is more sensitive than ultrasound scanning in demonstrating small tumours in the contralateral kidney.

Xanthogranulomatous pyelonephritis

Xanthogranulomatous pyelonephritis results from chronic infection in an obstructed kidney and children present with a history of general malaise, low-grade fever and flank pain and may be found to be anaemic. The finding of a palpable abdominal mass on examination often leads to an early diagnosis of a possible Wilms’ tumour. On sonography the kidney is diffusely enlarged, with loss of the normal corticomedullary differentiation. The presence of calyceal dilatation with debris and calculi in the collecting system and confirmation of urinary infection in addition to the generalized involvement of the kidney helps to differentiate this condition from Wilms’ tumour (Fig. 9.12B). Occasionally
CT scanning may also be helpful. The kidney will usually be found to be non-functioning on a DMSA scan and nephrectomy is required.

Renal vein thrombosis (RVT)

RVT primarily occurs in the neonatal period but may occur in the older child, particularly in association with renal malignancy and amyloidosis. Classically the sick neonate is noted to develop gross haematuria in association with a palpable abdominal mass. RVT is usually unilateral but may be bilateral and is associated with acute adrenal haemorrhage when left-sided. Sonographically the affected kidney is enlarged and globular and develops an inhomogeneous echogenicity of the renal parenchyma with areas of increased echogenicity due to haemorrhage (Fig. 9.12C). Thrombus may be detected in the

Figure 9.12  (A) Large Wilms’ tumour arising in the left kidney and filling the left flank with a solid, heterogeneous mass. (B) Xanthogranulomatous pyelonephritis was the cause of the renal mass in this 8-year-old boy presenting with anaemia and a flank mass. (C) Renal vein thrombosis in a dehydrated neonate, showing an enlarged ‘globular’ kidney with loss of the normal corticomedullary differentiation.
ipsilateral renal vein and IVC and Doppler sonography shows reduced or absent blood flow in the renal vein and loss of the normal variation in the renal vein waveform. Arterial flow is also decreased. On follow-up the kidney may completely recover due to the development of collateral blood flow or early recanalization of the renal vein, but in severe cases the kidney may atrophy and calcify.

**ADRENAL GLANDS**

**Normal appearances**

In utero and postnatally, the adrenal glands are large, about one-third the size of the kidney, and composed mainly of the bulky, hypoechoic fetal cortex which makes up about 80% of the gland. The neonatal adrenal glands are easily demonstrated on ultrasound. The bulky fetal cortex is sonographically apparent as a thick hypoechoic layer surrounding the thinner, hyperechoic adrenal medulla (Fig. 9.13A). The fetal cortex surrounds the smaller, permanent cortex and gradually starts to involute after birth. By the age of 2–4 months, the adrenal glands have attained their normal adult configuration of the thin, hypoechoic cortex with a tiny layer of hyperechoic adrenal medulla within.

**Neuroblastoma**

The neuroblastoma is a malignant tumour arising in the sympathetic chain, most commonly the adrenal medulla. The majority of neuroblastomas present before the age of 4 years with a palpable abdominal mass, and many already have metastases at the time of presentation to the liver, bone marrow, skin or lymph nodes. Table 9.4 lists the most frequent abdominal tumours occurring in childhood.

The tumour is usually large on presentation, displacing the kidney downwards and laterally. In some cases it may invade the adjacent kidney, becoming difficult to distinguish from a Wilms’ tumour. Neuroblastoma is predominantly solid on ultrasound, having a heterogeneous texture and frequently containing calcification. The tumour margins are ill-defined and infiltrate the surrounding organs and tissues, crossing the midline and encasing vascular structures: it may be difficult to differentiate from lymphadenopathy (Fig. 9.13B, C and D). Nodes tend to surround and elevate the aorta and IVC.

MRI and CT are used for staging, particularly in assessing retroperitoneal spread. Bone scintigraphy and MIBG scans are also useful in demonstrating metastases.

**Adrenal haemorrhage**

After birth, the bulky fetal cortex normally involutes. Adrenal haemorrhage occurs in the neonate as a result of trauma to the vulnerable fetal cortex during delivery or in association with perinatal asphyxia. Haemorrhage may occur in up to 2% of births. This may be uni- or bilateral and may cause a palpable mass and abdominal pain. Ultrasound can be used to follow the resolution of the haemorrhage over a period of weeks; in the initial stages of haemorrhage the adrenal mass is hyperechoic, gradually liquefying into a well-defined mass of mixed echo pattern and becoming cystic (Fig. 9.13 E, F). This may completely resolve over a period of some weeks leaving a normal adrenal gland or the gland may become atrophic and calcify. In rare cases an adrenal haemorrhage may progress to an abscess.

**Adrenal calcification**

Calcification of the gland in babies and infants is usually the result of previous infection or haemorrhage. Adrenal abscess cavities may calcify after successful treatment. Gross calcification in bilateral adrenal glands in association with hepatosplenomegaly in the infant indicates the likely diagnosis of Wolman’s disease, an inborn error of lipid metabolism that is invariably fatal.

**GASTROINTESTINAL TRACT**

Bowel ultrasound in paediatrics is an established and readily accepted investigation, replacing contrast radiology in many cases. The range of potential applications continues to increase. Most gastrointestinal tract scanning in paediatrics is best performed with a high-frequency (15–7.5 MHz) linear or small footprint curvilinear probe.
Figure 9.13  (A) Normal adrenal gland in a neonate, demonstrating the bulky, hypoechoic fetal cortex surrounding the thinner, hyperechoic medulla. (B) Left adrenal neuroblastoma. (C) Metastases were also present throughout the liver. (D) Confirmation of the left adrenal neuroblastoma and liver metastases on CT. (E) Adrenal haemorrhage in a neonate. (F) Same patient as in (E); 3 months later the haemorrhage has resolved and calcification has developed in the involuted adrenal gland.
Hypertrophic pyloric stenosis (HPS)

HPS is a condition occurring in newborn infants commonly about 6 weeks of age when the pyloric muscle becomes hypertrophied and elongated, restricting the passage of gastric contents, causing projectile vomiting. Most infants with HPS are found to have a hypochloraemic alkalosis and, when seen in association with a palpable epigastric mass the size of an olive on test feeding, the diagnosis is clear without the need for ultrasonic imaging. However, ultrasound is very successful in demonstrating HPS in approximately 20% of infants in whom the pyloric olive cannot be palpated.

The baby should be positioned comfortably right side down and the stomach and pylorus identified usually just to the right of the midline in the low epigastric region. A small feed, of approximately 20–30 ml of sugared water (preferable to milk as it does not contain echoes which may obscure vital detail), may be used to aid visualization of the gastric antrum if the stomach is empty. A nasogastric tube may also be used to administer clear fluid in a controlled way providing that the gastric position of the tube is confirmed prior to injection of the fluid. A small, high-frequency linear or curved linear transducer is best.

The pylorus projects into gastric lumen and is outlined by the fluid. HPS can be confirmed by the demonstration of:

- thickened and elongated pyloric muscle
- increased but ineffective peristalsis
- failure of the pylorus to relax and open

Various figures have been quoted for muscle thickness in hypertrophic pyloric stenosis ranging from 2.5 to 5 mm but 3 mm is most commonly accepted (Table 9.5).

Intussusception

Intussusception is the invagination of a segment of bowel into the lumen of the adjacent bowel. It is a common paediatric emergency, especially in younger children aged 3 months to 3 years, and tends to affect the ileocaecal region.

The child presents with abdominal pain, sometimes with a palpable mass, vomiting or rectal bleeding. Intussusception can result in bowel necrosis and subsequently perforation requiring surgery.

The ultrasound appearances of bowel within bowel are characteristic. In cross-section, the bowel assumes a ‘doughnut’ configuration, with concentric rings of bowel wall (Fig. 9.15). Dilated loops of fluid-filled obstructed bowel may be demonstrated proximal to the intussusception.

The use of ultrasound to diagnose this condition is highly reliable, reducing or eliminating the need for contrast radiology.

An air enema is most commonly used to reduce the intussusception using inflation pressures of up to 120 mmHg. Hydrostatic reduction (that is, with water/saline) under fluoroscopic or ultrasound control is also an accepted treatment.

<table>
<thead>
<tr>
<th>Table 9.5 Pyloric muscle dimensions</th>
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<tr>
<td>Normal pylorus</td>
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<td>Pyloric length (mm)</td>
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<td>Pyloric width (mm)</td>
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<td>Muscle thickness (mm)</td>
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Figure 9.14  Hypertrophic pyloric stenosis.

(A) Normal pylorus demonstrating measurement of length of pyloric canal and thickness of the muscle. (B) A few minutes later the pylorus relaxed and opened widely, excluding the diagnosis of hypertrophic pyloric stenosis. (C) Thickened and elongated pylorus of hypertrophic pyloric stenosis seen in longitudinal section. S represents a fluid-filled stomach. (D) TS view of the thickened pylorus. (E) Demonstrates the measurements of pyloric length, muscle thickness and pyloric width.
The main contraindications to attempting a non-surgical reduction are peritonitis and free intraperitoneal air. A number of sonographic features have been reported to be associated with a decreased success rate of non-surgical reduction, including a hypoechoic rim greater than 10 mm, absent blood flow on colour flow Doppler sonography, or a large amount of fluid trapped within the intussusception, but these findings are not contraindications to a careful attempt at non-surgical reduction. Approximately 10% of cases recur whether the initial intussusception was treated surgically or non-surgically.

**Midgut volvulus**

Malrotation of the midgut occurs as a result of failure of normal rotation of the small bowel during intrauterine development, resulting in a shortened...
mesenteric fixation of the small bowel to the posterior abdominal wall. This predisposes the small bowel to twisting (volving) around the mesenteric vascular axis, resulting in bowel obstruction and vascular compromise with a risk of infarction of most of the small bowel if the volvulus is not treated quickly.

Following volvulus the child presents with acute pain and bile-stained vomiting. The bowel may intermittently twist and untwist, resulting in temporary alleviation of symptoms, which may make diagnosis more difficult.

The definitive diagnosis is usually made fluoroscopically during an upper gastrointestinal contrast study. In malrotation the duodenal jejunal flexure is generally found to be lower and in a more medial position than is normal and if a volvulus has occurred a corkscrew appearance of the volved small bowel may be seen (Fig. 9.16). The proximal duodenum will be dilated secondary to the duodenal obstruction.

Malrotation without volvulus may be suspected during a sonographic examination performed for intermittent abdominal pain due to the associated malposition of the mesenteric vessels and is best seen on colour Doppler sonography. The normal relationship of the superior mesenteric vein to the superior mesenteric artery is reversed, with the superior mesenteric vein lying anteriorly and/or to the left of the superior mesenteric artery. However this finding is not always present and may occasionally be seen in normal individuals and therefore a contrast study is required for confirmation.

When volvulus has occurred the vessels may be noted to be spiralling around a bowel mass, that is, the ‘whirlpool sign’ (Fig. 9.16). Other ultrasound appearances include a dilated, fluid-filled obstructed duodenum, although the obstructed duodenum may be gas-filled, obscuring visualization. This sign is not invariable, however, and a contrast study may still be needed to confirm or exclude the diagnosis of a midgut volvulus. Surgery is performed to untwist the bowel, which is then laid carefully in the correct position; attachment is usually unnecessary, as abdominal adhesions tend to stabilize the bowel.

![Figure 9.16](image-url) Volvulus. (A) Mesentery and superior mesenteric vein are twisted around the superior mesenteric artery, which is seen in cross-section at the centre of the film. (B) Barium meal shows corkscrew of the duodenum away from the midline, consistent with a malrotation and volvulus. (By kind permission of Dr Delia Martinez, Leeds.)
Gastro-oesophageal reflux

Reflux through the gastro-oesophageal hiatus is a common problem associated with neonatal vomiting, leading to oesophagitis. The diagnosis is usually made with a contrast meal, pH probe and isotope milk scan. Reflux can be observed on ultrasound as the retrograde flow of stomach contents through the hiatus and up the oesophagus.

The normal intra-abdominal segment of the oesophagus can be demonstrated through the left lobe of the liver, is usually between 2 and 3 cm long, and makes an acute angle with the gastric wall. When episodes of reflux are seen over three times in 10 minutes, this is said to be pathological.

Appendicitis

Ultrasound is the first line of investigation for the child presenting with acute abdominal pain, where the diagnosis is uncertain following clinical assessment. The position of the appendix in small children may vary—pointing upwards, downwards or to the patient’s left—making the clinical diagnosis difficult, as the pain is not always confined to the right lower quadrant. Ultrasound is particularly useful in establishing the diagnosis of acute appendicitis and in diagnosing other possible causes of acute abdominal pain, such as gynaecological disorders. It is always good practice to perform a full abdominal survey when the clinical presentation is indeterminate.

Figure 9.17  Appendicitis. (A) The normal appendix (arrows) lying transversely across the psoas muscle. (B) Longitudinal scan through dilated inflamed appendix containing appendicolith. (C) Dilated thick-walled appendix seen in LS. (D) Same patient as (C) where appendix is seen in cross-section surrounded by echogenic oedematous mesentery, with dilated fluid-filled caecum seen just laterally.

(Continued)
Ultrasound demonstrates a hypoechoic, thickened appendix, > 6 mm thick, with a blind end (Fig. 9.17). Occasionally an appendicolith, with strong acoustic shadowing, is present. The inflamed appendix is not compressible on gentle, graded compression with the transducer. This should be done very carefully, and released very slowly to avoid rebound tenderness. Ultrasound cannot reliably exclude appendicitis, especially if the appendix is retrocaecal.

Perforation may not be easy to see with ultrasound, as fluid may disperse through the abdomen with decompression of the appendix itself. However, a frank periappendiceal fluid collection or abscess is easily demonstrable in a proportion of children and may, in some cases, be treated conservatively with antibiotics or drained percutaneously prior to surgery. The presence of free fluid, particularly if clear, in the abdomen is a non-specific finding and is not a reliable indicator of an acute abdomen. If echogenic fluid is seen, this is suggestive of intraperitoneal infection in the child with acute abdominal pain, but may be seen in other conditions, for example rupture of a haemorrhagic ovarian cyst. If ultrasound is equivocal, the clinicians may decide to observe the child but further imaging with CT scanning can be helpful in a few selective cases. Alternatively a laparoscopic examination may be performed where there is significant clinical concern.

**Enteric duplication cysts**

These comparatively rare lesions present in infancy or early childhood with nausea, gastrointestinal bleeding, intestinal obstruction and, occasionally, a palpable mass. Most are intra-abdominal but oesophageal
duplication cysts cause a thoracic lesion with respiratory symptoms. Multiple cysts may be present. The fluid-filled lesion may demonstrate a spectrum of ultrasonic appearances, from anechoic to hyperechoic, sometimes with gravity-dependent debris or blood.38

The wall is well defined and a hyperechoic inner rim of mucosa may be identified in some cases of intestinal duplication (Fig. 9.18). The cyst is closely related to the adjacent bowel and this can be appreciated on real-time scanning as the bowel peristaltic. CT and MRI rarely add anything to the ultrasound information. Contrast radiography may show an extrinsic defect but communication with the cyst is rare.

There are many causes of intra-abdominal cystic masses in children. (Table 10.6). The main differential diagnosis in the infant girl is from an ovarian cyst as the ovary is generally an intra-abdominal organ at this age. Useful indicators of an ovarian origin can be detected on careful sonography, by detecting some residual ovarian tissue in the cyst wall, and the finding of a clearly seen multifollicular ovary on one side with absent visualization of a definite ovary on the other side.

**References**


General reading

Ultrasound has an increasingly important role in the initial evaluation of the acute abdomen. Many trauma centres recognize the value of ultrasound as a first-line investigation in properly trained hands. Small portable scanners now offer bedside—even roadside—assessment that can speed the triage process, whereas higher-specification scanners enable the experienced operator to diagnose detailed pathology in the acute abdomen. CT also has an increasing role in this situation. It is readily available in most centres and is proven to be highly accurate. But CT is static, takes longer to arrange and perform and is not always possible, particularly in acutely ill and unstable patients.

There is little doubt that the accuracy of the ultrasound scan is directly attributable to the skill and experience of the operator.\textsuperscript{1} For instance, a detailed knowledge of the anatomy, and therefore potential communications, of the peritoneal and retroperitoneal fascial spaces is essential in order to understand the significance and likely origin of an abdominal fluid collection. A left iliac fluid collection may simply be due to local causes such as a diverticular abscess, but could be the result of fluid tracking from a leaking aortic aneurysm or an acutely inflamed or ruptured pancreas.

One other significant advantage of ultrasound is that it is usually an ‘interactive’ process. In the acute setting, the simple question ‘Where does it hurt?’ will frequently direct the operator to the underlying pathology, for example in acute bowel inflammation or acute cholecystitis. Clinical signs, such as \textit{erythema ab igne}, which results from pain relief by the patient applying a hot water bottle to
the symptomatic area, may also help to focus the examination. The operator should be alert to potential clues and be prepared to step outside standard scanning protocols, adapting to the many possible presentations of trauma or other acute abdominal conditions.

Although many of the following conditions are dealt with in other relevant chapters, together with details of the respective ultrasound appearances, there are issues that are specific to the patient who presents acutely.

**TRAUMA**

Blunt or penetrating trauma to the torso, frequently due to a road traffic accident (RTA) or other forms of accident or violence, is a frequent cause of referral to most accident and emergency departments, and forms the main indication for trauma ultrasound. Internal organ injury as a result of trauma is extremely difficult to assess clinically, especially as many patients are admitted unconscious or in a highly unstable condition. Such trauma patients may require emergency laparotomy and ultrasound has been shown to be an invaluable tool in the triage process. This may be accompanied by CT, which has the advantage of being able to recognize other injuries which may be present, such as bony, spinal or retroperitoneal trauma which may or may not be accessible to ultrasound investigation.

A system of scanning known as FAST (focused assessment with sonography for trauma) has recently become widely adopted in trauma centres. This system depends upon the proper training of appropriate personnel, and a number of standardized training and accreditation programmes have been devised, notably by the American College of Emergency Physicians. FAST scanning involves a minimum four-view examination, principally to detect the presence of fluid which may result from the rupture of internal organs. The four-view scan should include the right and left flanks (for hepatorenal space, perisplenic regions and spaces above and below the diaphragm), the subcostal region (to include the pericardial space) and the pelvis (retrovesical and retrouterine spaces).

Free fluid is associated with numerous types of injury, which may be detected on ultrasound with varying success. These include rupture of the liver, spleen, kidney, pancreas or bowel (Fig. 10.1). A notable limitation of sonography in the trauma situation is in detecting free fluid in the pelvis, as the bladder is frequently empty or underfilled, and the use of the Trendelenburg position, if possible, helps to reduce the number of false-negative results in this respect by allowing any free fluid to collect in the pelvis under the influence of gravity. Ultrasound is more successful in detecting free fluid than in detecting organ injury directly. One study reported a 98% sensitivity for detection of fluid, but only 41% of organ injuries could be demonstrated. However, most of the published studies have concentrated only on the presence or absence of free fluid, rather than the comprehensive assessment of the abdomen by suitably qualified sonographers. The presence of free fluid on ultrasound in a trauma situation therefore infers organ injury requiring careful ultrasonic assessment, further investigation with CT or direct referral for surgery depending on the state of the patient.

Direct visualization of organ rupture is difficult unless a haematoma or other collection is seen. Laceration or contusion may be demonstrated in the liver, kidneys or spleen, but less easily in the pancreas and very infrequently in the bowel. A subtle change in texture may be observed by the experienced operator, or a fine, high-reflectivity linear band representing an organ tear. A delayed scan may demonstrate more obvious organ injury than that apparent on an immediate post-trauma examination. Small visceral lacerations not visible on ultrasound may become apparent when imaged with CT. In particular, pancreatic damage (often due to the sudden pressure of a seat belt across the abdomen during road accidents) may not be obvious immediately post-trauma on either ultrasound or CT. Damage to the pancreatic duct (Fig. 10.1E) causes leakage of pancreatic fluid into the abdominal cavity, resulting in pancreatitis and possible pseudocyst formation or peritonitis.

Free fluid may be present as the result of vessel, rather than organ, rupture. A reduction or loss of blood flow to all or part of the relevant organ, for example the kidney, may be demonstrated using colour and power Doppler ultrasound. The finding of free fluid in women should prompt a detailed
scan of the pelvis where possible. Gynaecological masses may rupture or haemorrhage, presenting acutely, and in women of childbearing age, ectopic pregnancy should be included in the list of differential diagnoses.

When visceral trauma is treated conservatively, follow-up ultrasound may be used to monitor the resolution of any fluid collections or haematoma.

**GASTROINTESTINAL TRACT**

Most acute presentations of gastrointestinal tract pathology are due to obstruction or inflammation, and the ultrasound appearances of these conditions are discussed more fully in Chapter 8. Appendicitis, and its possible complications, is one of the most common reasons for referral (Fig. 10.2). Ultrasound

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**Figure 10.1** (A) The presence of free fluid in a trauma patient implies organ injury, even if this cannot be successfully demonstrated on ultrasound. CT on this patient demonstrated perforation of the bowel. (B) A patient who has been stabbed on the right side has injury to the liver causing a subcapsular haematoma. Blood is also present in the right chest. (C) Laceration of the spleen following a road traffic accident. Free fluid was also present in the abdomen. (D) Splenic lacerations are more obvious several hours after injury. This large splenic haematoma resolved following conservative treatment.

(Continued)
has a high sensitivity for acute appendicitis, particularly in children.

Although the detailed assessment of the primary gastrointestinal pathology usually requires evaluation by an experienced operator with a high-frequency linear probe, many useful indicators can be found with the basic curvilinear or sector abdominal scan. The presence of fluid-filled bowel segments, which may also show ‘overactive’ peristalsis, should alert the operator to the possibility of acute intestinal obstruction. Such segments frequently lie proximal to the obstructing lesion, and so the point at which they appear to end should be the subject of detailed examination. Ultrasound is highly accurate in demonstrating obstruction. However, it is less successful in finding its cause and contrast CT or other bowel studies are usually undertaken when obstruction is diagnosed. With both intestinal obstruction and focal pain it may be necessary to examine the hernial orifices. A small but symptomatic epigastric hernia often goes unnoticed unless a detailed scan of the abdominal wall is performed.

Fluid collections such as abscesses may also point to the diseased segment, for example in Crohn’s disease or acute diverticulitis. Such inflammatory bowel conditions may well present with an established history which helps the operator to focus the ultrasound examination accordingly.

Perforation of an abdominal viscus can produce small amounts of ascites. This is usually ‘mucky’, i.e. containing particulate or gas bubble echoes, and may be localized close to the perforation site, around the duodenum or within the lesser sac. Although gas is usually regarded as an obstacle to ultrasound diagnosis, recent studies have shown that specific patterns of gas echoes can make ultrasound more sensitive than plain radiography in the diagnosis of pneumoperitoneum.

HEPATOBLIARY EMERGENCIES

Ultrasound scanning is invariably the first-line investigation for suspected biliary tract emergencies. These include inflammatory conditions causing right upper quadrant and epigastric pain, mostly acute cholecystitis or gallstone pancreatitis, and the various causes of obstructive jaundice (Fig. 10.3). If possible, interventional treatment should be delayed until a detailed imaging assessment of the cause of biliary obstruction has been made, since the presence of a biliary stent can compromise subsequent imaging by CT, MRI or endoscopic ultrasound. Similarly, biliary stents
frequently cause bile duct wall thickening and may introduce gas into the biliary tree. These will prevent the diagnosis of cholangitis or ductal calculi with ultrasound, and may impede detailed Doppler investigation of, for example, the portal vein. If urgent biliary drainage is required, particularly when the bile is infected, this can quickly be effected by endoscopic stent placement or sphincterotomy. These less invasive methods are replacing surgery as the treatment of choice in this situation, having a lower mortality rate. Endoscopic sphincterotomy and stone extraction have been found to be preferable to surgery, particularly in cases of severe gallstone pancreatitis where patients may be poor operative risks and in cases of stone-related cholangitis.

Ultrasound-guided bedside cholecystostomy may also be useful in high-risk patients with infected gallbladders and is an effective treatment for acalculous cholecystitis brought on by prolonged postoperative fasting.

The liver itself may be acutely tender in systemic venous congestion due to cardiac failure, acute hepatitis, or the presence of an intrahepatic abscess. The management of liver abscesses is determined by their size, number and cause. Ultrasound is used to guide diagnostic aspiration and drainage procedures, and most types of hepatic

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Figure 10.3  (A) An acutely tender, inflamed gallbladder containing stones and debris. (B) A patient with known carcinoma of the head of the pancreas has presented acutely with obstructive jaundice. Her stent (arrow) is blocked, causing intrahepatic biliary duct dilatation with cholangitis (C). (D) Large liver abscess in an acutely ill patient.
abscess can be treated successfully using these techniques combined with appropriate antibiotic therapy.

THE ACUTE PANCREAS

(See also Chapter 5.) Most cases of acute pancreatitis are suspected clinically, with raised amylase levels and often a history of recurrent epigastric pain pointing to the diagnosis of acute pancreatitis (Fig. 10.4). Although pancreatitis may be due to abdominal trauma, it is more frequently due to gallstone obstruction or alcohol abuse. The pancreas often appears normal even when acutely inflamed, so ultrasound examination should focus on the possible causes (such as gallstones, biliary dilatation or evidence of alcoholic liver disease) and complications (pseudocysts, portal or splenic vein thrombosis). Many pancreatic pseudocysts are now managed successfully by endoscopic ultrasound-guided transgastric drainage.13

RENAL TRACT EMERGENCIES

(See also Chapter 7.) Ultrasound is usually the first-line investigation in the assessment of acute loin pain, which in the absence of trauma is commonly due to acute urinary tract obstruction and/or renal infection (Fig. 10.5). Less common acute presentations include renal vein thrombosis or spontaneous haemorrhage, usually from a renal tumour or cyst.

Until recently, ultrasound and/or intravenous urography (IVU) have been the investigations of choice in acute renal colic due to suspected ureteric calculus, and in most UK centres the IVU is currently the method of choice for demonstrating ureteric obstruction (Fig. 10.5E). Low-dose unenhanced multislice CT is increasingly being recommended as a replacement for these two modalities,14 but even with this technique diagnostic pitfalls exist.15 Abdominal ultrasound with or without plain radiography may still provide comparable accuracy where CT resources are limited.16,17

The main limitation of ultrasound in acute ureteric obstruction is that obstruction may be present in the early stages without collecting system dilatation. But the minimally dilated renal pelvis, which would normally be dismissed as unremarkable in a patient with a full bladder, should raise the operator’s suspicion in the patient with acute loin pain. Doppler ultrasound of the kidneys shows a higher resistance index in the obstructed kidney than in the normal side.18 Upper tract obstruction can be relieved via cystoscopy-guided ureteric stent placement. Ultrasound-guided percutaneous nephrostomy may be required if this is not practicable, or if there is evidence of infection.

Renal infection with parenchymal involvement (acute pyelonephritis) may be the cause of severe acute loin pain with fever, but ultrasound examination mostly shows no abnormality. Occasionally the skilled operator using high-specification equipment may be able to identify segmental areas of high reflectivity, showing decreased blood flow with power Doppler. The diagnosis of this condition is usually based on clinical criteria, but these segments can be demonstrated with CT if necessary.

OTHER RETROPERITONEAL EMERGENCIES

(See also Chapter 8.) Ultrasound has an established role in identifying the presence of an abdominal aortic aneurysm, but should not be used to assess subacute leakage or rupture. However, where rupture is suspected, and no previous imaging results
Figure 10.5  (A) Obstructed kidney with pelvicalyceal system (PCS) dilatation and a dilated upper ureter. (B) Mobile stones were demonstrated in the bladder, but the level of obstruction in the ureter could not be positively identified. Intravenous urogram (IVU) confirmed a stone in the ureter. (C) Severe laceration to the liver following a road traffic accident. (D) The same patient’s CT scan confirms the liver injury and demonstrates an avascular right kidney (compared with the normal left kidney (LK)) due to laceration of the renal vessels. (E) Acute renal colic. IVU demonstrates a left hydronephrosis with a stone in the lower ureter. (This area is not usually demonstrable with ultrasound.)
are available, ultrasound can be a time-saving triage tool to exclude an aneurysm from the differential diagnosis of abdominal pain. Suitably trained emergency department clinical staff can perform this quickly and successfully.\textsuperscript{19} Rupture of an aortic aneurysm is a catastrophic event, and although an urgent contrast-enhanced CT can be helpful, emergency surgery based on clinical findings should not be delayed by imaging investigations.

Ultrasound is also the first investigation of choice for demonstrating suspected psoas abscess or haematoma\textsuperscript{20} (Fig. 10.6).

References


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The development of ultrasound-guided minimally invasive procedures, incorporating diagnostic biopsy, therapeutic drainage and treatment techniques, has developed significantly over the last decade and is now accepted practice, in many circumstances being used in isolation as a definitive treatment, and in others in conjunction with other radiological or surgical options. These minimally invasive methods are advantageous, with lower patient mortality and morbidity, increased patient acceptability, and are economically beneficial.

The relative speed and ease with which these procedures can be carried out have resulted in a reduction of the diagnostic laparotomy and more prompt and appropriate patient treatment. Whilst both ultrasound and CT may be used for many of these procedures, in general, ultrasound is often the first-line method as it is effective in the vast majority, generally more accessible, and does not carry a radiation risk. Clearly, the choice of technique will depend upon the experience of the individual, machine availability and the site and depth of the lesion.

**ULTRASOUND-GUIDED BIOPSY: GENERAL CONSIDERATIONS**

Percutaneous biopsy of organs, masses or focal visceral lesions is an integral part of the diagnostic process for a large number of patients. Although changes on ultrasound may confirm the suspected clinical suspicion, that is, a bright liver may indicate fatty change, a nodular liver may suggest cirrhosis or enlarged kidneys of increased echogenicity may...
suggest glomerulonephritis, imaging alone is not enough and a definitive histological diagnosis is required. The advantages of using ultrasound to guide such procedures are numerous:

- The needle tip is directed, in real time, along the biopsy path and visualized within the lesion.
- Greater precision is obtained; needle guidance is essential for all small lesions and lesions at depth.
- Fewer needle passes are required to obtain the desired result.
- The best route can be utilized and vital structures, such as blood vessels, avoided.
- Postprocedure complications, such as haematoma, are minimized.
- Confidence in the biopsy result, particularly a negative one, is increased due to direct visualization of the needle tip in the lesion.
- All the advantages of ultrasound over other imaging methods apply (quick, direct vision, no radiation hazard, low cost). The limitations due to bone and air-filled structures also apply.
- The capability to perform bedside procedures for critically ill patients and to use in conjunction with other imaging techniques, for example fluoroscopy, is advantageous.

With ultrasound the biopsy procedure is quick, safe and accurate and is therefore acceptable to the patient. There are several accepted methods of performing a guided biopsy, but certain generic rules are common to the procedure, regardless of the organ under investigation:

- A written request form from a medical practitioner with the results of any previous investigations should be available. The reason for biopsy should be appropriate.
- Assessment of blood clotting status. Normally the prothrombin time should be within 3 s of the control, platelet count > 75 000/ml and international normalized ratio (INR) < 1.3.
- Identification of possible contraindications to biopsy, for example an uncooperative patient, coagulopathy.
- Careful explanation of the procedure to the patient, including risks and benefits.
- Informed, written consent for the procedure.
- Procedure should be performed in a quiet and clean environment. Appropriate measures should be taken to preserve pre-, peri- and postprocedure sterility.
- A prebiopsy scan to identify a suitable biopsy route avoiding vital structures.
- Satisfactory care of the patient both during and after the biopsy procedure with relevant observations of vital signs. A pulse oximeter and appropriate nurse cover are now recommended.
- Appropriate preparation of the specimen.
- Contraindications are relative and include the biopsy pathway, an uncooperative patient and uncorrectable coagulation and should be assessed on an individual basis.

**Analgesia**

For the vast majority of biopsy procedures local anaesthetic is administered following localization of the biopsy site on ultrasound. Either 1% or 2% lidocaine (lignocaine) is commonly used; the volume will depend upon patient build, depth of lesion and patient anxiety. Normally a short period of time, commonly 4–5 min, is allowed to pass so that the anaesthetic can work, after which a small scalpel incision is made in the skin to facilitate the biopsy needle’s introduction, with little or no discomfort to the patient.

In cases of, for example, simple aspiration with a 22-gauge needle or smaller, local anaesthetic is normally unnecessary.

Patients who are particularly apprehensive may require preprocedure medication with a sedative such as diazepam or similar anxiolytic agent; however this is not common. Very occasionally intravenous analgesia and/or sedation may be required during the procedure; it is often a good idea to have an intravenous cannula in situ prior to biopsy.

The use of a general anaesthetic for children is common practice, to enable the procedure to be carried out quickly and accurately while the child remains still.
Methods of ultrasound guidance

There are various ways of performing ultrasound-guided procedures: organ/lesion localization (‘blind biopsy’), biopsy guide or freehand technique. The choice of method depends upon the procedure in question, equipment and the experience and skill of the operator.

Blind biopsy

With this method a position on the skin surface is marked overlying the organ or lesion to be biopsied, using ultrasound to localize. This remains acceptable for diffuse disease, when only a representative sample of liver tissue is required. Nevertheless, it is good practice even in these situations to visualize the needle during the procedure, and this method of biopsy is now used less frequently.

Biopsy guidance

Most manufacturers provide a biopsy guide which fits snugly on to the transducer head and provides a rigid pathway for the needle (Fig. 11.1). These are now the commonest and preferred method of biopsy. Previously adjustable angle biopsy guides were available; however these offered no specific advantages and were prone to user error. The fixed biopsy guides contain a groove for a series of plastic inserts ranging from 14G to 22G size, depending on the size of the biopsy needle. It is often preferred to use one size greater than the needle, that is a 16G insert for an 18G needle, as the needle tends to move more freely. These guides are sterilized and fitted on to the transducer, which can either be covered by a sterile sheath or thoroughly cleaned with chlorhexidine solution. The use of a sheath is highly recommended, as it maintains the sterility of the procedure, reducing the risk of infection, with no adverse effect on the image.

The needle pathway is displayed on the ultrasound monitor electronically as a line or narrow sector, through which the needle passes. The operator then scans in order to align the electronic pathway along the chosen route, the needle is inserted and the biopsy taken. These attachments should be tested regularly to ensure the needle follows the correct path (Fig. 11.2).

Freehand

A freehand approach, in which the operator scans with one hand and introduces the needle near to the transducer with the other, may be used for larger or more superficial lesions. This technique is commonly used for breast biopsy and biopsy in the head and neck. The needle is inserted from one end of the probe at right angles to the ultrasound beam; generally speaking the angle utilized is shallow in comparison with the fixed guide systems for deeper structures.

Figure 11.1  (A) Necessary component parts to perform an ultrasound-guided biopsy procedure. A series of plastic inserts (A) range in size from 14 to 22G. The appropriate insert is inserted into a fixed biopsy guide (B). The procedure is performed with sterile jelly (C) and a sterile probe cover (D) if required. (B) The assembled biopsy guide.
Equipment and needles

The core of tissue for histological analysis is obtained with a specially designed needle consisting of an inner needle with a chamber or recess for the tissue sample and an outer, cutting needle which moves over it—the Tru-Cut needle. The biopsy is obtained in two stages: first the inner needle is advanced into the tissue, then the outer cutting sheath is advanced over it and the needle withdrawn containing the required tissue core (Fig. 11.3).

The use of a spring-loaded gun to operate these needles is now commonplace (Fig. 11.4). Such devices are designed to operate the needle with one hand; the whole needle is advanced into the tissue, just in front of the area to be biopsied. By pressing the spring-loaded control, the inner part is rapidly advanced into the lesion, followed rapidly by the cutting sheath over it. These needles can be obtained in a variety of sizes—generally 14, 16, 18 or, less commonly, 20 gauge. Most focal lesions are biopsied with a standard 18G needle. As a general principle, as the needle advances approximately 1.5–2.0 cm during biopsy, it is advisable to position the needle tip on the edge of a lesion to obtain a good histological sample as most lesion necrosis tends to be centrally located.

Such biopsy guns enable the operator to scan with one hand and biopsy with the other, observing the needle within the lesion, yielding a high rate of diagnosis with a single-pass technique¹ and minimizing post-biopsy complications.
As an alternative to the gun/needle combination a number of ‘self-fire’ needles are available. This is essentially a single-use spring-loaded biopsy needle. Again these come in a variety of sizes but their advantage is that they are easier and lighter to use than the gun/needle combination, and therefore are easier employed in the CT situation. Most departments will tend to utilize a combination of both.

In cases where the clinician is not familiar with ultrasound techniques, appropriate guidance by a sonographer, while the clinician biopsies, is highly successful, quick and avoids potential complications.

Fine-needle histology, involving the use of needles of 21 gauge or less, reduces even further the possibility of postprocedural complications. These are generally not used as only small amounts of tissue are obtained for analysis and, as thin needles, they are apt to bend more easily, and are therefore more difficult to see and retain within the plane of the scan. Biopsy of deep lesions is therefore more difficult, if not impossible.

**Fine-needle aspiration cytology**

Cytology is the analysis of cells rather than the core of tissue obtained for histology. This is generally more difficult to interpret pathologically, as the characteristic architecture and intercellular relationships seen in a histological sample are absent. It has the advantage, however, of allowing a finer needle to be used. This can be passed through structures, for example the stomach, blood vessels, en route to the site of interest, with no adverse effects.

Fine needles for cytology are of 21 gauge or smaller. They are of a simple design with a bevelled, hollow core and no cutting mechanism.

The needle is introduced under ultrasound guidance to the required position. Fragments of tissue are removed into the needle by applying negative (sucking) pressure with a syringe to the needle, while moving the needle to and fro to loosen the tissue.

These can then be expelled on to a microscope slide and smeared. The main disadvantage of this technique is that it requires a highly trained and specialized pathologist to interpret the samples, whereas all trained pathologists can view histological specimens. In addition, for many conditions, histological diagnosis is required, although cytology remains a useful tool in the breast and thyroid.

**ULTRASOUND-GUIDED BIOPSY PROCEDURES**

**Liver biopsy**

The most common reason for ultrasound-guided biopsy is for suspected metastatic disease. The liver is one of the most common sites for metastases and histology is often required to confirm the diagnosis, or to identify the origin of an unknown primary lesion (Figs 11.5 and 11.6).

Biopsy of other focal lesions in patients with chronic liver disease (for example, cirrhosis, hepatitis B or C) in whom there may be suspected hepatocellular carcinoma and occasionally in patients with benign disease (for example, capillary haemangiomas or focal nodular hyperplasia) can also be performed, although MRI and contrast ultrasound are increasingly used to characterize lesions, without recourse to biopsy.

Focal lesion biopsy is generally safely and accurately performed with an 18G Tru-Cut needle which yields reliable tissue for histological analysis. In general an accuracy of 96% should be achievable² (Fig. 11.7).

In addition to focal lesion biopsy another common reason for liver biopsy is to assess the
presence/absence of parenchymal liver disease, severity of disease and, where appropriate, the aetiology of the disease process. This is often performed in patients with abnormal liver function tests with no evidence of biliary obstruction. The clinical history and serological analysis can be helpful in determining aetiology; however biopsy is often required. This is normally performed with a 14G or 16G Tru-Cut needle. Very often the liver is simply identified with ultrasound and a suitable mark made on the skin, often in the mid-axillary line, and the biopsy performed through the right lobe. Although this is acceptable for this type of biopsy, as no guidance is required towards a specific focal lesion, ultrasound guidance during the procedure is still preferable to the ‘blind’ technique in order to avoid large vessels and reduce the subsequent risk of haematoma. Biopsy may also be performed for patients with suspected rejection following hepatic transplantation.

Where coagulation profiles are not correctable (and most generally are), liver biopsy can be performed using a ‘plugged’ technique or, more commonly, by the transjugular route (Fig. 11.8).

**Pancreatic biopsy**

The commonest reason for biopsy of the pancreas is in patients presenting with obstructive jaundice due to a mass in the head of the gland. A fine-needle technique enables the mass to be accessed through the stomach and left lobe of liver without
complications. However an 18G needle biopsy is advisable to reduce false-negative results due to the well-known situation of a carcinoma being associated with an element of peripheral inflammation. Pancreatic biopsies are often better performed under CT control (Fig. 11.9), particularly when lesions are small, patients big and/or the lesion is difficult to identify with ultrasound. In those patients with negative biopsies very often interval CT scans are performed to see if the lesion is static or progressive.

Native kidney biopsy

Histology is frequently required in order to direct further management of diffuse renal disease. Biopsy of solid renal masses is rarely performed as the diagnosis of renal cell or transitional cell carcinoma is usually clear from imaging. Biopsies are still performed however in those patients who are not having surgery to confirm the diagnosis; this is often required prior to chemotherapy or new therapeutic regimes. Biopsy of the native kidney is

Figure 11.8  (A) Transjugular biopsy of the liver. Access is via the right internal jugular vein, through the right atrium and into the inferior vena cava and hepatic veins. Once the catheter is wedged in the hepatic vein the cutting needle is released and a biopsy is taken. (B) Plugged liver biopsy technique. This is no longer, or only rarely, used. A 4F sheath can accept an 18G biopsy needle and is inserted into the liver. Multiple biopsies can be taken: at the end of the procedure the needle is removed and the biopsy track embolized via the sheath with embolic material, e.g. sterespon and coils. (C) X-ray of the post-embolization track.
performed in the majority of centres under ultrasound guidance. Contraindications to biopsy include hydronephrosis, which may be more appropriately treated with catheterization or nephrostomy, or small kidneys, that is < 8 cm longitudinal axis (these appearances being indicative of chronic renal impairment). Kidneys > 9 cm can potentially be biopsied; however other factors, including cortical thickness, age, clinical history and the requirement for definitive diagnosis will all have a bearing on whether biopsy is performed or not. Hydronephrosis and kidney size are easily assessable with a prebiopsy scan.

In most cases the biopsy is performed with the patient prone over a small bolster to maximize access to the kidney. The shortest route, avoiding adjacent structures, is selected; subcostally, traversing the cortex of the lower pole and avoiding the collecting system and major vessels is recommended. With ultrasound guidance, either kidney may be chosen and accessibility will vary between patients. The depth of penetration and angle of approach are carefully assessed. Biopsy is normally with a 16G needle.

The patient’s cooperation is required with suspending respiration at the crucial moment. This avoids undue damage to the kidney as the needle is introduced through the capsule. The needle should be positioned just within the capsule prior to biopsy so that the maximum amount of cortical tissue is obtained for analysis, as the throw of the needle may be up to 2 cm.

Renal transplant biopsy

Biopsy is a valuable tool in the postoperative management of the transplant patient (Chapter 7), enabling the cause of graft dysfunction to be identified, in particular differentiating acute tubular necrosis from acute rejection. Ultrasound guidance is essential in order to reduce complications such as haematoma, vascular damage (which may result in arteriovenous fistula or pseudoaneurysm formation) and laceration of the renal collecting system. A single-pass technique, using the spring-loaded biopsy gun with a 16-gauge needle, is usually sufficient for histological purposes; however two passes are often required so that electron microscopy and immunofluorescence can also be performed. The procedure is well tolerated by the patient and the complication rate low, at less than 5%.3
A full scan of the kidney is first performed to highlight potential problems, for example peri-renal fluid collections, and to establish the safest and most effective route. The transplanted kidney lies in an extraperitoneal position and the chosen route should avoid puncturing the peritoneum, to minimize the risk of infection. Unlike the native kidney, the upper pole of the transplanted kidney is usually chosen to avoid major blood vessels and the ureter, which pass close to the lower pole.

The biopsy aims to harvest glomeruli, and the chosen route should therefore target the renal cortex. An angle is chosen to include the maximum thickness of cortex and, where possible, avoid the renal hilum (Fig. 11.10).

Complications of ultrasound-guided biopsy

Postprocedure complications such as haematoma requiring blood transfusion and trauma to adjacent viscera occur very infrequently when ultrasound guidance is used. As expected, the risk of complications is less in fine-needle biopsy than with larger needles; however, there is no significant difference in complication rate between a standard 18G Tru-Cut needle and a 22G Chiba needle.5 The mortality and major complication rates vary but using a standard 18G needle these are approximately 0.018–0.038% and 0.18–0.187% respectively, mortality being due to haemorrhage in 70%. As a working figure this means the mortality is approximately 1 in 3300–5400 and morbidity 1 in 530 biopsies (Table 11.1).4,6,7 The risk of haemorrhage is increased in patients with coexistent cirrhosis and is more likely to occur with malignant than benign lesions,8,9 although large haemangiomas also can carry a significant risk of bleeding.

As with any procedure of this nature, there is a very small risk of infection, which can be minimized by using an aseptic technique.

Tumour seeding of the biopsy tract is an uncommon complication of biopsy and reports of tumour seeding are associated with repeated passes into the mass using large needles. Although much talked about, tumour track seeding is in fact rare, occurring in approximately 1 in 20 000 biopsies.7,10 The best-known tumours for this are mesothelioma and hepatoma.

Complications following abdominal biopsy are increased with multiple passes and are at least in part related to the skill and experience of the operator.

If the biopsy result is negative or unexpected then a number of scenarios should be considered and include sampling error, poor histological specimen, sonographic or pathological misinterpretation or indeed a true negative finding. A repeat biopsy is sometimes justified.

ULTRASOUND-GUIDED DRAINAGE

Many fluid collections are the result of surgical intervention and often cannot be differentiated on ultrasound alone. Diagnostic aspiration of
fluid collections is used to establish their exact nature: this may include haematoma, lymphocoele, urinoma, biloma, pseudocysts and others.

Postoperative haematomas are normally treated conservatively and tend to resolve spontaneously. Insertion of a drain into such a collection is at high risk of converting the collection into an abscess.

Abscess drainage

Ultrasound-guided drainage of abscesses is now the preferred treatment when the collection can be visualized on ultrasound and a safe route chosen. These may result from postoperative infection, inflammatory bowel conditions, such as Crohn’s disease or appendicitis, or other sources of infection, particularly in immunosuppressed patients. Drains come in different sizes and generally the thicker the pus, the larger the bore of drain that is required. Whilst aspiration is initially performed to confirm the nature of the collection, very often a drain is left in situ; together with appropriate antibiotic therapy this is usually effective. At the very least it normally leads to an improvement in the overall clinical condition to allow definitive treatment and can in itself be a definitive cure.

Ultrasound is particularly useful in cases of hepatic abscesses and in draining the subphrenic, pericolic and subhepatic areas. Superficial collections, usually associated with wound sites, are also readily accessible to ultrasound. Collections obscured by bowel gas are best drained under CT guidance.

Table 11.1

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of biopsies</th>
<th>Mortality rate</th>
<th>Major complication rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fornari et al</td>
<td>1989</td>
<td>10,800</td>
<td>1:5400</td>
<td>1:530</td>
</tr>
<tr>
<td>Nolsøe et al</td>
<td>1990</td>
<td>8000</td>
<td>1:2700</td>
<td>1:540</td>
</tr>
<tr>
<td>Smith</td>
<td>1991</td>
<td>16,400</td>
<td>1:3300</td>
<td>—</td>
</tr>
</tbody>
</table>

Gallbladder drainage

Gallbladder drainage under ultrasound control is a temporary, palliative procedure which tends to be reserved for particularly ill patients with septicaemia, as a method of stabilizing their condition prior to surgery. Drainage of, for example, a gallbladder empyema buys useful time, reducing the risk of perforation and subsequent peritonitis and improving clinical status prior to surgical removal. Although the portable nature of ultrasound allows a bedside procedure to be performed (which is particularly useful in patients under intensive therapy who cannot be moved), these procedures carry a high risk to the patient and full anaesthetic, nursing and medical support is required.

Nephrostomy

Renal obstruction in which the pelvicalyceal system is dilated may be alleviated by the percutaneous introduction of a nephrostomy tube under ultrasound guidance. This procedure relieves pressure in the renal collecting system and avoids potential irreversible damage to the renal parenchyma (Fig. 11.11). Although the procedure may be carried out completely under ultrasound control, it is normally performed in a screening room where a combination of ultrasound and X-ray screening can be used to maximal effect.

Cyst drainage

The percutaneous treatment of renal and hepatic cysts by simple aspiration may afford only temporary relief as they frequently recur, but a more permanent result may be achieved by injecting a sclerosant, for example absolute alcohol or tetracycline into the cyst. In addition, percutaneous treatment of hydatid liver disease (traditionally avoided because of the risk of spreading parasites along the needle track and causing further infection) has been successfully performed by injecting of a scolicidal agent, avoiding the need for surgical removal.

Other applications include draining of pancreatic pseudocysts and inserting a cystogastrostomy tube with combined fluoroscopy and ultrasound guidance; the cyst is allowed to drain through this...
tube into the stomach. This is now better done endoscopically.\textsuperscript{12}

\textit{Indirect ultrasound guidance}

Not infrequently drainage of fluid, for example from the pleural cavity, may be performed away from the ultrasound department in the ward or clinic. Although ideally this is done under guidance with a portable scanner, in practice excellent results are obtained for larger, non-loculated collections, particularly pleural effusions, by marking the skin surface with a felt-tip marker in the main scanning department to enable drainage to be safely carried out on the ward.

The mark should be made with the patient in the position in which drainage is to be attempted, for example sitting or decubitus right side raised,

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure11.11.png}
\caption{(A) Longitudinal ultrasound image of the left kidney. There is clear evidence of hydronephrosis. (B) Similar image during a nephrostomy procedure. The electronic ultrasound guide path can be easily visualized. The guide wire (arrow) can also be seen within the renal pelvis and collecting system. (C) Longitudinal ultrasound scan of the left kidney immediately following nephrostomy. The collecting system remains dilated due to injected contrast. The echogenic tips of the drainage cathether (arrow) can be visualized within the renal pelvis.}
\end{figure}
and this information communicated to the clinician performing the drainage, together with the depth from the skin surface to the fluid. The puncture site should be marked so that the route is perpendicular to the skin surface. Drainage of pleural effusions and of ascites are the two most commonly performed procedures using this method.

**INTRAOPERATIVE ULTRASOUND (IOUS)**

IOUS is increasingly used in the abdomen, in both the diagnosis and treatment of lesions. Its applications are varied and its dynamic nature, mobility and high resolution make it ideal for surgical work.

**Hepatic IOUS**

The most frequent application in the abdomen is in diagnosing and locating liver metastases prior to surgical resection. Resection of metastases, particularly from colorectal tumours, is a potential cure, but results are unsuccessful if small lesions, undetected preoperatively, are not removed at operation.

The direct contact of the IOUS probe with the liver surface, avoiding attenuative subcutaneous tissue, enables a high-frequency (7.5 MHz) probe to be used. IOUS can demonstrate lesions too small to be detected on preoperative imaging, and as a result can change operative management in terms of altering the resection line to include more tissue, removing additional hepatic segments or even abandoning the operative procedure altogether.

A combination of surgical palpation, which detects small surface lesions, and IOUS, which detects small, deep lesions, has the highest diagnostic accuracy. IOUS is quick to perform in the hands of an experienced operator and its contribution to the success of surgery is invaluable (Fig. 11.12).

IOUS is particularly useful when there has been a delay between preoperative imaging and surgery, as progression of disease may have occurred during this interval, or when preoperative imaging is equivocal (for example, differentiating tiny cystic from solid lesions). IOUS is often able to offer a definitive diagnosis and when doubt still exists guided biopsy under ultrasound control may be performed.

In addition to lesion detection it is able to demonstrate vascular invasion by tumour and to demonstrate clearly, in real time, the relationship of the tumour to adjacent vascular structures; this is essential for planning a resection line. The greater the margin of normal tissue around the resected tumour, the better the long-term prognosis, and a margin of greater than 1 cm normal tissue is preferred. IOUS can also be used to locate deep lesions for ultrasound-guided biopsy or ablation.

**Other applications of IOUS**

There are numerous extrahepatic applications for IOUS in the abdomen, including urological, vascular and gastrointestinal tract scanning.

Ultrasound evaluation of the common duct for calculi following cholecystectomy can identify small fragments which may not be easily palpable through the duct wall. Using this technique the duct is less susceptible to injury which may be associated with direct examination or the introduction of X-ray contrast agents.

Pancreatic scanning is particularly useful in identifying small tumours of the body and tail of pancreas for curative resection and in differentiating small pancreatic retention cysts from solid nodules.

The treatment of tumours by percutaneous ultrasound-guided techniques, rather than surgical resection, is becoming more common. However, it may not always be possible to achieve success percutaneously and techniques have been developed to ablate tumours during open surgery. Cryotherapy, in which the lesion is frozen by introducing a cryo-probe into the centre of the lesion under intraoperative ultrasound guidance, has been successfully used, but is now largely superseded by radiofrequency and microwave ablation (Fig. 11.13). These techniques have resulted in long-term survival in patients with hepatocellular carcinoma and multiple liver metastases. The success of such techniques depends to a large extent upon patient selection. Those with very large and/or multiple lesions tend to have a poor prognosis compared with patients with smaller, well-confined disease. However these techniques continue to develop and are likely to offer hope to many patients currently untreatable with conventional methods.
LAPAROSCOPIC ULTRASOUND

Dedicated laparoscopic ultrasound probes may be passed through the laparoscopic port during surgical procedures to investigate the liver, biliary tree, pancreas and other viscera without the need for open surgery (Fig. 11.14).

The trend towards laparoscopic rather than open cholecystectomy has increased the need for accurate laparoscopic exploration of the biliary ductal system to confirm the presence or absence of stones. Laparoscopic ultrasound is better at demonstrating stones in the duct and anatomical ductal variations than conventional intraoperative cholangiography.21

Laparoscopic ultrasound has also proven advantageous in staging patients with hepatic tumours for liver resection,22 demonstrating deep tumours not visible on surgical laparoscopy, or by preoperative imaging methods and so avoiding the need to proceed to open hepatic resection in some patients.

Patients with pancreatic head and ampullary carcinomas are potentially resectable in only a minority of cases. Preoperative imaging is known to underestimate the extent of the disease, and so many patients traditionally undergo a staging laparotomy before resection is attempted. However, over one-third of patients previously considered resectable...
will demonstrate occult metastases, often in the peritoneum.

Staging laparoscopy still cannot demonstrate intrahepatic metastases, and the use of laparoscopic ultrasound at this stage greatly increases the accuracy of staging and influences the surgical decision.\(^{23}\) Laparoscopic ultrasound is also useful in staging patients with gastric cancer\(^ {24}\) and colorectal cancer.\(^ {25}\) Curative resection of bowel cancer can be performed with either open surgery or laparoscopic resection. Laparoscopic ultrasound can be used to examine the liver to confirm the absence of metastases: this is particularly useful in a laparoscopic resection as the surgeon is unable to palpate the liver under these circumstances. This laparoscopic approach reduces patient morbidity when compared with open surgical exploration.

**ULTRASOUND CONTRAST AGENTS IN THE ABDOMEN**

Ultrasound contrast media have been well established for cardiac imaging since the 1980s and the first clinical use of such an agent was in 1968 and involved the injection of saline to identify echoes from the mitral valve.\(^ {26}\)

These early contrast agents were composed of relatively large (by today’s standards) microbubbles of air in solution. They were unstable, short-lived and the bubbles were too large to pass through the capillary beds, hence their use exclusively for cardiac ultrasound.
Since those early years there have been a number of developments in the field of contrast ultrasound. Agents such as Albunex (Molecular Biosystems, San Diego, USA), consisting of albumin-coated microbubbles, were small enough to pass through the pulmonary capillaries and enter the left side of the heart; however they were too weak to withstand systolic pressure and could not therefore enter the blood pool in any appreciable quantity.

A more stable suspension was then produced, consisting of small microbubbles in the order of 2–5 µm which passed through the pulmonary capillary bed after intravenous injection, and acted as a true blood-pool agent. Called Levovist (Schering, Berlin, Germany), this is a galactose-based agent (99.9%) containing palmitic acid (0.1%) for stability, which traps air which is subsequently released when the bubbles burst. As the first stable blood-pool agent it could be used for examining the abdominal viscera and vasculature.

By coincidence, microbubbles of this size can pass through the pulmonary capillaries and resonate at frequencies used in clinical diagnostic ultrasound (1–20 MHz). This resonance causes a much greater capacity for scattering the beam than that from a non-resonating particle and thus a stronger signal is produced of up to 25 dB on both grey-scale and Doppler. The Doppler signal from a contrast-enhanced blood vessel is therefore much easier to identify. In addition, vessels too small to be identified on normal grey-scale or non-enhanced Doppler scans can be identified when using a microbubble agent (Fig. 11.15).

Despite the use of microbubble agents, blood flow in tiny vessels can still be difficult to detect; harmonic imaging techniques however aid detection further. When insonated with ultrasound of a certain frequency, microbubbles emit a secondary harmonic frequency twice that of the incident wave, in addition to the primary harmonic. As the second peak is a purer signal, this increases the sensitivity, enabling smaller vessels with slow flow to be successfully detected and distinguished from surrounding tissues. Many harmonic-based pulse methods are used with contrast agents and some of the more popular ones include pulse and phase inversion, for example pulse inversion is a dual pulse technique, 180° out of phase, resulting in summation of signal from non-linear scatterers (microbubbles) and cancellation of signal from linear scatterers (tissue).

Potential applications of these agents include situations in which ultrasound findings are equivocal or in which Doppler information is suboptimal. A contrast agent will enhance the Doppler ultrasound signal from the blood pool and increase diagnostic confidence. This may therefore obviate the need for other more invasive angiographic investigations. These agents therefore have the potential to extend the applications of Doppler ultrasound in the abdomen.

With regard to the abdomen it can be useful in patients with chronic liver disease for the investigation of portal vein thrombosis. Increased sensitivity and specificity have been reported for examination of the portal vein, avoiding the need for contrast angiography. In patients with hepatic transplantation it is helpful in confirming hepatic artery patency in the early postoperative period: this can be difficult to confirm with conventional imaging alone. Although it is felt intuitively that it may be of help in the diagnosis of renal artery stenosis, the evidence is as yet not convincing to support its routine use.

The diagnosis and characterization of hepatic tumours are also improved with contrast agents as these agents, for example, Levovist and Sonovue, are preferentially taken up by the hepatosplenic parenchyma and so focal lesions appear as filling defects in much the same way as CT or MRI (Fig. 11.16). The exact site of accumulation within the liver is unknown but may be within the reticuloendothelial system or liver sinusoids. There is growing evidence to support the differentiation of lesions within the liver, not previously possible with conventional ultrasound, and certainly microbubble agents are helpful in the diagnosis of capillary haemangiomas, hepatomas and focal nodular hyperplasia. How are microbubble agents used currently? Generally an agent such as Sonovue, currently the most commonly used, which consists of a phospholipid membrane containing perfluorocarbon gas, is injected intravenously. Imaging, for example in the liver, can now be performed in both a hepatic arterial and portal venous phase similar to CT. Most imaging is performed with a harmonic-based technique—pulse or phase inversion—and utilizing a low mechanical index (< 0.15) to
prolong longevity of the bubbles. Although there is no definitive evidence as yet to support its routine use, it is currently undergoing a number of trials comparing it with CT and MRI in the detection of focal liver disease, and early results are favourable.31

Other simple substances, technically considered contrast agents, including water or saline, are used to outline the stomach (for example, to visualize the pancreas or to assess the nature of an epigastric mass) or the rectum. In the future, oral ultrasound contrast agents may be developed specifically to examine the stomach or colon and to reduce bowel gas.

THE TREATMENT OF PRIMARY AND SECONDARY HEPATIC TUMOURS BY PERCUTANEOUS METHODS

In patients with colorectal carcinoma the presence of liver metastasis is the most accurate predictor of survival. Resection of liver metastases is known to increase the lifespan of patients, with good quality
of life and an overall 5-year survival of 20–45%, and up to 60% in unifocal disease. Without surgery the 5-year survival in this patient group is effectively zero. However, not all patients with liver metastases are deemed suitable for resection, being poor surgical risks or having lesions which are either too large or affect too many hepatic segments. Percutaneous ablation of liver tumours is now a viable and rapidly developing option for control of liver metastases, prolonging survival time after initial diagnosis and, in some cases, shrinking tumours to enable future curative resection. Various methods have been investigated, using ultrasound guidance.

- Alcohol injection has proved highly effective for hepatocellular carcinoma (HCC), shrinking tumours over a period of time and causing necrosis within them, but has not proved as effective for metastatic liver disease. This is thought to reflect the fact that HCC is a ‘soft’ tumour and so the alcohol can be instilled effectively into the tumour whereas metastases are ‘hard’ lesions and often the alcohol seeps out of the lesion.

- Radiofrequency (RF) thermal ablation and laser ablation are also developing as minimally invasive percutaneous therapeutic techniques and are becoming increasingly popular.

Ablation of liver metastases using RF is a recent method of ultrasound-guided therapy for liver metastases and HCC in which RF, applied to monopolar electrodes either individually or with multiprobe arrays, is guided into the lesion to be treated. RF tissue ablation through an 18G needle uses fewer probes than laser. It is an outpatient procedure: 1–4 sessions has been reported to achieve complete necrosis of liver metastases in 67% of lesions. It is a simple, safe and potentially effective treatment for liver metastases, associated with a low rate of complications (in one study only one small area of haemorrhage was observed in 75 sessions) together with a significant rate of shrinking or stabilization of the metastases.

**ENDOSCOPIC ULTRASOUND**

Some of the limitations of conventional ultrasonography in biliary and pancreatic imaging can be overcome by the use of endoscopic probes and miniprobes. Endoscopic probes are either radial or linear arrays which are incorporated into the end of an endoscope. They have a frequency of 7.5–12 MHz and are used to image the pancreas, biliary tract, portal vein and adjacent structures.
within 5–6 cm of the probe. Radial probes may be used in the preoperative staging of a number of diseases, including oesophageal, gastric, pancreatic and lung cancer, whilst linear array probes are used for interventional procedures such as fine-needle aspiration analysis of mediastinal lymph nodes, solid organ assessment, for example pancreas, occasionally liver, adrenals, pseudocyst drainage and coeliac plexus neurolysis.

Endoscopic ultrasound is more sensitive and specific than spiral CT, MRI or transabdominal ultrasound in the detection of small pancreatic masses and its diagnostic ability can be further enhanced by the use of endoscopic ultrasonically guided fine-needle aspiration cytology and biopsy.

It may also detect early changes of pancreatitis which are not visible on endoscopic retrograde cholangiopancreatography (ERCP), and one of its

Figure 11.16  (A) Conventional ultrasound of the liver showing no abnormality. (B) Pulse inversion mode following intravenous Levovist injection showing a focal lesion (arrow) i.e. metastasis in the same patient as Fig. 16a. (C) Conventional grey-scale scan of the liver. A number of metastases were seen throughout the liver. One in the left lobe has been arrowed. (D) Pulse inversion mode with intravenous Levovist in the same patient as (C). The metastasis seen on the unenhanced grey-scale image can still be seen (arrow); however, easily discernible additional lesions are now also appreciated.
main uses is in staging pancreatic tumours, predicting their resectability, identifying small lymph node metastases and assessing vascular invasion. It is particularly accurate in identifying small pancreatic insulinomas, often difficult or impossible to identify on conventional cross-sectional imaging despite a documented biochemical abnormality, and thus guiding subsequent surgical procedures. Endoscopic ultrasound is also used in the detection of biliary calculi, particularly in the normal-calibre common bile duct, with a much higher accuracy than other imaging techniques and without the potential additional risks of ERCP.

Further, less-established uses of endoscopic ultrasound include gastrointestinal examinations, in which invasion of gastric lesions into and through the wall of the stomach can be assessed, anal ultrasound, which is used to visualize the sphincter muscles in cases of sphincter dysfunction, the staging of colorectal carcinomas and the demonstration of bowel wall changes in inflammatory bowel conditions.

The miniprobe has a higher frequency (20–30 MHz) and may be passed down a conventional endoscope. It therefore has the advantage of a one-stage gastrointestinal tract endoscopy/ERCP, rather than requiring a separate procedure. It may be inserted into the common duct of the biliary tree to assess local tumour invasion and to clarify the extent and/or nature of small lesions already identified by other imaging methods. It shows remarkable accuracy in the detection of common bile duct tumours and other biliary tract disease when compared with other imaging modalities.

It may be used in the staging of oesophageal and gastric cancer, and is especially useful when a tight oesophageal stricture prevents the passage of the endoscope. The layers of the oesophageal or gastric wall and the extent of tumour invasion can be accurately assessed.

The miniprobe is also used in patients with suspected pancreatic carcinoma, for example in patients with a negative CT but who have irregularity of the pancreatic duct on contrast examination. The probe can be passed into the pancreatic duct during ERCP to detect small lesions, assess the extent of the tumour and predict resectability. It is superior to conventional endoscopic ultrasound in the detection of the smaller, branch tumour nodules, and can also detect local retroperitoneal or vascular invasion in areas adjacent to the probe.

The use of endoscopic ultrasound is currently limited to a few specialist centres. A steep learning curve together with the expense of the equipment is likely to restrict its widespread use; however, as its applications expand and its value becomes proven, it is likely to become a more routine investigation at many centres.

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