Manual of diagnostic ultrasound

During the last decades, use of ultrasonography became increasingly common in medical practice and hospitals around the world, and a large number of scientific publications reported the benefit and even the superiority of ultrasonography over commonly used X-ray techniques, resulting in significant changes in diagnostic imaging procedures.

With increasing use of ultrasonography in medical settings, the need for education and training became essential. WHO took up this challenge and in 1995 published its first training manual in ultrasonography. Soon, however, rapid developments and improvements in equipment and indications for the extension of medical ultrasonography into therapy indicated the need for a totally new ultrasonography manual.

The manual (consisting of two volumes) has been written by an international group of experts of the World Federation for Ultrasound in Medicine and Biology (WFUMB), well-known for their publications regarding the clinical use of ultrasound and with substantial experience in the teaching of ultrasonography in both developed and developing countries. The contributors (more than fifty for the two volumes) belong to five different continents, to guarantee that manual content represents all clinical, cultural and epidemiological contexts.

This new publication, which covers modern diagnostic and therapeutic ultrasonography extensively, will certainly benefit and inspire medical professionals in improving ‘health for all’ in both developed and emerging countries.
Manual of diagnostic ultrasound

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Domenico Arduini: Department of Obstetrics and Gynecology, University of Roma Tor Vergata, Rome, Italy
Stan Barnett: Discipline of Biomedical Science, Faculty of Medicine, University of Sydney, Sydney, Australia
Ibtissem Bellagha: Department of Paediatric Radiology, Tunis Children’s Hospital, Tunis, Tunisia
Paolo Belli: Department of Radiological Sciences, Catholic University of the Sacred Heart, Rome, Italy
Leonardo Caforio: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Lucia Casarella: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Anna Franca Cavaliere: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Giovanni Cerri: School of Medicine, University of Sao Paulo, Sao Paulo, Brazil
Maria Cristina Chammas: School of Medicine, University of Sao Paulo, Sao Paulo, Brazil
Ferid Ben Chehida: Department of Radiology, Ibn Zohr Center, Tunis, Tunisia
Melania Costantini: Department of Radiological Sciences, Catholic University of the Sacred Heart, Rome, Italy
Alain Couture: Department of Paediatric Radiology, Arnaud de Villeneuve Hospital, Montpellier, France
Vincenzo D’Addario: Department of Obstetrics, Gynecology and Neonatology, University of Bari, Bari, Italy
Marco De Santis: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Josef Deuerling: Department of Internal Medicine, Klinikum Bayreuth, Bayreuth, Germany
Alessandra Di Giovanni: Department of Obstetrics and Gynecology, University of Roma Tor Vergata, Rome, Italy
Alessia Di Legge: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Wiem Douira Khomsi: Department of Paediatric Radiology, Tunis Children’s Hospital, Tunis El Manar University, Tunis, Tunisia
Caterina Exacoustos: Department of Obstetrics and Gynecology, University of Roma Tor Vergata, Rome, Italy
Hassen A Gharbi: Department of Radiology, Ibn Zohr Center, Tunis, Tunisia
Azza Hammou: National Center for Radio Protection, Tunis, Tunisia
Hela Louati: Department of Paediatric Radiology, Tunis Children’s Hospital, Tunis, Tunisia
Lucia Masini: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Maria Elena Pietrolucci: Department of Obstetrics and Gynecology, University of Roma Tor Vergata, Rome, Italy
Maurizio Romani: Department of Radiological Sciences, Catholic University of the Sacred Heart, Rome, Italy
Paolo Rosati: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Cristina Rossi: Department of Obstetrics, Gynecology and Neonatology, University of Bari, Bari, Italy
Renato A. Sernik: Musculoskeletal Dept. Clinical Radiology, University of Sao Paulo, Sao Paulo, Brazil
Stefania Specia: Department of Radiological Sciences, Catholic University of the Sacred Heart, Rome, Italy
Antonia Carla Testa: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Claudia Tomei: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Corinne Veyrac: Department of Paediatric Radiology, Arnaud de Villeneuve Hospital, Montpellier, France
Daniela Visconti: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
Maria Paola Zannella: Department of Obstetrics and Gynecology, Catholic University of the Sacred Heart, Rome, Italy
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Paediatric ultrasound

Introduction

Ultrasound incorporating new technological improvements is widely used in paediatrics, and high-resolution images are produced because children’s bodies have low levels of fat. Nevertheless, it should be remembered that children are not small adults but have their own specificities and specific pathological conditions, especially malformations. If necessary, the examination room should be heated, and infants must be covered. The parents should be present in the room to help keep the infant quiet and calm. The examination should be as short as possible, and the operators should be specially trained. The ultrasound system used must have appropriate high-frequency probes, and accessories such as pillows should be available. A child’s history should be well known before the examination is begun. The more the physician (or operator) knows about the child’s symptoms, the easier he or she can solve the medical problem and begin treatment.

Ultrasound is the imaging modality of choice for children with abdominal pain, abdominal masses and intra-abdominal anomalies. Several diseases that occur frequently should be excluded by ultrasound examination. Although ultrasound imaging is a powerful technique, it is sometimes insufficient, and other modalities, such as plain X-rays, CT scan, MRI and nuclear medicine, if available, are required to confirm a diagnosis. For example, cystography is needed to evaluate vesico-ureteral reflux, and evaluation of tumour extension requires CT or MRI. Use of ultrasound imaging, however, will save time and reduce costs and can avoid exposure to radiation with no reduction in diagnostic accuracy. Misuse of ultrasound must be avoided, as it discredits the technique and the operator and wastes time and money.

Liver and biliary tract

Indications

Ultrasound is the preferred initial imaging modality for evaluating the liver and biliary tract in children. Typical indications are hepatomegaly, jaundice, anomalous hepatic assessment, ascites, suspected liver abscess or liver mass, abdominal trauma, right upper abdominal pain and screening for endemic echinococcosis. Ultrasound gives information on the size and structure of the liver and demonstrates both
localized lesions (tumour, cyst and abscess) and diffuse diseases. It can also be useful for histological and therapeutic purposes, as it can be used to guide fine-needle biopsies, punctures and drainage of abscesses.

**Preparation**

Fasting is not necessary before an examination of the hepatic parenchyma; however, 2–6 h of fasting, depending on the age of the child, is necessary for a study of the gall bladder, the intrahepatic and extrahepatic bile ducts and the hilus of the liver.

**Examination technique**

The child should lie in the supine position initially and later on the left or right side. No premedication is needed (an important advantage of ultrasound). Coupling agent is applied liberally, first over the right upper abdomen, then over the rest of the abdomen as the examination proceeds.

Scanning should be carried out in the longitudinal, transverse and oblique planes, systematically, including scans through the intercostal and subcostal routes. Convex probes should be used, ranging from 3.5 to 7 MHz, and linear probes of at least 7–15 MHz for neonates. The frequency should always be as high as possible.

Doppler ultrasound is useful for locating vessels and for ensuring the permeability of the vascular structures. It is helpful for assessing the presence and direction of blood flow in the hepatic artery, hepatic veins and portal veins. Normal vascular flow patterns can be readily seen in children of all ages.

**Normal findings**

The normal hepatic parenchymal echogenicity is uniform, with clear, delineated vessels. Its sonographic appearance is similar to that of the renal medulla during the first 6 months of life, but the echogenicity becomes similar to that of the cortex later (Fig. 5.1). Its surface is smooth, and the inferior edge is wedge-shaped. The vertical diameter in the right middle clavicular line is 5 cm at birth, then increases gradually to reach 10 cm at 5 years and 14 cm at puberty (Fig. 5.2). The tip of the liver should not extend below the inferior pole of the right kidney.
The intrahepatic bile ducts are not seen in infants. The cystic duct is difficult to identify, and the common hepatic duct cannot be distinguished from the common bile duct. The size of the common bile duct increases linearly with age; its diameter should not exceed 1 mm in neonates, 2 mm in infants up to 1 year of age, 4 mm in children 1–10 years of age and 6 mm in adolescents (Fig. 5.3).

The normal gall bladder is seen as a cystic structure with an echo-free content. In neonates and infants under 2 years of age, the gall bladder is < 3 cm long and < 1 cm wide; in children aged 2–16 years, the length is < 8 cm and the width < 3.5 cm. The wall of the gall bladder is thin and well defined, with measurements similar to those in adults (usually < 3 mm) (Fig. 5.4).
The intrahepatic vessels and ducts are well delineated, especially the portal vein branches and the hepatic veins (Fig. 5.5). The branches of the portal vein show strong echoes from the wall. The portal vein diameter is 4 mm in a neonate and 8–10 mm in children (Fig. 5.6).
Pathological findings

Hepatic tumours

Hepatic tumours are rare in children, with an estimated frequency of 3% of all paediatric tumours. Malignant tumours are by far the most frequent, accounting for two thirds. Ultrasound is important in the diagnosis and monitoring of tumours; most cases can be diagnosed by combining ultrasound with clinical and biological data.

Primary malignant hepatic tumours

Ninety per cent of malignant hepatic tumours in children are of epithelial origin and consist of hepatoblastomas and hepatocellular carcinomas. The most specific radiological sign of malignancy is amputation or thrombosis of a portal vein branch.
or hepatic vein. The absence of this sign does not, however, eliminate a diagnosis of malignancy, especially in the case of tumours located in the periphery of the liver.

**Hepatoblastoma** is by far the commonest malignant hepatic neoplasm in children under the age of 3 years, with a median age of 1 year. The tumour is more common in males than in females and can be seen in neonates. The tumour most often presents as a painless mass. It generally occurs in a healthy liver and is usually associated with Beckwith-Wiedemann syndrome, biliary atresia or familial polyposis coli. Serum α-fetoprotein levels are markedly elevated in 90% of cases.

The sonographic appearance of hepatoblastoma is variable: it may be echo-poor, isoechoic or echo-rich in comparison with the normal liver tissue and a pseudocapsule may be present. The tumour is usually unifocal and in the right lobe of the liver. It may be multicentric or diffuse throughout the liver. Hepatoblastomas are typically heterogeneous, containing calcifications and necrotic areas (Fig. 5.7). They tend to invade vascular structures, especially the portal vein. Doppler imaging usually shows increased hepatic arterial flow. Metastatic disease occurs in 10–20% of cases, most commonly in the chest.

**Hepatocellular carcinoma** is the second commonest paediatric malignant liver tumour after hepatoblastoma, generally occurring in children over 3 years of age. Preexisting liver disease, such as familial cholestatic cirrhosis, hepatitis B virus infection, tyrosinaemia and type I glycogen storage disease, is present in about one half of cases. Serum α-fetoprotein levels are elevated in up to 50% of cases. The tumour is often extensively invasive or multifocal at the time of diagnosis. The ultrasound findings are similar to those of hepatoblastoma.

Biopsy is necessary to differentiate hepatoblastoma from hepatocellular carcinoma and tumours with low serum α-fetoprotein.

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**Fig. 5.7.** Hepatoblastoma in a 2-year-old boy. (a) Transverse scan shows a large heterogeneous mass occupying the right lobe of the liver. (b) Contrast-enhanced CT during the hepatic arterial phase showing the tumour with heterogeneous enhancement and calcifications (arrows)
**Undifferentiated embryonal sarcoma** is a rare malignant tumour, which primarily affects children between 6 and 10 years of age; α-fetoprotein levels are normal. The usual presenting features are an abdominal mass and pain. On ultrasound, the tumour commonly appears as a predominantly cystic mass with multiple septations of varying thickness (Fig. 5.8). Punctate calcification may be seen in these tumours.

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Fig. 5.8. Undifferentiated hepatic embryonal sarcoma in a 7-year-old girl. Transverse scan shows a predominantly cystic mass containing fluid-filled locules and thin intermixed septa; RK, right kidney

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**Embryonal rhabdomyosarcoma of the biliary tree** is a rare malignant tumour that occurs in children aged 2–5 years. The child presents with jaundice in most cases. Ultrasound shows bile-duct dilatation, which is often proximal to a usually inhomogeneous echogenic mass, which may be quite echo-rich (Fig. 5.9).

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Fig. 5.9. Hepatobiliary embryonal rhabdomyosarcoma in a 22-month-old boy. (a) Oblique ultrasound scan reveals a multicystic septated mass occupying the hepatic hilum (arrows). (b) Coronal T1-weighted enhancement magnetic resonance image shows extension of the tumour along the extrahepatic bile duct (arrows); the portal vein is slightly compressed
Hepatic metastases

The malignant tumours of children that most frequently metastasize to the liver are Wilms tumours, neuroblastomas and lymphomas. Neuroblastomas may affect the liver in stage IV or IV-S disease. Hepatic metastases appear on ultrasound as hepatomegaly with multiple well-delineated echo-poor or echo-rich lesions (Fig. 5.10).

Benign hepatic tumours

Benign hepatic tumours are rare in children. The most frequent are haemangioendothelioma, haemangioma, cystic mesenchymal hamartoma, focal nodular hyperplasia and adenoma.

Haemangioendothelioma is a benign vascular tumour that occurs in children under 6 months of age. Its natural history is similar to that of cutaneous haemangioma, with a rapid proliferation phase lasting 12–18 months, followed by a slower involution phase, lasting 5–8 years. Haemangioendotheliomas can be solitary or multifocal. They are found either because of hepatomegaly or fortuitously, sometimes at antenatal ultrasound. Associated cutaneous haemangiomas have been reported in 9–87% of cases and are frequently seen with multifocal hepatic lesions. Ultrasound shows heterogeneous lesions, typically with echo-poor regions and calcifications (Fig. 5.11). The tumour margins may be well circumscribed. Colour Doppler shows dilatation of the hepatic artery and hepatic veins. The progression is often simple, with calcification and regression of the lesion within an average of 1 year. The prognosis of the diffuse multinodular form is poor. The sonographic aspect is that of a metastatic liver with multiple echo-poor nodules or a rosette associated with obvious signs of hypervascularization, as seen by Doppler. In extensive forms, before
regression of the lesion, life-threatening complications can occur, such as massive haemoperitoneum due to spontaneous tumour rupture, anaemia, thrombocytopenic coagulopathy, refractory congestive heart failure and obstructive jaundice.

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**Haemangioma** or cavernous haemangioma is rare in children. It is usually asymptomatic and is detected as an incidental finding on sonography. The classical common appearance on ultrasound is a well-defined, echo-rich lesion with acoustic enhancement. The echogenicity may vary due to internal fibrosis, thrombosis, necrosis and occasionally calcification. Compression tends to reduce the hyperechogenicity.

**Cystic mesenchymal hamartoma** is considered to be a developmental anomaly originating in the connective tissue along the portal tracts, rather than a true neoplasm. It usually affects children under 2 years of age and is slightly more common in boys than girls. The child may present with an abdominal mass and normal α-fetoprotein levels. Mesenchymal hamartomas may be detected as echo-poor lesions on antenatal ultrasound. Postnatal ultrasound shows a predominantly cystic lesion with echogenic septa (Fig. 5.12). The cystic locules are echo-free or echo-poor. Occasionally, solid material is identified with the appearance of a complex mass. The prognosis after surgery is generally good.

**Focal nodular hyperplasia** can be seen in children of any age, with a female prevalence. It consists of normal hepatocytes, bile ducts and Kupffer cells. The etiology is thought to be a localized hepatocyte response to an underlying congenital vascular malformation. The lesion is usually asymptomatic. Ultrasound shows a well-demarcated mass that is either echo-rich or isoechoic with the liver parenchyma. A central stellate scar is seen in approximately 20% of cases; demonstration of arterial flow in the central scar is highly suggestive of the diagnosis (Fig. 5.13).
Fig. 5.12. Cystic mesenchymal hamartoma in a 17-month-old boy. (a) Transverse ultrasound scan reveals a large hepatic mass containing multiple echo-free cystic areas surrounded by thin septa. (b) Axial and (c) coronal reformatted contrast-enhanced CT scans show a predominantly cystic mass composed of multiple cystic spaces (C) of varying size and enhanced solid areas within the mass ((c), arrows); L, liver.

Fig. 5.13. Focal nodular hyperplasia in a 3-year-old girl. Axial sonogram shows a sharply marginated echo-rich mass within the right lobe (arrows), with a central echo-poor area due to fibrosis.
Adenoma is very rare in children, occurring under specific conditions, such as hormone treatment, type I glycogen storage disease, Fanconi anaemia and galactosaemia. These children may be asymptomatic or may present with hepatomegaly or abdominal pain. The appearance on ultrasound is nonspecific, as the lesion may be echo-poor, isoechoic or echo-rich to normal liver. Most are heterogeneous because of the presence of haemorrhage and necrosis. Colour and pulse Doppler show central venous flow and peripheral venous and arterial flow, in contrast to focal nodal hyperplasia, in which central arterial flow at the site of the central scar is more typical.

Non-neoplastic diseases

Abscess

The clinical findings and the imaging appearance of liver abscesses are variable and nonspecific. Patients present with fever, abdominal pain, hepatomegaly, abnormal liver function tests and leukocytosis. Ultrasound can provide early diagnosis. The ultrasound features vary with the evolution of the lesion. Initially, an abscess may appear to be solid and echo-rich relative to the normal hepatic parenchyma but eventually develops into an echo-poor or echo-free area with posterior acoustic enhancement. Later, abscesses are usually spherical or ovoid, and the wall is irregular or thick but may be well defined. They can be unilocular or multilocular. The ultrasound pattern can vary from purely echo-free to highly echogenic. Internal septations, fluid and debris may be present.

Pyogenic liver abscesses are rare in children and occur predominantly in the first 5 years of life (Fig. 5.14). Bacteria can invade the liver by a number of routes. The common causative agent is Staphylococcus aureus in infants and children and Escherichia coli in neonates.

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Fig. 5.14. Pyogenic hepatic abscess in a 2-year-old boy. Longitudinal scan through the right lobe of the liver shows a unilocular, highly echogenic abscess (A) with a fluid–debris level (arrow)
Fungal microabscesses are found almost exclusively in immunocompromised children. The common causative agents are Candida albicans and Aspergillus species. Amoebic liver abscesses are commonest in children < 3 years of age. They are caused by the parasite Entamoeba histolytica, which is endemic in tropical and subtropical climates. Antibiotic therapy with percutaneous drainage of macroscopic abscesses under ultrasonographic control is now the treatment of choice for most liver abscesses.

Hepatic trauma
The liver is one of the most frequently injured abdominal organs in childhood. The right hepatic lobe is injured more often than the left and the posterior segment of the right lobe more often than the anterior segment. Hepatic injuries include subcapsular and parenchymal haematomas, contusions, lacerations and rupture (Fig. 5.15). On ultrasound, subcapsular haematomas often show a lenticular-shaped fluid collection (Fig. 5.16). Intrahepatic haematomas are frequently initially echo-rich and ill-defined within the hepatic parenchyma but become echo-free and diminish in size with time and progressive liquefaction. Hepatic lacerations result in linear or branching parenchymal defects that may be superficial or deep (Fig. 5.17). Hepatic fractures are deep parenchymal lacerations. Haemoperitoneum often accompanies hepatic injuries.

Late complications of hepatic trauma are biloma and pseudoaneurysm. Bilomas appear as well-defined fluid collections in the liver or peritoneal cavity (Fig. 5.18). Pseudoaneurysms are round lesions that show flow on Doppler.

Fig. 5.15. Hepatic contusions. Oblique scan in a 7-year-old boy with abdominal trauma shows a heterogeneous, echo-rich area in the right hepatic lobe (arrows).
Fig. 5.16. Hepatic subcapsular haematoma in a newborn boy; oblique scans. (a) A huge echo-rich subcapsular haematoma (H), sharply delineated from the hepatic parenchyma. (b) One month later, decreased echogenicity.

Fig. 5.17. Hepatic laceration in a 4-year-old boy with abdominal trauma. Axial scan shows a superficial linear parenchymal defect (arrows).

Fig. 5.18. Hepatic biloma in a 6-year-old girl with abdominal trauma. Oblique scan performed 12 days later shows a large intrahepatic contusion (C) within the right lobe, with a more central, well-defined fluid collection representing biloma (arrows).
**Hydatid cyst**

Hydatid disease is due to the development of larvae of canine *Echinococcus granulosus* in humans. Human infestation is accidental, due to ingestion of parasite eggs. In children, a hepatic localization is the most frequent after the lung. The clinical manifestations of abdominal hydatidosis are variable. Ultrasound is the initial modality of choice for positive and topographic diagnosis of hydatid cyst in the liver and may be the only preoperative morphological examination. The sensitivity of ultrasound for diagnosis is 95–100%. Several classifications of ultrasound findings have been proposed; the most commonly used worldwide is Gharbi’s classification, described in 1981:

- **Type I**: pure fluid collection (Fig. 5.19)
- **Type II**: fluid collection with a split wall (Fig. 5.20)
- **Type III**: fluid collection with septa or multicystic appearance (Fig. 5.21)
- **Type IV**: cyst with heterogeneous echo patterns (Fig. 5.22)
- **Type V**: reflecting thick walls or a densely calcified lesion (Fig. 5.23).

Type I appears to be the most frequent in children. Sometimes, the cyst ruptures or becomes infected. In the liver, the most frequent complication is cystic rupture into the biliary ducts, through the diaphragm or into the peritoneum. In these cases, ultrasound may show a dilated biliary tract with fragments of membranes in the gall bladder or the common biliary duct, Budd-Chiari syndrome with compression of the hepatic vein by a hydatid cyst, multiple peritoneal cysts, ascites and, in some cases, diaphragmatic breach with a communicating supradiaphragmatic space (Fig. 5.24).

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Fig. 5.19. Liver hydatid cyst type I. Axial scan shows a large, pure fluid collection, rounded, with well-defined borders, in the left hepatic lobe. C, cyst
Fig. 5.20. Liver hydatid cyst type II. Oblique scan shows a fluid collection containing detached membranes typical of hydatid disease (arrows); a unilocular echo-poor cyst (C) is seen anteriorly.

Fig. 5.21. Liver hydatid cyst type III. Oblique scan shows a fluid collection with multiple secondary vesicles (arrows).

Fig. 5.22. Liver hydatid cyst type IV. Oblique scan shows a cyst with heterogeneous echo patterns in the right hepatic lobe (arrows); serological cultures revealed *Echinococcus granulosus* infection.
Biliary cysts are relatively rare in children. They may be multiple or solitary. Multiple cysts usually occur in association with inherited syndromes, such as autosomal dominant polycystic disease, Turner syndrome and tuberous sclerosis. Biliary cysts are usually detected incidentally on imaging. On ultrasound, they usually appear as echo-free, unilocular, round or oval masses with no visible wall (Fig. 5.25).
Steatosis

Steatosis, or fatty hepatic infiltration, is rare in children. Fat deposition occurs commonly in metabolic disorders, such as glycogen storage disease, fructose intolerance, tyrosinaemia, Wilson disease and Reye syndrome. It can be focal or diffuse. Regions of fatty liver appear brighter than the spleen and are echo-rich on sonography. Nodular fatty infiltration shows no mass effect, is sharply delineated, crossed by hepatic vessels and close to a hepatic vein, and it has a morphological appearance that allows differentiation from other lesions (Fig. 5.26). It may be located in subcapsular areas, the posterior part of segment IV, the anterior part of segment I, areas surrounding the gall bladder and in front of the hepatic hilum. The ultrasound findings are the same as in adults.

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Fig. 5.25. Biliary cyst in a newborn girl. Oblique ultrasonogram reveals a well-delineated, echo-free mass with no visible wall

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Fig. 5.26. Nodular fatty infiltration in an 8-year-old girl with cystic fibrosis. (a) Oblique scan shows a focal echo-rich area (arrows) in the right hepatic lobe of the liver (L). (b) Axial contrast-enhancement CT scan confirms the focal fatty infiltration in the liver (arrow) and shows diffuse small calcifications within the pancreas (P)
**Hepatitis**

Hepatitis is common in children and is not diagnosed by imaging. It is usually of viral origin and may be due to hepatitis A, B, C, D or E viruses. Noninfectious causes of hepatitis include drugs, toxins, autoimmune diseases and sclerosing cholangitis.

Hepatomegaly is the commonest manifestation of acute hepatitis, although the liver is often sonographically normal. In severe disease, ultrasound shows a heterogeneous parenchyma with increased echogenicity. Sonography may also show thickening of the gall bladder wall, lymphadenopathy and ascites. The ultrasound findings should be correlated with clinical information and laboratory results.

Chronic hepatitis may be sequelae of acute hepatitis, with eventual progression to cirrhosis. A liver biopsy may be necessary to confirm the diagnosis.

**Biliary atresia**

Biliary atresia consists of an absent or severely deficient extrahepatic biliary tree, which affects 1 in 10 000 neonates. Its etiology is unknown; possible causes include viral infection, ischaemic injury, abnormal bile–acid metabolism, pancreatic–biliary maljunction, genetic effects and development anomaly (Fig. 5.27).

Biliary atresia is often confused with neonatal hepatitis syndrome, a disease that develops secondarily to conditions such as infection (cytomegalovirus, herpes simplex virus, toxoplasmosis, protozoa and syphilis), metabolic defects (α1-antitrypsin deficiency, galactosaemia, glycogen storage disease, tyrosinosis) and Alagille syndrome.

Biliary atresia and neonatal hepatitis syndrome are the common causes of conjugated hyperbilirubinaemia, as two overlapping conditions, usually present at 3–4 weeks of life in infants with jaundice. In both conditions, hepatic function tests show elevated serum levels of transaminases and bilirubin. It is important to distinguish the two, as neonatal hepatitis is managed medically, whereas biliary atresia requires early surgical intervention to prevent biliary cirrhosis.

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**Fig. 5.27.** Anatomical types of biliary atresia. Type I (a), common bile-duct atresia; type II (b), common hepatic duct atresia with a small gall bladder; type III (c), right and left hepatic duct atresia
On sonography, both biliary atresia and neonatal hepatitis syndrome can show normal or increased echogenicity of the liver parenchyma. The liver size is usually normal, and ductal dilatation is absent in both conditions. In biliary atresia, a marked increase in periportal echoes may be seen, which may represent early periportal fibrosis. A triangular or tubular echogenic density adjacent to the portal vein bifurcation has also been described in children with biliary atresia and has been called the triangular cord sign, considered to represent the fibrous remnant of biliary atresia. This sign is relatively specific for extrahepatic biliary atresia (Fig. 5.28).

**Fig. 5.28.** Biliary atresia in a 41-day-old girl with jaundice. Longitudinal sonogram shows an echogenic cord (long and short arrows) anterior to the portal vein (PV) and the hepatic artery (HA), indicating fibrosis along the course of the common hepatic duct; there is also a small gall bladder.

In neonate hepatitis syndrome, the gall bladder may be large, normal or small. In biliary atresia, the gall bladder is usually small or absent and not visualized (Fig. 5.29).

**Fig. 5.29.** Small gall bladder in biliary atresia (arrow) in a newborn boy. Oblique scan.
A change in gall bladder size after a milk feeding suggests that the common hepatic and common bile duct are patent; this is seen only in neonatal hepatitis.

In 10–20% of children with biliary atresia, other anomalies are found, such as choledochal cyst, polysplenia, preduodenal portal vein, azygous continuation of the inferior vena cava, diaphragmatic hernia, situs inversus or hydronephrosis. The abdomen should be examined for signs of end-stage liver disease, including ascites, hepatofugal flow in the portal and splenic veins and collateral venous channels.

Alagille syndrome (also known as arteriohepatic dysplasia) is characterized by a paucity of interlobular bile ducts. It is usually an autosomal dominant trait and is associated with cholestatic jaundice, pulmonary artery stenosis, butterfly vertebrae and hemivertebrae, and abnormal facies (deep-set eyes, pointed chin, frontal bossing, bulbous tip of the nose). The ultrasound findings are similar to those in biliary atresia. In these children, histological analysis reveals a paucity and hypoplasia of the interlobar ducts. Hepatobiliary scintigraphy and MRI cholangiopancreatography can also provide useful information for evaluating the patency of intra- and extrahepatic biliary ducts.

When neonatal hepatitis and biliary atresia cannot be differentiated by imaging, percutaneous liver biopsy may be necessary, especially when scintigraphy is not available or when small-bowel activity cannot be demonstrated on hepatobiliary scintigraphy. Cholangiography is indicated when the imaging and pathological findings suggest a diagnosis of biliary atresia. It may be performed percutaneously, endoscopically or intraoperatively via the gall bladder. When extrahepatic biliary atresia is confirmed intraoperatively, a Kasai portoenterostomy is performed, which may be effective in infants under 3 months. Poor results are seen in cases of cirrhosis. Liver transplantation may be the final option.

Changes in the Doppler-assessed portal venous velocity have been described in children with biliary atresia, and a correlation between decreased velocity and poor postoperative prognosis has been reported. Patients with reduced portal venous velocity, elevated hepatic arterial resistance or a flattened hepatic vein needed transplantation, while children with normal velocity do well with portoenterostomy alone.
**Choledochal cyst**

Choledochal cysts are malformations of the extrahepatic and intrahepatic bile ducts. Their origin is unknown, but they may be the result of an anomalous junction of the pancreatic and distal common bile duct, resulting in reflux of pancreatic enzymes into the biliary tree, which causes chemical cholangitis and eventually dilatation of both the common bile duct and the entire biliary tree.

The child may be asymptomatic or have pain, an abdominal mass and cholestatic jaundice. Sonography shows a well-defined cystic mass in the region of the porta hepatis that is in continuity with the hepatic bile duct and separate from the gall bladder. The cyst may measure 2–35 cm. The pancreas and pancreatic duct should be examined for evidence of pancreatitis or ductal dilatation. Antenatal ultrasound may show a choledochal cyst as early as 15–20 weeks’ gestational age. Biliary scintigraphy and MRI cholangiography can be used to confirm that the dilated cystic structure communicates with the biliary tree. Five types of choledochal cysts with several subtypes have been described by Todani et al. (Fig. 5.30).

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**Fig. 5.30.** Four anatomical types of choledochal cysts (Alonso-Lej classification). Type I, fusiform dilatation of the common bile duct; type II, true diverticulum arising from the common bile duct; type III, choledochocoele; type IV, multiple intra- and extrahepatic cysts
Type I cysts, which are characterized by segmental or diffuse fusiform dilatation of the common bile duct, are the commonest, accounting for 75–95% of cases (Fig. 5.31). The Todani type II choledochal cyst consists of a true diverticulum arising from the common bile duct and is found in 2% of cases. Todani type III is a cholecchoele that involves only dilatation of the intraduodenal portion of the common bile duct and is found in 1–5% of cases. Todani type IV accounts for about 10% of cases and is divided into two subtypes: type IVA is the second commonest form and consists of multiple intra- and extrahepatic cysts; type IVB involves multiple extrahepatic cysts and is rare. Type V, or Caroli disease, consists of single or multiple intrahepatic biliary cysts; it is rarely seen in neonates or young infants. Imaging shows multiple, branching, tubular structures, corresponding to dilated biliary radicals (Fig. 5.32). The portal radicals may be partially or completely surrounded by dilated ducts, and there may be dilatation of the common bile duct. Caroli disease is usually associated with hepatic fibrosis, portal hypertension or polycystic kidney disease.

The differential diagnosis of choledochal cyst includes hepatic cyst, enteric duplication cyst, pancreatic pseudocyst, hepatic artery aneurysm and spontaneous perforation of the common bile duct. Use of colour Doppler to identify vessels in
cases of aneurysm is helpful, as it is helpful to identify the digestive layers in cases of digestive duplication cysts. The commonest complications of choledochal cyst are cholelithiasis, choledocholithiasis, pancreatitis, abscess, malignancy and cirrhosis.

**Inspissated bile syndrome**

Inspissated bile syndrome, or bile plug, consists of extrahepatic obstruction of the bile ducts by biliary sludge in full-term infants. Ultrasound shows dilated bile ducts containing moderately or highly echogenic material without acoustic shadowing. Sludge may be seen within the gall bladder (Fig. 5.33). The causes include total parenteral nutrition, Hirschsprung disease, intestinal atresia, rhesus incompatibility, haemorrhage and cystic fibrosis.
**Cirrhosis**

Cirrhosis is rare in neonates but may occur in older children. It can cause jaundice. This condition, consisting of chronic destruction of the hepatic parenchyma with replacement by fibrosis and nodular regeneration, may be caused by chronic hepatitis, congenital hepatic fibrosis, biliary atresia, cystic fibrosis, metabolic disease (Wilson disease, glycogen storage disease, tyrosinaemia, galactosaemia, α-antitrypsin deficiency), Budd-Chiari syndrome or total parenteral nutrition.

On ultrasound, a dystrophic liver appears, with an atrophic right hepatic lobe and medial segment of the left lobe, and compensatory hypertrophy of the lateral segments of the left and caudate lobes. The hepatic echo pattern is often heterogeneous, with multiple regenerating nodules. Other signs of cirrhosis, including ascites and portal hypertension, are often seen. Colour Doppler is useful to determine the permeability and the direction of portal flow, to look for porto-systemic shunts and the aspect of the hepatic veins, and to visualize flow in the splenic and mesenteric veins, the hepatic artery and the inferior vena cava.

**Cholelithiasis and choledocholithiasis**

Gall stones in infancy are generally asymptomatic; their incidence is approximately 1.5%. Common causes of cholelithiasis in infants and children include furosemide therapy, malabsorption, total parenteral nutrition, Crohn disease, cystic fibrosis, bowel resection and haemolytic anaemia. Calculus formation can also be idiopathic. The sonographic appearance of a gall stone is an echo-rich intraluminal structure that causes distal acoustic shadowing and which moves with changes in the child’s position (Fig. 5.34).

Cholecystitis is an inflammation of the mucosa of the gall bladder wall due to bacterial infection. Acute cholecystitis is uncommon in infants and children. It may be either calculous or acalculous; 50% of paediatric cases are caused by stones obstructing the cystic duct. Imaging findings in acute cholecystitis include gall bladder distension, intraluminal sludge, wall thickening > 3 mm, pericholecystic fluid and inflammatory changes in the pericholecystic fat (Fig. 5.35).
Complications of acute cholecystitis include gangrene, emphysema of the gall bladder wall and perforation. The presence of a Murphy sign (localized sub-hepatic pain during ultrasound exploration) can assist diagnosis. Irregularities in the thickened gall bladder wall may suggest gangrenous changes, bubble gas signs indicate emphysema and pericholecystic fluid suggests perforation.

Hydrops, or gall bladder distension, is characterized by massive dilatation of the gall bladder in the absence of inflammation. It may be asymptomatic or manifested as a right mass with abdominal pain (Fig. 5.36). The common causes include Kawasaki disease (mucocutaneous lymph node syndrome), scarlet fever, sepsis, leptospirosis, ascariasis, typhoid fever, total parenteral nutrition and familial Mediterranean fever.
Spleen

Indications
Ultrasound is the preferred imaging modality for initial evaluation of the spleen in children with splenomegaly (haematological, infectious or rheumatic disease), palpable abdominal mass, ascites, suspected spleen abscess, abdominal trauma, suspected endemic echinococcosis or liver disease.

Preparation
No particular preparation is needed.

Examination technique
No premedication is needed. The child lies in the supine position initially and later on the left or right side. Coupling agent is applied liberally, first over the left upper abdomen and then over the rest of the abdomen as the examination proceeds. Scanning should be performed in the longitudinal, transverse and oblique planes, including scans through the intercostal and subcostal regions. The examination should be carried out with high-frequency convex or linear probes ranging from 3.5 to 7 MHz. Ultrasound Doppler is useful for locating vessels and for ensuring the permeability of the vascular structures.
Normal findings

The normal spleen has a homogeneous echo texture, similar to that of the liver (Fig. 5.37). The splenic hilar vessels are usually obvious, but intrasplenic vessels are not. The size of the spleen depends on the age of the child: in neonates, the normal length is 4 cm, which increases linearly with age by about 0.5 cm per year (Fig. 5.38). The upper limit of normal spleen length is 6 cm at 3 months, 7 cm at 12 months, 8 cm at 2 years, 9 cm at 4 years and 10 cm at 8 years. In adolescents, the upper limit for length is 12 cm for girls and 13 cm for boys; the upper limit is 7 cm for width and 3 cm for thickness. In general, the tip of the spleen should not extend below the inferior pole of the left kidney.

Fig. 5.37. Normal echo texture and echogenicity of the spleen (S) in a 5-year-old boy. Longitudinal scan shows a homogeneous echo texture; splenic hilar vessels are well visualized (arrow)

Fig. 5.38. Spleen size in a 2-month-old girl. Longitudinal scan shows a spleen measuring 4.26 cm between the lower and upper pole
Pathological findings
Anomalies of form, number and position

**Splenic lobulation**

Splenic lobulation is simple persistent fetal lobulation with no particular pathological symptoms. It is frequent in children and appears sonographically as a medial or anterior notch within the splenic parenchyma (Fig. 5.39).

Fig. 5.39. Splenic lobulation in a 5-month-old girl. Longitudinal scan shows lobulation (arrows) of the spleen (S)

**Accessory spleen**

Single or multiple accessory spleens are common anatomical variants, found in 10–30% of people at autopsy. They are inborn disorders, resulting from defective fusion of splenic mesenchymatous aggregates. A single accessory spleen is usually smooth and presents as a round or oval formation < 4 cm in diameter. Its echogenicity

Fig. 5.40. Accessory spleen in a 3-year-old boy. Longitudinal scan shows a small nodule (arrows) of tissue adjacent to the splenic hilum and the left kidney (LK), with echogenicity similar to that of the adjacent splenic (S) parenchyma
is similar to that of the normal spleen (Fig. 5.40). Accessory spleens are usually located in the splenic hilum and along the splenic vessels, but can be found remotely, even in the thorax. Accessory spleens may develop after splenectomy.

**Wandering spleen**

Wandering spleen is a disorder characterized by laxity of the suspensory splenic ligaments, which allows the spleen to lie in an ectopic location. In the event of vascular pedicle laxity, the spleen may be mobile in the abdominal cavity. These spleens, also known as portable lamps, are vulnerable to ischaemia and splenic infarction due to torsion of the pedicle. The imaging findings are an absence of splenic tissue in the upper left quadrant and a mass elsewhere in the abdomen with a shape and echo texture similar to those of normal spleen. Ultrasound allows a diagnosis of ectopic spleen, and Doppler consolidates a diagnosis of ischaemia or infarction by visualizing either torsion of the pedicle or defective vascularization of the splenic parenchyma.

**Polysplenia and asplenia**

Polysplenia and asplenia are rare and are often associated with visceral heterotaxy, cardiac and pulmonary abnormalities, interruption of the inferior vena cava and azygous continuation and a preduodenal portal vein or bile duct atresia (Fig. 5.41). Polysplenia is characterized by multiple splenic nodules in the left or right upper quadrants (Fig. 5.42). Asplenia is characterized by an absence of splenic tissue. Polysplenia is sometimes completely isolated and is detected fortuitously, in contrast to asplenia, which is generally found in the polymalformation syndrome. Asplenia must be differentiated from splenic atrophy post-infarction in sickle-cell anaemia.

![Fig. 5.41. Polysplenia with interruption of the inferior vena cava in a 5-year-old boy.](image)

(a) Ultrasonography shows two spleens (S) in the upper right quadrant, associated with situs inversus. (b) Axial contrast-enhancement CT scan shows azygous continuation (arrow) of the inferior vena cava
Anomalies of size

*Splenic atrophy*

Splenic atrophy may be seen in sickle-cell anaemia after splenic infarction (Fig. 5.43), coeliac disease and in Fanconi anaemia.

**Fig. 5.42.** Polysplenia in a 7-month-old girl. Multiple small spleens (S) are seen in the upper left quadrant; just above the diaphragm, a small quantity of pleural effusion (PE) is seen, with an atelectatic lower lobe of the left lung (LL)

**Fig. 5.43.** A 15-year-old boy with splenic atrophy and infarction secondary to sickle-cell disease. Oblique sonogram shows splenic atrophy with increased echogenicity of the spleen parenchyma (arrow) and multiple echo-poor nodular lesions (N)
**Splenomegaly**

Splenomegaly in children is usually the result of infectious or parasitic processes but can be found in many paediatric conditions, either as part of the general condition (portal hypertension, haemolytic anaemia, lymphoma, leukaemia, overload disease) or in isolation as a sign of another condition, such as Gaucher disease. The ultrasound findings are usually nonspecific (Fig. 5.44).

**Portal hypertension**

Portal hypertension usually results from increased resistance to hepatopetal portal venous flow. The clinical signs include splenomegaly, ascites, prominent abdominal vein, haematemesis and hepatic encephalopathy. The ultrasound findings in portal hypertension include a large portal vein, decreased or reversed portal venous flow, increased calibre of the hepatic artery, portosystemic shunts, splenomegaly, a thick lesser omentum, ascites and signs of cirrhosis. Colour Doppler detects the flow, localizes the obstacle in the portal or hepatic vein and indicates whether another imaging modality, follow-up or shunting treatment is needed.

**Parasitic and viral infections**

Parasitic and viral infections, such as Epstein-Bar virus infection and cat-scratch disease, are major causes of splenomegaly in children. In areas in which *Plasmodium falciparum* is endemic, so-called tropical idiopathic splenomegaly is common in young people. This clinical entity is defined by splenomegaly with or without hepatomegaly, elevated immunoglobulin M and coagulopathy of unclear secondary etiology. Splenomegaly is also common in fungal infections and in protozoan diseases such as malaria and leishmaniasis.
Haemoglobinopathy and haematological malignancies

Haemoglobinopathy and malignancies such as leukaemia and lymphoma may be associated with splenomegaly (Fig. 5.45).

**Fig. 5.45.** Splenomegaly in an 11-year-old boy with Hodgkin lymphoma. Longitudinal scan shows splenomegaly with multiple echo-poor lesions

Focal lesions

**Bacterial and fungal sepsis**

Bacterial and fungal sepsis can be the cause of single or multiple nodular intrasplenic lesions. Patients usually present with fever and upper left quadrant pain, and splenomegaly is found on physical examination. Imaging shows splenomegaly with multiple small abscesses that are echo-poor on sonography and clearly demarcated. Calcifications may be seen after treatment (Fig. 5.46).

**Fig. 5.46.** Splenic microabscesses secondary to *Mycobacterium tuberculosis* infection in a 4-year-old girl. Oblique scans. (a) Echo-rich lesions (caliper), well demarcated, in the splenic parenchyma (S), surrounded by an echo-poor halo. (b) 8 months later, multiple calcifications (arrows) in the spleen (S)
Epidermoid cyst
Epidermoid cysts are congenital lesions, which are often rich in cholesterol crystals. They are generally isolated, unilocular and rarely calcified. The imaging findings are nonspecific. On sonography, they usually appear as unilocular, smooth-walled, echo-free lesions (Fig. 5.47). Septations and wall calcification are infrequent. The internal echogenicity is probably due to cholesterol crystals or lipid droplets. Epidermoid splenic cysts can be complicated by intracystic haemorrhage or splenic rupture in the case of large cysts.

Fig. 5.47. Epidermoid splenic cyst in an 8-year-old girl. Longitudinal scan reveals a round, sharply marginated cyst (C) with internal echoes; S, spleen

Splenic angioma
Splenic angioma is a congenital malformation which is rarely encountered in childhood. Angiomas are composed of vascular channels lined with a single endothelial layer and filled with red blood cells. They may be isolated or part of a syndrome, such as Klippel-Trenaunay-Weber and Beckwith syndromes. Immature angiomas are characterized by a proliferative phase, a phase of stabilization, then spontaneous regression with calcifications.

The imaging findings of splenic angioma are similar to those of the liver. The ultrasound appearance is an echo-rich, homogeneous lesion with well-defined margins (Fig. 5.48). Calcification may occur. Colour Doppler shows a prevalence of veins with broad, low-flow vascular lakes or a prevalence of capillaries.
Hydatid cyst of the spleen

Splenic hydatid disease is rare but not exceptional. It has been reported to account for up to 4% of cases of abdominal hydatid disease. The ultrasound aspect is similar to that of hydatid cyst of the liver (Fig. 5.49).

Splenic lymphangioma

Lymphangiomas are congenital malformations of the lymphatic and venous systems that result in a mass of dilated lymphatic channels with aberrant or obstructed outflow. They are considered to be benign vascular tumours and can occur elsewhere; the splenic location is rare. Progression is slow, with inflammatory and infectious episodes.
The lesion may be cystic, solid or mixed. Typically, ultrasound shows multiple well-defined echo-free or echo-poor lesions throughout the spleen. Colour and pulse Doppler may give an objective vascular pattern within the fine loculations, which confirms the diagnosis of haemolymphangioma. In cases of haemorrhagic or infectious complications, fine echoes and thick loculations can be seen. The extension study is best performed with CT or MRI.

**Trauma**

Splenic lesions are the most frequent traumatic abdominal lesions in children. The imaging characteristics of splenic trauma are similar to those seen in the liver. They are classified as parenchymal haematoma, subcapsular haematoma (Fig. 5.50), contusion (Fig. 5.51), laceration or fracture (Fig. 5.52).
Hepatosplenomegaly

Haematological diseases
Leukaemia, Hodgkin disease and lymphomatous infiltration are frequently the cause of massive hepatosplenomegaly. The usual associated signs are nodular formations, echo-poor lesions in the spleen or liver, lymph node enlargement, kidney infiltration, pleural effusion, ascites and other abdominal masses.

Metabolic diseases
The diseases that result in hepatosplenomegaly are mainly glycogenosis and dyslipidaemia; storage diseases may also have this result.

Pancreas

Indications
Ultrasound allows study of the echoic structure of the pancreatic parenchyma, detection of focal lesions and characterization of its consistency and limits. Typical indications are: jaundice, an upper abdominal mass, abdominal pain, recurrent chronic pancreatitis, polycystic kidneys and abdominal trauma.

Preparation
Infants should take nothing by mouth for 3 h before the examination. If they require fluid to prevent dehydration, only water should be given.
Examination technique
No premedication is needed. The child lies in a supine position initially and subsequently on the left or right side. Scanning should be in the longitudinal, transverse and oblique planes, including scans through the intercostal and subcostal regions. The ultrasound examination is carried out with high-frequency convex probes ranging from 3.5 to 7 MHz and linear probes of at least 7–15 MHz for neonates.

Ultrasound Doppler makes it possible to localize vessels and assess the permeability of vascular structures.

Normal findings
The normal pancreas in children is homogeneous and nearly isoechochogenic with the liver (Fig. 5.53); however, in neonates, especially when premature, the pancreas can be echo-rich to the liver. Fatty replacement is not a normal finding in children. The dimensions of the pancreas vary directly with age. The pancreatic head and tail are usually similar in size and larger than the neck and body (Fig. 5.54). The upper anteroposterior dimension of the body is 1.5 cm, and the normal anteroposterior dimensions of the head and tail range from 1 to 2.5 cm. The main pancreatic duct may be seen as a single- or double-track echogenic line (Fig. 5.55). Its normal diameter should be no more than 1–2 mm.

Fig. 5.53. Normal echo texture of the pancreas in a 3-month-old boy. Transverse sonogram; homogeneous pancreatic parenchyma (arrows) with echogenicity similar to that of the adjacent liver parenchyma (L). IVC, inferior vena cava; SV, splenic vein; Ao, aorta
The pancreas develops from dorsal and ventral primordia, which usually fuse in utero. The ventral bud gives rise to the pancreatic head and the uncinate process, and the dorsal bud forms the remainder of the pancreatic head, as well as the body and tail. After fusion, the ventral duct joins the distal portion of the dorsal pancreatic duct to form the Wirsung duct. The proximal portion of the dorsal duct may regress or persist as an accessory duct, the Santorini duct. The Wirsung duct drains into the major papilla of Vater, while the Santorini duct empties into the accessory duodenal papilla, proximal to the ampulla of Vater.
Pancreas divisum
Pancreas divisum is the commonest and clinically most important major anatomical variant. It results from failure of the dorsal and ventral pancreatic ducts to fuse. The child may be asymptomatic or present with pancreatitis. It usually cannot be diagnosed with ultrasound but is suggested by CT, MRI or endoscopic retrograde cholangiography.

Pancreas anular
Although uncommon, pancreas anular is the second commonest congenital anomaly of the pancreas. It is characterized by two separate ventral moieties encircling the second part of the duodenum and results in a variable degree of duodenal obstruction. Most cases are diagnosed in infancy at the time of surgery for duodenal atresia or stenosis. The diagnosis is best made with CT and MRI, which show a thick circumferential band of pancreatic tissue encircling the duodenum. Many other associated abnormalities have been described: the commonest are intestinal malrotation, tracheo-oesophageal fistula, cardiac abnormalities, anal atresia and trisomy 21.

Congenital short pancreas
In congenital short pancreas, only the pancreatic head develops. The diagnosis can be made by sonography, CT and MRI and is based on identification of a pancreatic head and the absence of pancreatic tissue in the expected locations of the neck, body and tail. Polysplenia may be an associated finding.

Cystic fibrosis
Cystic fibrosis is a recessively inherited disease, with an estimated prevalence of 1 per 2000. The major pathological finding is obstruction of the ducts and ductules by mucoid secretion, which eventually leads to glandular atrophy, fibrosis and fatty replacement. Ultrasound shows a normal-size pancreas that is echo-rich to the liver.

Other causes of congenital pancreatic lipomatosis are Shwachman-Diamond syndrome, characterized by exocrine pancreas insufficiency, neutropenia, metaphyseal dysostosis and dwarfism.

Acute pancreatitis
Acute pancreatitis is uncommon in childhood. The commonest etiology is trauma, usually in motor vehicle accidents; other causes include non-accidental injury, postsurgical trauma, systemic disease, congenital anatomical abnormalities, metabolic diseases and drug toxicity. The systemic diseases include Reye syndrome, lupus, haemolytic uraemic syndrome, sepsis, shock and viral infections. Mumps virus has been specifically implicated as a causal agent.
A diagnosis of acute pancreatitis is usually based on combined clinical and biochemical findings. Ultrasound is the imaging procedure of choice for initial evaluation of possible pancreatitis. It shows focal or diffuse enlargement of the gland, with dilatation of the pancreatic duct and decreased echogenicity of the gland (Fig. 5.56). Severe acute pancreatitis often shows diffuse pancreatic enlargement, heterogeneous attenuation and inflammatory changes in the contiguous peripancreatic fat. The late complications of pancreatitis include pseudocyst fluid collection, abscess, vascular complications and extrapancreatic collection. Pseudocyst fluid collection and abscess occur more than 4 weeks after the onset of acute pancreatitis. On ultrasound, a pseudocyst is an encapsulated, echo-free or echo-rich collection with variable transmission (Fig. 5.57). A pancreatic abscess is a collection of pus, usually in close proximity to the pancreas. Pseudoaneurysm is a complex mass with enhanced transmission and turbulent arterial flow on duplex or colour flow Doppler imaging. CT is considered the procedure of choice for demonstrating the complications of pancreatitis, such as parenchymal necrosis, abscesses, haemorrhage and extrapancreatic collection.

Fig. 5.56. Acute pancreatitis in a 7-year-old girl. Transverse scan shows a diffuse, enlarged pancreas (P)
Chronic pancreatitis

Chronic pancreatitis is a continuing inflammatory process of the pancreas characterized by irreversible morphological changes, typically causing pain and permanent loss of exocrine and endocrine function. It is most commonly due to hereditary pancreatitis. Acute pancreatitis rarely becomes chronic in children. On ultrasound, the pancreas appears echogenic, with calcification and ductal dilatation (Fig. 5.58).

Fig. 5.57. Pancreatic pseudocyst in a 7-year-old girl due to accidental trauma on the handlebars of a bicycle. (a) Longitudinal scan shows well-defined pseudocyst (between calipers) anterior to the pancreatic body (P). (b), (c) Post-contrast CT images show the pseudocyst in the pancreas body and tail (arrows). L, liver; S, spleen.
Trauma

Traumatic pancreatic injuries account for fewer than 5% of abdominal injuries. Most are due to motor vehicle accidents, bicycle handlebars or child abuse, and they are the commonest cause of acute pancreatitis in children. Early diagnosis is important, as a delay of more than 24 h is associated with increased morbidity. Ultrasound may show interruption of the pancreas, peripancreatic fluid collections and altered echogenicity (Fig. 5.59, Fig. 5.60).

Fig. 5.58. Chronic pancreatitis in an 8-year-old boy. (a) Axial ultrasound scan through the anterior pararenal space shows pancreatic duct dilatation (arrow) and slightly echo-rich parenchyma; st, stomach. (b) Corresponding axial contrast-enhanced CT scan reveals the atrophic pancreatic parenchyma and the duct dilatation (arrow)

Fig. 5.59. Pancreatic laceration in a 7-year-old girl after abdominal trauma. Transverse scan shows a heterogeneous pattern and enlargement of the pancreas neck, body and tail, with a branching laceration (arrow)
Pancreatic tumours
Pancreatic tumours, both benign and malignant, are extremely rare in children. They are classically divided into three groups: exocrine, endocrine and cystic.

Exocrine tumours
The exocrine tissues of the pancreas give rise to benign and malignant tumours that are hormonally inactive. Pancreatoblastoma is the commonest exocrine tumour; it arises from the pancreatic acinar cells, usually in the head or tail of the gland. It is a low-grade malignancy with a favourable outcome. It occurs most commonly in children aged 1–8 years. On ultrasound, a pancreatoblastoma is a well-defined, large mass, typically with a mixture of cystic and solid components.

Endocrine tumours
Islet-cell tumours are usually functioning and benign. They include insulinoma, gastrinoma, VIPoma (a tumour that produces vasoactive intestinal peptide), glucagonoma and somatostatinoma. Insulinoma is the commonest: children present with hypoglycaemia, and the symptoms are relieved by intravenous glucose. Insulinomas are typically small, round or oval masses. On ultrasound, they may be echo-rich, homogeneous masses, and the tumour margin may be well circumscribed.

Cystic tumours
The commonest cystic mass is a papillary epithelial tumour, which occurs primarily in adolescent girls and young women. The tumour is typically large and usually arises in the pancreatic tail. On sonography, it is a well-demarcated mass with variable solid and cystic components, reflecting the presence of haemorrhage and cystic degeneration (Fig. 5.61).
Multiple pancreatic cystic tumours may be seen in von Hippel-Lindau disease, an autosomal dominant polycystic disease, and in cystic fibrosis.

**Digestive tract**

**Indications**
The main indications for exploration of the digestive tract are:

- acute and chronic, generalized or localized pain, including suspected intussusception, indeterminate appendicitis, ascites and peritonitis;
- abdominal masses;
- vomiting, including suspected hypertrophic pyloric stenosis or the controversial gastro-oesophageal reflux in the recurrent bronchitis etiology;
- blunt abdominal trauma;
- congenital abdominal abnormalities.

**Preparation**
No specific preparation is needed in urgent and acute cases. In general, fasting 2 h before the examination is helpful. A full bladder is useful for checking the pelvis. Mothers should be present to breastfeed or to give infants food, water or milk.
Examination technique

Infants should be in the supine position initially and later on the left or right side. Older children should, if possible, take a deep breath and hold it while a specific area is being scanned.

The operator should start with the appropriate probe, which should be of the highest frequency, and then decrease the frequency if there is insufficient penetration. A frequency of 5–10 MHz is suitable for most children, and the correct gain should be set to obtain the best image. The operator should place the transducer centrally at the top of the abdomen and gradually move it clockwise. Gradually compressing the abdomen and gently pushing the bowel gas away allow better visualization if the abdomen is gassy.

The observations should include bowel-wall thickness, bowel motility, bowel contents, free fluid or collections in the abdomen and any mass or cyst related to the bowel. Doppler techniques, if available, are helpful, particularly in cases of suspected appendicitis, masses, intussusception and bowel inflammatory diseases. It is essential to check all the intra-abdominal organs.

Normal findings

Ultrasound usually demonstrates five layers of the wall of the digestive tract between the cervical oesophagus and the rectum: the echo-rich lumen interface, the echo-poor mucosa, the echo-rich submucosa, the echo-poor muscle layer and the echo-rich interface with the surrounding tissue (Fig. 5.62).

Most of the lower part of the cervical oesophagus can be seen behind the left lobe of the thyroid gland (Fig. 5.63; see also Fig. 5.174). The abdominal oesophagus and the cardia are seen behind the left liver lobe (Fig. 5.64).
When the stomach is empty, it is easily identified below the left diaphragm as a star-shaped body. After a meal, pylorus (Fig. 5.65) and the rectum are observed behind the bladder (Fig. 5.66). The thickness of the normal digestive tract is ≤ 3 mm.
Pathological findings
Acute and chronic generalized or localized pain

Intussusception
Intussusception occurs most commonly between the ages of 6 months and 2 years. A proximal segment of the bowel (the intussusceptum) telescopes into a more distal segment (the intussuscipiens). Its incidence is seasonal. About 90% of intussusceptions are ileocolic and are thought to be due, in this age group, to enlarged lymphoid follicles (mesenteric adenitis) in the terminal ileum. Ultrasound is useful in the diagnosis of intussusception. The commonest site is the region of the ascending and transverse colon underneath the liver, but an intussusception can occur anywhere along the colon and, if severe, can protrude from the rectum.

Typical alternating echo-poor and echo-rich bands of mucosa and muscle layer can be seen, described as the target appearance in cross-section and as pseudokidney
in the longitudinal section (Fig. 5.67). Doppler shows hypervascularity. Poor vascularity suggests possible infarct of the bowel. The presence of free fluid trapped between the colon and the intussusceptum or in the Douglas pouch is associated with a significantly lower rate of success of reduction, with ischaemia of the bowel or peritonitis. Reduction of the intussusception in these situations is absolutely contraindicated.

Intussusception can be reduced with gas under ultrasound. The latter plays an important role in the follow-up of intussusception reduction by gas, water or barium enema and may allow detection of relapse of the intussusception or other complications.

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**Appendicitis**

Appendicitis is one of the commonest paediatric emergencies, occurring at any age but primarily in late childhood. In acute appendicitis, a child will typically present clinically with initial pain in the umbilical region or the right iliac fossa, with exquisite tenderness and fever. The ultrasound findings are similar to those in adults. It is generally easier to visualize the appendix in children than in adults because the transducer has a high frequency and the distance to the appendix is short.

The normal appendix, which is generally clearly seen, should be < 6 mm in diameter (Fig. 5.68). A diagnosis of appendicitis requires identification of an abnormally inflamed appendix, which is noncompressible, round and with a diameter > 6 mm; the surrounding mesentery and omentum are highly echogenic (Fig. 5.69). Fecaliths are identified in 20–30% of cases (Fig. 5.70). Increased vascularity may be seen with Doppler imaging (Fig. 5.71). If the appendix is perforated, a pelvic mass may be seen, with liquid in the Douglas pouch. Sometimes, ileus may be present, or there may be enlarged lymph nodes or a peri-appendiceal abscess and pus collection (Fig. 5.72).
Fig. 5.68. Normal appendix in a 4-year-old boy. Longitudinal sonogram through the right lower quadrant shows a normal-sized appendix (arrows), measuring < 6 mm in diameter. Note the central echogenic stripe representing the mucosa and submucosa and the peripheral echo-poor wall.

Fig. 5.69. Acute appendicitis in a 6-year-old girl. Longitudinal scan through the right lower quadrant shows a fluid-filled appendix (A) between calipers.

Fig. 5.70. Acute appendicitis in a 5-year-old boy. Longitudinal scan shows a fecalith (arrow) within an enlarged appendix (A) between calipers.
Mesenteric lymphadenitis is the main differential diagnosis of appendicitis. It is a viral mesenteric lymph node infection with nearly the same clinical presentation as appendicitis but with a normal white count. Ultrasound shows multiple nodal enlargement (more than one in the right iliac fossa), > 1 cm in size, with a normal appendix and normal appearance of the bowel wall (Fig. 5.73).

**Mesenteric lymphadenitis**

Acute appendicitis in an 8-year-old girl. Longitudinal colour flow Doppler image shows a dilated appendix with peripheral hyperaemia.

Peri-appendiceal abscess in a 4-year-old girl. Transverse scan through the right lower quadrant shows a localized fluid collection representing a peri-appendiceal abscess (arrows). Note the echogenic fecalith (F) on the right side and the surrounding inflammation.
Abdominal masses
Ultrasound is useful for exploring abdominal masses in order to define the consistency, the organ affected and potential complications.

Cystic abdominal masses
A cystic mass in the abdomen is a common finding. The main types of cyst in the digestive tract, except for ascites, are parasitic masses, mesenteric or omental cysts and duplication cysts.

Parasitic masses are mainly hydatid cysts in children > 2 years in endemic areas. The most frequent abdominal location is the liver, but the spleen, kidneys and peritoneum may be affected. The ultrasound findings depend on the age of the cyst and whether it is complicated, corresponding to its developmental stage. In the Gharbi classification, the cyst appears as an echo-free space with a well-defined border (type I), as a fluid collection with a floating membrane (type II), as a septated fluid collection (type III), as a heterogeneous body (type IV) or as a calcified formation (type V). The complications of the cyst seen by ultrasound include compression of the neighbouring organs and rupture.

Lymphangiomas, the most common of mesenteric or omental cysts, are congenital malformations of the lymphatic vessels in the mesentery, with no communication with the intestine. They are generally large and homogeneous but often multiloculated and with a thin wall, which is sometimes partially solid (Fig. 5.74). Doppler imaging may show septal vascularization. These masses may be intimately associated with the intra-abdominal organs (bowel wall, liver, kidneys, pelvis), and ascites may be present.

Digestive tract duplication, also known as duplication cyst, is a spherical or tubular structure lined with gastrointestinal epithelium, which contains smooth muscle in its wall. It is due to incomplete canalization of the bowel. The cyst may
occur anywhere in the gastrointestinal tract, from the oesophagus to the rectum, but is usually found in the distal ileum, oesophagus, duodenum or stomach. Duplication cysts are of variable size and are sometimes palpable. They may communicate with the lumen of the bowel. Ultrasound examination shows certain identifying features, such as an echogenic mucosa and an echo-poor muscular layer. Most cysts are clear and echo-free, but internal echoes may be seen if there has been bleeding or if they communicate with the digestive tract lumen (Fig. 5.75). Tc-99 pertechnetate scintigraphy can confirm the presence of ectopic gastric mucosa.

Fig. 5.74. Mesenteric cyst in a 3-year-old girl. (a) Transverse ultrasound scan shows a large cystic (C) lesion with thin internal septations (arrows). (b) Axial contrast-enhanced CT demonstrates a well-circumscribed cystic mass with smooth, thin walls and faint, thin septations (arrows)

Fig. 5.75. Duodenal cyst duplication in an 8-year-old boy with abdominal pain. (a) Longitudinal and (b) transverse scans of the right abdomen show a cystic mass (C) under the liver (L), with floating and layering internal debris (arrowheads); the wall is thickened, with alternating echo-rich and echo-poor layers (arrow)
Non-cystic abdominal digestive masses

The main cause is enlarged lymph nodes (Fig. 5.76). Mesenteric lymphadenopathy is a common finding in the abdomens of children, with lymph nodes measuring < 5–6 mm in diameter. Enlarged mesenteric, para-aortic or para-iliac lymph nodes in the abdomen, often multiple or conglomerated into huge masses, suggest lymphoma or tuberculosis (Fig. 5.77). The lymphoma may infiltrate the bowel wall, the mesentery and omentum (Fig. 5.78; Fig. 5.79).
Vomiting

Ultrasound examination must be the first imaging procedure used for vomiting infants. The cause depends on the age of the infant and the clinical and biological findings. Vomiting is frequent in children, and imaging should be limited to infants with a potential organic cause, confirmed by a well-trained physician. Ultrasound must exclude surgical causes of vomiting, such as hypertrophic pyloric stenosis, hiatus hernia, gastro-oesophageal reflux, mechanical bowel obstruction, appendicitis and intussusception.

Fig. 5.78. Non-Hodgkin lymphoma in a 7-year-old boy with abdominal pain. Longitudinal scan of the right abdomen shows a large, echo-poor mass (M) with some adjacent ascitic fluid.

Fig. 5.79. Burkitt lymphoma in a 4-year-old girl. Axial scan through the right lower quadrant of the abdomen shows thickened bowel wall (BW) between calipers, pseudokidney aspect, with an echogenic centre.
**Hypertrophic pyloric stenosis**

Pyloric stenosis is an evolving condition of pyloric muscle hypertrophy, which narrows and elongates the antropyloric canal. The condition can be familial. Typically, it occurs in male newborns between 3 and 6 weeks of age with nonbilious vomiting. Ultrasound is the modality of choice for confirming the diagnosis.

Infants present with projectile vomiting and sometimes a palpable epigastric mass, known as an olive. Marked gastric peristalsis can be seen in infants with a thin abdominal wall. Ultrasound shows a full stomach, which can be totally atonic when an early diagnosis has not been made. In other situations, a hyperperistaltic stomach and a dilated antrum are often seen. Pyloric hypertrophy appears as echopoor thickening of the pyloric muscle and elongation of the canal.

Normally, the pyloric muscle is < 2 mm thick, the canal is < 12 mm long and the pyloric diameter is < 6 mm. In hypertrophic pyloric stenosis (Fig. 5.80), the pyloric muscle is > 3 mm thick and the canal length is > 15 mm. The clinical findings are important for a positive diagnosis, before sending an infant to surgery. If there is any doubt, an upper gastrointestinal barium series will confirm the dilated stomach and the typical narrowing of the antrum.

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**Fig. 5.80.** Hypertrophic pyloric stenosis in a 2-month-old boy. (a) Longitudinal scan shows thickened muscle and elongated pyloric channel over 2 cm (arrows). Note also the redundant mucosa (arrowhead) protruding into the stomach (st). (b) Transverse scan shows the target sign; muscle layer thickness, 4 mm (arrow)
Gastro-oesophageal reflux

Gastro-oesophageal reflux is a retrograde flow of milk and solids from the stomach up the oesophagus. This condition is frequent in infants and is well demonstrated by ultrasound. When an infant has been given a liquid feed before the examination and is placed in the supine position, the gastro-oesophageal junction lies just to the left of the aorta, in the region of the xiphisternum, and can be seen by scanning longitudinally over the upper abdominal aorta. If a gastro-oesophageal reflux is present, air and gastric contents can be seen rising up to the oesophagus (Fig. 5.81). The presence of a hiatus hernia is well demonstrated by ultrasound. Gastro-oesophageal reflux may result in failure to thrive, and aspiration can cause cyanotic spells and chronic lung disease.

Use of ultrasound for identifying gastro-oesophageal reflux is controversial. The accepted procedure is a pH test, in which a probe is placed in the lower oesophagus and acidity in the oesophagus is monitored over 24 h. A conventional barium meal is probably still the most widely used examination, and it has the added advantage of demonstrating the anatomy of the lumen of the oesophagus, the stomach and the bowel.

Fig. 5.81. Gastro-oesophageal reflux in a 3-month-old girl. Longitudinal scan shows bubbling fluid (arrows) in the abdominal oesophagus lying under the heart (H), posterior to the liver (L) and above the stomach (st)

Blunt abdominal trauma

Abdominal trauma is frequent in countries where children often play or walk on the street. An important finding is fluid in the peritoneal cavity (haemoperitoneum). Ultrasound is used to observe all the intra-abdominal organs (liver, spleen, kidneys, bladder, pancreas, bowel and mesentery) that may be affected by the trauma. CT, when available, is useful in complicated cases. Trauma to the bowel may result in intramural haematoma (Fig. 5.82), intra- or retroperitoneal perforation or transection (Fig. 5.83). Free air in the abdomen indicates traumatic rupture of the digestive-tract wall somewhere between the stomach and the rectum. A bowel haematoma can occur anywhere in the tract wall, but most are found in the duodenum.
Fig. 5.82. Duodenal haematoma in a 10-year-old boy after abdominal trauma. (a) Transverse ultrasound scan shows a smooth echoic mass (H) projecting into and completely obstructing the duodenal lumen, with pancreatic duct dilatation (arrow). (b) Axial contrast-enhanced CT image shows an extending duodenal haematoma (H). (c) Corresponding coronal reformatted CT scan.

Fig. 5.83. Digestive tract perforation in a 6-year-old boy after abdominal trauma. Longitudinal scan shows subtle bubbles of free air (arrow) in the abdominal cavity, indicating perforation.
Inflammatory disorders

**Crohn disease**, or regional enteritis, is the most frequent inflammatory bowel disease in children. The terminal ileum and the proximal colon are involved in the majority of cases. The children affected are usually over 10 years of age at the time of diagnosis. The common clinical findings are abdominal pain and diarrhoea, weight loss, growth failure and perianal fistulae. On sonography, the inflamed bowel appears as a compressible or partially compressible tubular structure on longitudinal views, with a bull’s-eye appearance on transverse views (Fig. 5.84). Complications of Crohn disease include abscesses, sinus tracts and fistulae.

**Ulcerative colitis** occurs most often in children over 10 years of age. Bloody diarrhoea and abdominal pain are frequent features. The disease characteristically starts in the rectum and extends proximally in a continuous pattern for a variable distance. Ultrasound shows colonic wall thickening, usually by 6–10 mm (Fig. 5.85). Abscess formation and fistulae are unusual.
Non-inflammatory disorders

**Henoch-Schönlein purpura** is the commonest non-inflammatory digestive tract disease in children. It is a nonthrombocytopenic vasculitis that affects the bowel, skin, joints and kidneys. Abdominal pain and rash are the common presenting signs. Abdominal pain is due to bowel haemorrhage or intussusception. The ultrasound findings include high-attenuation intramural bleeding, thickened bowel wall and thickened valvulae conniventes (Fig. 5.86). The bowel lumen may be narrowed or completely obstructed by the haematoma or by intussusception.

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**Fig. 5.85.** Ulcerative colitis in an 11-year-old girl with bloody diarrhoea and abdominal pain. (a) Longitudinal and (b) transverse scans show uniform thickening of the left colon with thickening of pericolonic fat (F) and some adjacent ascitic fluid (asterisk)

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**Fig. 5.86.** Henoch-Schönlein purpura in a 4-year-old girl with abdominal pain. Longitudinal scan shows wall thickening in the distal jejunum associated with small, echo-rich intramural bleeding (arrows)
Ischaemic bowel disease

Ischaemic bowel disease is represented in children essentially by necrotizing enterocolitis and haemolytic uraemic syndrome. **Necrotizing enterocolitis** is considered to be the result of hypoxia and superimposed infection in neonates. It is associated with respiratory distress syndrome, birth asphyxia, low Apgar scores and shock. Necrotizing enterocolitis begins in the mucosa and submucosa and may extend through all the layers of the bowel wall; the distal ileum and right colon are usually involved. Sonography can be used to confirm the diagnosis. The early findings are nonspecific and include bowel distension; a later finding is intramural gas (pneumatosis intestinalis), which appears as highly echogenic intramural echoes with acoustic shadowing (Fig. 5.87). Portal venous gas is seen as mobile echoes within the portal vein (Fig. 5.88).

Fig. 5.87. Necrotizing enterocolitis with pneumatosis in a 2-month-old girl presenting with abdominal distension, vomiting and blood in the stools. (a) Longitudinal and (b) transverse scans show pneumatosis intestinalis with intramural gas (arrows), associated with mild bowel-wall thickening and small-bowel dilatation.

Fig. 5.88. Necrotizing enterocolitis in a 1-month-old girl. Transverse scan through the liver (L) shows multiple, mobile echogenic areas, representing gas (arrows) in the portal veins.
Haemolytic uraemic syndrome is a disorder characterized by a prodrome of bloody diarrhoea followed by acute renal failure, haemolytic anaemia and thrombocytopenia. The cause is thought to be an antigen–antibody reaction to the bacterial toxin *Escherichia coli* serotype O. The sonographic findings include a markedly thickened colonic wall, which is avascular in the prodromal stage.

**Urinary tract and retroperitoneum**

**Indications**
Ultrasound is useful for inspecting the urinary tract and the retroperitoneum in children, to confirm any antenatally diagnosed abnormality and to treat children with various congenital and acquired disorders. The main indications for exploration of the urinary tract and the retroperitoneum are urinary-tract infections, confirmation of urinary-tract anomalies detected antenatally, retroperitoneal masses and screening for intra-abdominal congenital abnormalities in some clinical situations.

**Preparation**
No specific preparation is needed in urgent and acute cases or for studying the retroperitoneum. Examination of the bladder and pelvis is best done in a well-hydrated child with a full bladder, when possible.

**Examination technique**
The infant should be supine on the left or right side. The bladder and pelvis should be examined first, before the infant micturates. Older children should, if possible, take a deep breath and hold it while a specific area is being scanned. As for all ultrasound examinations, the entire abdomen should be checked, including the kidneys and the retroperitoneum. The bladder and kidneys must be explored before and after micturition; however, an overfull bladder can cause mild fullness of the collecting system.

Colour Doppler, if available, should be used as an adjunct in assessing the renal pelvis and hilar vessels, for a quick overview of kidney blood flow or to demonstrate the vascularity of renal or adrenal masses. The report should state the size of the kidneys and pelvis, the thickness and regularity of the bladder wall and the approximate volume after micturition.

**Normal findings**
The normal ultrasound appearance of the kidneys in neonates is different from that of adults. It typically shows higher cortical echogenicity and stasis nephropathy resulting from deposition in the tubules of a glucoprotein known as Tamm-Horsfall.
protein. The precipitated proteins increase the echogenicity of the medullary pyramids and then disappear spontaneously within the 1st week of postnatal life (Fig. 5.89).

**Fig. 5.89.** Precipitation of Tamm-Horsfall protein in kidney of a newborn boy. (a) Longitudinal and (b) transverse scans show greater echogenicity in the renal cortex than in the liver (L) and echo-rich areas in the renal pyramids (arrows).

The normal parenchyma is isoechogenic or echo-rich to the liver and spleen up to 6 months of age. The medullary pyramids are prominent, echo-poor, triangular structures with a large base on the renal cortex, regularly arranged around the central collecting system. It is important to demonstrate this normal aspect in neonates and to differentiate between abnormal calyceal dilatation and cysts. The central sinus echoes in a neonate are less evident than in older children or adults because of the paucity of fat in this area (Fig. 5.90).

**Fig. 5.90.** Normal renal anatomy in a newborn boy. Longitudinal scan shows similar echogenicity of the renal cortex and liver (L), with prominent pyramids (P). The central renal sinus (arrows) is barely discernible.
By the end of the 1st year of life, the renal cortex is usually more echo-poor than the adjacent liver or spleen, and the medullary pyramids are even less echogenic. The renal sinus appears as a central echogenic area with an appearance similar to that in adults (Fig. 5.91). Occasionally, fetal renal lobulation persists into postnatal life up to 6 months of age. This should not be confused with renal scarring, which is associated with parenchymal thinning (Fig. 5.92).

The size of the kidney depends on the age of the child: the normal renal length is 4.5 cm at birth, 6 cm at 1 year, 8 cm at 5 years and 10 cm at 10 years (Fig. 5.93).
The anteroposterior renal pelvis shows some variation in size, but 10 mm is accepted as the largest diameter in a normal child, if the calyces are not seen (Fig. 5.94). The ureters are normally not seen on ultrasound. The thickness of the normal bladder wall is around 1 mm if the bladder is full and 2–3 mm when it is empty (Fig. 5.95). The bladder capacity depends on age but is never less than 30 ml. The volume after micturition varies from 0 to 15 ml.

The urethra is not seen by ultrasound in normal infants. The resistive index of the renal artery varies with age: in neonates, it is as high as 0.85; it decreases during the postnatal period, and is ≤ 0.7 by the middle of the first decade of life.
Pathological findings
Anomalies of the upper urinary tract

*Congenital anomalies*

Congenital anomalies are relatively common. They must be monitored carefully and are readily detected by ultrasound.

*Bilateral renal agenesis* is rare and incompatible with life. In *unilateral renal agenesis*, one kidney is absent, with compensatory hypertrophy of the contralateral kidney and adjacent organ displacement. Associated genital malformations are common, including absence of the seminal vesicles, seminal vesicle cysts, undescended testes, uterine duplication and vaginal imperforation with haematocolpos.

In *ectopic kidneys*, one or both kidneys are in an abnormal position when they fail to progress along their normal migratory path. In simple ectopia, the kidney and ureter are on the expected sides of the spine, most commonly in the pelvis. Rarely, they are found in the chest. In crossed ectopia, both kidneys are located on the same side of the spine. The ectopic kidney is usually smaller than the normal kidney, is malrotated and frequently has a dysmorphic configuration, such as a pancake kidney, disc or lump shape.

*Horseshoe kidneys* are characterized by fusion of the lower poles of the kidneys, which appears as a prevertebral mass. The ultrasound findings include anteriorly located renal pelves, a medial orientation of the lower poles of the kidneys and an isthmus of tissue crossing the midline anterior to the great vessels (Fig. 5.96).

In *crossed-fused ectopia*, one kidney may be displaced, cross the middle line and fuse inferiorly with the normally positioned kidney.

*Duplex kidney* is the commonest renal anomaly. It may be partial or complete. Renal duplication is easy to diagnose by sonography when partially dilated renal calyces occur and if ureterocoele is associated in the bladder. The duplex kidney is larger than the normal single system and has two separate renal sinus echo complexes.
A small kidney may be congenital, with normal parenchymal echogenicity, or it may be associated with renal artery stenosis or dysplasia. Acquired small kidney is often a late complication of vesico-ureteral reflux.

**Simple renal cysts** are rare in children, with an incidence less than 1%. Simple cysts arise in the renal cortex, do not communicate with the collecting system and are more often solitary than multiple. They are usually asymptomatic and detected during examinations for other indications. Calyceal diverticula which communicate with the collecting system through a narrow orifice should be distinguished from simple cysts (Fig. 5.97).
Multicystic dysplastic kidney is a nonhereditary developmental anomaly characterized by the presence of multiple noncommunicating cysts separated by tissue-containing primitive dysplastic elements in one kidney. It is often diagnosed during the antenatal period (Fig. 5.98). Ultrasound shows multiple cysts of varying size with a random distribution, absence of communication between the cysts, no discernible renal pelvis or sinus and absent or dysplastic renal parenchyma (Fig. 5.99). The other kidney may be normal, hydronephrotic or dysplastic.

A dysplastic kidney can be unilateral or bilateral. On ultrasound, the kidney appears small and echogenic with small peripheral cortical cysts.

Polycystic kidneys occur as two conditions. In autosomal recessive polycystic kidney, or infantile polycystic kidney, the kidneys are both highly echogenic,
heterogeneous and large (Fig. 5.100). Macrocysts are uncommon but may be seen. An antenatal diagnosis can be made. Depending on age, hepatic fibrosis appears, with increasing echogenicity, particularly in the periportal region, and cystic dilatation of the biliary tree (Caroli syndrome). In older children, portal hypertension may appear, with an enlarged spleen, ascites and digestive varices.

**Fig. 5.100.** Polycystic kidney in a newborn boy. (a) Longitudinal scan through the kidney shows an enlarged, echogenic kidney (K) and loss of corticomedullary differentiation, with tiny cysts (arrows). (b) Oblique scan through the liver (L) shows multiple small cysts (arrowheads)

Autosomal dominant renal disease, or adult polycystic kidney, usually manifests after the third decade, but cysts may be found in the kidney during childhood. Both kidneys are affected but unequally, varying from a kidney with a few isolated cysts to one filled with cysts. The more cysts there are in the kidneys, the larger it is, with a lobulated outline. The complications may include haemorrhage, infection and rupture, which can usually be diagnosed by ultrasound.

**Renal pelvic dilatation,** or pelvi-ureteric junction syndrome, is unilateral and rarely bilateral. The ultrasound findings depend on the degree of hydronephrosis due to the obstruction (Fig. 5.101). The ureters are not seen. A diagnosis is often made during antenatal life (Fig. 5.102).

**Megaureter** is an enlarged ureter, which may reflux in vesico-ureteral junction. It may be unilateral or bilateral. The ureter is dilated, sometimes to > 10 mm, and elongated. Ultrasound examination shows the dilated ureter and is useful for evaluating the degree and severity of hydronephrosis, to identify ureterocoele into the bladder and to confirm that the bladder wall is normal. Vesico-ureteric reflux must be sought (Fig. 5.103).
A grading system can be used to evaluate the evolution of hydronephrosis: grade 0, no hydronephrosis; 1, only the renal pelvis visualized; 2, some calyces visible, in addition to the renal pelvis; 3, all calyces seen; and 4, all calyces seen, with parenchymal thinning. A simpler solution is to measure the thickness of the renal parenchyma. All these anomalies must be monitored. They are sometimes related to particular syndromes, such as the VACTERL association, consisting of vertebral anomalies, anal atresia, cardiovascular anomalies, tracheo-oesophageal fistula, oesophageal atresia, renal anomalies and limb defects.

Fig. 5.101. Ureteropelvic junction obstruction in a 15-day-old boy. (a) Longitudinal and (b) transverse scans show dilatation of the calyces (C) and renal pelvis (Pe), with a thin rim of parenchyma (arrows) surrounding the collecting system.

Fig. 5.102. Ureteropelvic junction obstruction in a fetus at 23 weeks’ gestation. (a) Longitudinal and (b) transverse scans show marked dilatation of the left renal pelvis (Pe).
Renal stones are common in people in many developing countries, even in childhood, because of a hotter climate. They are often idiopathic. The commonest type of stone consists of calcium oxalate; less commonly they are made of calcium phosphate, cystine or struvite (ammonium magnesium phosphate).

Ultrasound can be used to detect and monitor the stones, to determine the causes and to evaluate dilatation of the renal cavities (Fig. 5.104). The stones cause intensive echoes and, if > 3 mm, a posterior shadow. Ureteral stones may be missed on ultrasound if they are not prevesical. Simple abdominal radiography is usually sufficient.

**Renal calculi and nephrocalcinosis**

Fig. 5.103. Hydronephrosis due to vesico-ureteral reflux. Longitudinal scans show (a) hydronephrosis (C, calyces; Pe, renal pelvis) and (b) elongation and distension of the upper ureter (U) with echo-free fluid.

Fig. 5.104. Urolithiasis in a 6-year-old boy. Transverse scan through the left kidney (LK) shows a renal pelvis stone (S), a highly reflective structure with acoustic shadowing (arrowheads).
In nephrocalcinosis, ultrasound shows increased echogenicity of the pyramids. Ultrasound is much more sensitive in the early stage of calcium deposition in the kidneys than simple abdominal radiography. Initially, there is a small increase in echogenicity and ringing of the pyramids, which, in severely affected children, eventually fill the medullae and then cast acoustic shadows (Fig. 5.105). Nephrocalcinosis is always bilateral and symmetrical.

Fig. 5.105. Nephrocalcinosis in a 5-year-old boy. Longitudinal scan of the right kidney (RK) shows echo-rich renal pyramids (arrows) with some posterior acoustic shadowing.

Renal tumours
Wilms tumour (nephroblastoma) is the commonest solid renal tumour in childhood. It occurs in children aged about 3–5 years. The ultrasound appearance depends on the stage and size at presentation. Typically, it is a well-defined, solid renal mass, with a small sliver of remaining normal kidney (Fig. 5.106).

Atypically, the tumour is echo-poor (cystic aspect) or shows some calcification (coarse and linear, as opposed to neuroblastoma).

The tumour may invade the renal vein, causing tumour thrombosis (Fig. 5.107). The contralateral kidney must be carefully examined for bilateral nephroblastomatosis (Fig. 5.108).

Liver metastasis, ascites and lymphadenopathy are rare. The staging of Wilms tumour requires a complementary imaging modality, such as CT.

Other renal tumours include benign mesoblastic nephroma in the neonatal period; malignant rhabdoid tumour, a variant of nephroblastoma, which occurs within the 1st year; lymphoma (Fig. 5.109); multilocular cystic nephroma (Fig. 5.110) and rhabdomyosarcoma. Ultrasound is suitable for detecting these tumours but generally not for differentiating them.
Fig. 5.106. Wilms tumour in a 5-year-old boy. (a) Oblique scan through the left kidney shows a large, heterogeneous mass (M) with areas of increased and decreased echogenicity. (b) Axial contrast-enhanced CT demonstrates a large round hypoaattenuating mass (M), distorting and displacing the normal parenchyma (arrow) of the left kidney.

Fig. 5.107. Wilms bilateral tumour in a 2-year-old boy. (a) Oblique scan shows a large mass (M) arising from the left kidney (LK). (b), (c) Oblique scans show extension into the inferior vena cava (IVC) and right atrium (RA) (arrows).
Fig. 5.108. Bilateral Wilms tumour with focal nephroblastomatosis in a 3-year-old girl. (a) Longitudinal scan through the left kidney (LK) and (b) longitudinal scan through the right kidney (RK) show bilateral masses (M). (c) Contrast-enhanced CT shows bilateral masses (M) and a small hypoattenuating well-circumscribed subcapsular mass in the right kidney, representing nephrogenic rests (arrows).

Fig. 5.109. Renal lymphoma in a 2-year-old girl. Oblique scan shows an enlarged, echogenic kidney with loss of corticomedullary differentiation.
Infectious and parasitic diseases

Acute bacterial pyelonephritis results from an ascending infection and is associated with vesico-ureteral reflux. The common causative agent is *E. coli*. Patients present with fever, abdominal pain, irritability and vomiting. Abnormal findings are usually found on ultrasound in severe infection and include generalized or focal renal enlargement, abnormal parenchymal echogenicity, poor definition of the corticomedullary junction and thickening of the wall of the renal pelvis or ureter (Fig. 5.111).

**Fig. 5.110.** Multilocular cystic nephroma in a 10-year-old girl. (a) Longitudinal scan through the left kidney (LK) shows a complex mass (arrows) containing echo-free locules separated by echogenic septa. (b) Axial contrast-enhanced CT showing the complex mass with multiple cystic areas (C), surrounded by enhancing septations (arrow).

**Fig. 5.111.** Acute pyelonephritis in a 1-year-old boy. Longitudinal scan shows a focal enlarged area of increased echogenicity (arrows) in the upper pole of the left kidney.
Renal abscesses are relatively uncommon complications of inadequately treated acute pyelonephritis. There are no specific ultrasound findings in childhood. Ultrasound shows a well-defined, echo-poor mass with thick walls, internal septations and fluid–debris levels (Fig. 5.112).

Chronic pyelonephritis usually results from recurrent episodes of vesicoureteral reflux. Ultrasound shows a small kidney with focal parenchymal scarring overlying a blunted calyx (Fig. 5.113).

Hydatid disease of the urinary tract is rare, representing less than 2% of all hydatid locations, and occurs in children over 3 years of age. The ultrasound findings in the kidney depend on the location and the stage of development of the parasite. The most frequent aspect in the kidney is multivesicular, type III in the Gharbi classification. Cystic lesions with urinary-tract dilatation are clearly seen by ultrasound (Fig. 5.114).

Schistosomiasis, due to Schistosoma haematobium species, affects the urinary tract of older children, with alterations to the kidneys, ureters and bladder. Ultrasound shows hydronephrosis, a pseudomass or a pseudopolyp and calcifications in the bladder wall.
Vascular diseases

Haemolytic uraemic syndrome is characterized by the classic triad of microangiopathic haemolytic anaemia, thrombocytopenia and renal failure. It is caused by an antigen–antibody reaction to bacterial toxins and affects children under 5 years of age who present with a prodromal phase of bloody diarrhoea followed by onset of renal failure. Typical sonographic findings include increased cortical echogenicity and echo-poor pyramids (Fig. 5.115).

Renal vein thrombosis occurs predominantly in newborns. It is usually a complication of severe dehydration and associated haemoconcentration secondary to blood loss, diarrhoea or sepsis. In older children, it may be the result of trauma,
neoplastic invasion of the renal vein, dehydration or nephrotic syndrome. The ultrasound findings include renal enlargement, increased parenchymal echogenicity and loss of normal corticomедullary differentiation (Fig. 5.116). An echogenic thrombus may be identified in the renal vein or inferior vena cava. Colour Doppler imaging shows no flow in the main renal vein and a narrow systolic arterial peak with reversed diastolic flow in the renal artery.

**Renal arterial infarction** in children is usually a global event and a complication of traumatic dissection. Acute segmental infarction is less common and may result from vasculitis or an embolus from an indwelling arterial line or cardiovascular vegetation. The clinical features and imaging findings are similar to those in adults.

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**Fig. 5.115.** Haemolytic uraemic syndrome in a 3-year-old boy. Longitudinal US Doppler scan through the left kidney (LK) shows echo-rich cortex and echo-poor renal pyramids

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**Fig. 5.116.** Renal vein thrombosis in a 3-month-old girl with dehydration. Longitudinal scan shows an enlarged right kidney (RK) with loss of normal corticomедullary differentiation
Anomalies of the lower urinary tract

The distal ureter may show primary megaureter, defined as ureteral dilatation above a short aperistaltic juxtavesical segment of ureter that has a normal insertion into the trigone. Ultrasound shows the retrovesical ureter pelvic portion, which is rarely visible in normal children (Fig. 5.117).

Ectopic ureter refers to abnormal insertion of the ureter into the bladder. This is rarely seen by ultrasound.

Ureterocoele is a cystic dilatation of the intravesical segment of the ureter. It may be small or fill the entire bladder and may even prolapse out of the urethra. Ultrasound shows the ureterocoele as a cyst with a thin membrane and associated anomalies, such as dilated ureter, duplex kidney and obstructive bladder anomalies (Fig. 5.118).

Ultrasound is not the best imaging modality for detecting and staging vesico-ureteral reflux. The bladder may show urachal abnormalities, involving incomplete obliteration of the urachal lumen, which connects the anterior bladder wall to the umbilicus during fetal development and normally closes during the 5th month of gestation. Four main forms can be distinguished: patent urachus, urachal sinus, urachal diverticulum and urachal cyst. The form detected most frequently is a midline cyst located between the bladder dome and the umbilicus (Fig. 5.119).

Bladder duplication is a rare anomaly, easily diagnosed by ultrasound, which shows two bladders lying side by side.

Congenital diverticulum of bladder is the most frequent bladder abnormality. It is often unilateral and rarely bilateral. Ultrasound shows the size and position of the congenital diverticula and modifications after micturition.
In cases of **Prune belly syndrome**, ultrasound shows the associated abnormalities, which include renal dysplasia, a large bladder and undescended testes.

In **cloacal abnormalities**, the vagina, uterus, bladder, kidneys, lower spinal cord and hips must be evaluated.

**Urethral abnormalities** include posterior urethral valves, which are the commonest cause of urethral obstruction in newborn boys. Bladder distension and dilated posterior urethra and the upper urinary tract are clearly seen by ultrasound, even antenatally (Fig. 5.120).

Other urethral abnormalities, including anterior urethral valve and urethral duplication, cannot be seen by ultrasound, which shows only the consequence of urethral obstruction, which is mainly dilatation of the urinary tract.

**Stones** in the bladder and in the male urethra are frequent in hot, poor areas, at any age of childhood. Ultrasound shows the stones, their number, size and position.
and their consequences: thickening of the bladder wall and dilatation of the bladder and renal cavities (Fig. 5.121).

In neurogenic bladder, ultrasound shows the bladder capacity, thickening of the wall, the post-micturition volume and any associated anomalies, such as stones and hydronephrosis.

Most neoplasms of the urinary bladder in children are malignant. Rhabdomyosarcomas are the commonest. Ultrasound shows a pedunculated soft-tissue mass projecting into the bladder lumen, referred to as a botryoid appearance or as focal or diffuse wall thickening (Fig. 5.122).
Adrenal glands
The adrenal glands are located on the upper part of kidneys. They have an inverted Y or V shape and are usually seen on the right side through the acoustic window of the liver. The sonographic appearance of normal adrenal glands varies with age. In neonates, they are relatively large and prominent, with an echo-poor cortex and an echo-rich medulla (Fig. 5.123). The adult appearance is acquired at 1–3 years of age, when the adrenals are seen as thin, linear, echo-poor structures.

Congenital hyperplasia is the commonest cause of ambiguous genitalia in female infants. The role of ultrasound is to demonstrate the presence of a vagina, uterus and ovaries.
Adrenal haemorrhage is a frequent cause of an abdominal mass in a neonate and sometimes during antenatal life. It is usually secondary to birth trauma or perinatal anoxia. The ultrasound findings depend on the stage of evolution of the haemorrhage. In a fresh haemorrhage, the gland is enlarged and echogenic; 1–2 weeks later, the central area becomes increasingly echo-poor, with some internal echoes, indicating the liquefaction stage (Fig. 5.124). A rim of calcification may appear in the last stage, which is seen clearly by simple radiography. Ultrasound is used to investigate the contralateral gland and the permeability of the renal vein and the inferior vena cava. Bilateral adrenal haemorrhage and renal vein thrombosis can occur.

Adrenal abscesses are rare, and ultrasound cannot differentiate them from haemorrhage. The clinical findings are important.

Adrenal cystic lesions are rare and nonspecific.

Neuroblastoma is the commonest solid tumour of childhood. The tumour may arise anywhere along the sympathetic chain, but the most frequent sites are the adrenal gland, retroperitoneum and posterior mediastinum. Neuroblastoma usually occurs in children < 5 years of age. The commonest clinical presentation is an abdominal mass, and about 90% of children have increased serum or urinary levels of catecholamines or their metabolites, particularly vanillylmandelic acid and homovanillic acid.

On ultrasound examination, neuroblastoma appears as a suprarenal or para-aspinal solid mass (Fig. 5.125, Fig. 5.126). It may be homogeneous or heterogeneous, with small punctate echogenic areas, and it may contain echo-poor areas as a result of haemorrhage, necrosis or cystic degeneration. The tumour margins may be smooth or irregular. Peripheral or central vascularity can be observed on colour Doppler. Small calcifications may be seen, and these help to differentiate this
Ultrasound examination with Doppler is essential for evaluating liver metastasis and infiltration, displacement and encasement of the aorta, inferior vena cava and renal and mesenteric vessels. Pepper syndrome, which is a disseminated neuroblastoma to the liver, skin and bone marrow of infants < 1 year, can be diagnosed by ultrasound (see Fig. 5.10).

Other childhood adrenal tumours are ganglioneuroblastoma, adrenocortical tumours and phaeochromocytomas. These are less common than neuroblastoma. Sonography shows nonspecific, solid, well-defined masses in all cases.
Special conditions

Confirmation of urinary-tract anomalies detected antenatally

This situation is frequent. The role of ultrasound, conducted 2–3 days after birth, is to confirm an antenatal diagnosis, to identify any anomalies and to provide baseline measurements for long-term follow-up, if needed. If the condition requires urgent investigation and treatment, the infant should be referred immediately to the appropriate department.

Imaging protocol for urinary-tract infections

Ultrasound is the investigation of choice for any child with a urinary-tract infection; all children should be thoroughly assessed and investigated after their first proven urinary-tract infection. The protocol for imaging depends on the age of the child and the availability of equipment; it can include, besides the ultrasound, a simple radiography, a urethrocystogram, isotope studies, CT and MRI.

The features of the urinary tract that should be established by ultrasound are:

- the size of the kidneys, any renal scarring, the regularity of the outlines and echogenicity;
- localized or diffuse dilatation of the collecting system and renal thickness;
- the diameter of the ureters in the lumbar and pelvic portions;
- bladder parameters, such as capacity, thickening of the wall, contents, contour and post-micturition volume.
Abdominal trauma

Renal trauma is frequent in children. Ultrasound is the main modality for diagnosis and follow-up in cases of renal trauma, parenchymal laceration and fracture (Fig. 5.128), subcapsular haematoma (Fig. 5.129), shattered kidney or avulsion from the vascular and pelvic pedicle. It also reveals intrarenal or perirenal haematoma, secondary dilatation of the renal cavities, urinary leakage and perinephric collection of urine (Fig. 5.130) and rupture of the bladder wall.

Fig. 5.128. Renal fracture in a 5-year-old girl with abdominal trauma. (a) Longitudinal scan shows a linear area of low attenuation in the mid-pole of the right kidney (RK) that extends into the collecting system (arrows). (b) Axial contrast-enhanced CT reveals the right renal fracture, nonperfused parenchyma in the anterior part of the right kidney, a large parenchymal haematoma (H) and surrounding perirenal haematoma (arrows)

Fig. 5.129. Renal subcapsular haematoma in a 7-year-old boy after trauma. Longitudinal scan through the right kidney (RK) shows an echo-rich subcapsular haematoma (arrows)
Hypertension
Symptomatic hypertension in children is usually secondary and of renal origin. Ultrasound is used to establish the size and echogenicity of the kidneys, parenchymal thinning and scars, any dilatation of the collecting system and any anomalies of the aorta and renal arteries, such as aneurysm, changes in the calibre of the aorta and renal arterial stenosis. Intra-abdominal tumours should be sought; in particular, both adrenal glands should be examined for a phaeochromocytoma, which can be located anywhere in the abdomen or pelvis.

Screening for congenital renal abnormalities
Ultrasound is the most efficient tool for identifying congenital intra-abdominal anomalies associated with various syndromes.

Enuresis
Enuresis is common clinically, and no exploration is generally needed. In children over 5–6 years, ultrasound may be used to verify the entire urinary tract, including bladder-wall thickening and the post-micturition bladder volume.

Pelvis
Indications
Ultrasound remains the imaging modality of choice for initial evaluation of most abnormalities of the paediatric female pelvis. The main indications are:

- precocious puberty;
- disorders of puberty;
- pelvic pain;
- pelvic mass;
- ambiguous genitalia;
- abnormal vaginal bleeding;
- suspected vaginal foreign body;
- vaginal mass.

**Preparation**
A full bladder is required for ultrasound examination of the pelvis. The child should drink fluid 1 h before the examination; in urgent situations, the bladder can be filled with sterile normal saline through a urethral catheter.

**Examination technique**
The examination is usually carried out with the child in a supine position. A coupling agent is used to ensure good acoustic contact between the probe and the skin. Longitudinal scans are conducted, first in the midline between the umbilicus and the pubic symphysis and then more laterally, on the left and right sides. A transverse scan is then performed. If necessary, the child is turned to the oblique position for identification of the ovaries.

The examination should be carried out with the highest-frequency probes, usually 3.5, 5.0 or 7.5 MHz. Doppler may be used if available. In older children, the endorectal route may be useful.

**Normal findings**

**Uterus**
The size and appearance of the uterus vary with age and pubertal status. The neonatal uterus is relatively prominent due to the effects of maternal and placental hormones. The cervix is larger than the fundus (fundus-to-cervix ratio, 1:2), the uterus is about 3.5 cm long, with a maximum thickness of about 1.4 cm; the endometrial lining is often echogenic (Fig. 5.131). Some fluid may be seen within the endometrial cavity.

At 2–3 months, the uterus decreases in size, acquiring a tubular shape; the size of the cervix is equal to that of the corpus (Fig. 5.132). In prepuberty, until about 8–9 years of age, the uterus remains small with a tubular configuration (Fig. 5.133). A high-frequency probe can show the central line in some cases. The uterus is 2.5–4 cm long, with a thickness no greater than 10 mm. Some fluid can be seen within the vaginal cavity (Fig. 5.134).

At puberty, the corpus is larger than the cervix, resulting in the adult pear-shaped uterus, measuring 5–8 cm long, 3 cm wide and 1.5 cm thick (Fig. 5.135). The central endometrial stripe is identifiable; its dimensions vary with the phases of the menstrual cycle, with a thickness of 2–3 mm in the early menstrual phase, 8 mm in the proliferative phase and approximately 15 mm in the secretory phase.
Fig. 5.131. Normal neonatal uterus. Longitudinal scan shows a prominent cervix and a thin, echo-rich endometrial stripe (arrowheads)

Fig. 5.132. Normal uterus in a 1-year-old girl. Longitudinal scan shows the tubular shape (calipers). B, bladder

Fig. 5.133. Normal prepubertal uterus in a 7-year-old girl. Longitudinal scan shows a small, tubular uterus with no differentiation between the fundus and the cervix and no recognizable endometrial stripe
Ovaries

The ovaries, like the uterus, change in size and morphology with age and pubertal status. The ovarian size is usually based on assessment of the ovarian volume, from \( V = \text{length} \times \text{width} \times \text{depth} \times 0.5 \). In the neonatal period, the ovarian volume is relatively large (about 3.6 cm\(^3\)), with the presence of large follicles (Fig. 5.136). After the neonatal period, the ovarian volume decreases with the decrease in maternal hormone levels. In infancy and early childhood, the ovaries are quiescent and 1–1.2 cm\(^3\) in volume. Microcystic follicles are routinely seen in this period, most measuring 5–10 mm in diameter (Fig. 5.137).

At puberty, the ovarian volume is 1.3–2.3 cm\(^3\), and cystic follicles are more frequent (Fig. 5.138). From around 8 years of age, with the onset of puberty, the size of the ovary increases by at least four times. At puberty, the average volume is 3–5 cm\(^3\), and the length is > 3 cm (Fig. 5.139).
Fig. 5.136. Normal neonatal ovary. Longitudinal scan shows a large ovarian volume with multiple large follicles (arrows).

Fig. 5.137. Normal ovary in a 2-year-old girl. Longitudinal scan of the right ovary shows an ovary with a volume of about 1 cm³ and microcystic follicles (arrows).

Fig. 5.138. Normal prepubertal ovary in a 7-year-old girl. Longitudinal scan shows multiple small follicles (arrows) < 9 mm in diameter and an ovarian volume of 2 cm³.
Pathological findings
Ovarian masses
Ultrasound is the initial imaging modality used in the diagnosis of suspected ovarian masses in children or adolescents.

Ovarian cysts
*Functional ovarian cysts* are the commonest cause of ovarian masses and have a bimodal age distribution, in neonates and adolescent girls. Functional ovarian cysts are often asymptomatic and are discovered incidentally on pelvic ultrasound performed for other reasons. On sonography, the classical cyst is echo-free, with a sharp back wall and excellent through-transmission (Fig. 5.140). The cyst can become large but usually no more than 3 cm. Most functional ovarian cysts are treated...
conservatively and resolve spontaneously. Rarely, there are complications, such as ovarian torsion, haemorrhagic cyst or ruptured cyst. In neonates, large cysts can extend into the abdomen. Cysts in adolescent girls are usually confined to the pelvis.

**Haemorrhagic ovarian cysts** are complications of functional ovarian cysts. The typical clinical presentation is sudden, severe, transient pelvic pain lasting 1–3 h. Ultrasound shows a complex adnexal cystic mass containing septations, low-level echoes, a fluid–debris level or clotted blood (Fig. 5.141). A thick wall and fluid in the Douglas space may also be seen.

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**Fig. 5.141.** Haemorrhagic ovarian cyst. (a) Longitudinal scan of the right adnexal region of a 10-year-old girl shows a large echo-rich cystic mass (C), indicating internal haemorrhage (B, bladder; U, uterus). (b) Longitudinal scan of the left ovary of a 12-year-old girl showing a large complex cyst (C) with internal echoes and septations (arrows). A follow-up scan 1 month later revealed spontaneous resolution.
Polycystic ovary disease, also known as the Stein-Leventhal syndrome, is characterized clinically by amenorrhoea, obesity and hirsutism. The endocrine profile of affected children reveals decreased levels of follicle-stimulating hormone and increased levels of luteinizing hormone. The sonographic findings include bilateral enlargement of the ovaries, which contain multiple small follicles, usually 0.5–0.8 cm in diameter (Fig. 5.142). The mean ovarian volume on ultrasound is 12–14 cm³.

Paraovarian cysts are of paramesonephric or mesothelial origin and arise in the broad ligament or Fallopian tubes. Their classical ultrasound appearance is a fluid-filled mass with thin walls. Paraovarian cysts are indistinguishable from other ovarian cysts, unless a normal ipsilateral ovary is seen separate from the cyst.

Benign ovarian neoplasms

Mature ovarian teratoma, also known as dermoid cyst, is the commonest ovarian neoplasm in children. Clinically, girls present with a painless pelvic or abdominal mass. The sonographic appearance of teratomas is variable because of their varied contents. The classical ultrasound appearance is a predominantly cystic mass with a mural nodule containing varying amounts of fat and calcification. Septations, internal debris and a fat fluid level may be seen (Fig. 5.143).

Serous and mucous ovarian cystadenomas are much less common than mature ovarian teratoma (Fig. 5.144). They appear as well-defined, thin-walled cystic masses with internal septa of varying thickness and irregularity. Calcification may be seen in the septations or the wall of the tumour.

Fig. 5.142. Polycystic ovaries in a 14-year-old girl with obesity, amenorrhoea and hirsutism. Longitudinal scan of the right ovary (RO) shows an enlarged ovary with echogenic central stroma and multiple peripheral small follicles (arrows)
Fig. 5.143. Benign ovarian teratoma in a 4-year-old girl. (a) Longitudinal scan of the right adnexal shows a large, predominantly cystic mass (C) with peripheral mural nodules (arrows) containing fat (F). (b) Axial and (c) coronal reformed contrast-enhanced CT scans show a well-defined cystic pelvic mass (C) containing calcification (arrow) and a layer of fat (arrowhead); B, bladder. (d) Intraoperative photograph demonstrates the large cystic mass (C).

Fig. 5.144. Serous ovarian cystadenoma in a 5-year-old girl with abdominal mass. (a) Transverse and (b) longitudinal scans show a large cystic mass (C) extending from the pelvis into the abdomen.
Malignant ovarian neoplasms

Malignant ovarian neoplasms account for only 2–3% of all childhood cancers. On ultrasound, the size and echogenicity of the mass are different from those of other malignancies, such as ascites, lymph nodes and hepatic metastases. The various distinct histological types include germ-cell tumours (dysgerminoma, immature or malignant teratomas, endodermal sinus tumour, embryonal carcinoma and choriocarcinoma), stromal tumours and epithelial carcinomas.

Uterine masses

Uterine masses are uncommon in childhood. The predominant masses found in newborns and infants are due to congenital vaginal or vaginal–uterine obstruction. The term used to describe a vaginal obstruction depends on the fluid content: hydrocolpos refers to dilatation of the vagina by serous fluid, hydrometrocolpos to distension of both the uterus and the vagina by serous fluid, haematocolpos to distension of the vagina by blood, haematometra to distension of the uterus by blood and haematometrocolpos to distension of both the uterus and the vagina by blood.

In neonates, vaginal obstruction is usually caused by vaginal or cervical atresia, high-grade stenosis, a transverse septum or an imperforate membrane. In adolescent girls, vaginal obstruction is most often the result of a simple imperforate membrane, septum or hymen.

Sonography usually suffices for diagnosis, and the imaging findings are similar for newborns and menarchal adolescents. The distended vagina appears as a tubular, fluid-filled, midline mass between the bladder and the rectum (Fig. 5.145). The uterine cavity may be dilated. The echogenicity of the contents may be increased if they are haemorrhagic.

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**Fig. 5.145.** Haematocolpos in an 11-year-old girl with cyclic pain. (a) Longitudinal scan shows a dilated vagina (V) with echo-rich fluid, representing blood but a normal uterus (U). (b) Transverse scan showing the distended vagina medial and posterior to the bladder (B)
Prepuberal bleeding

A vaginal foreign body can be demonstrated on ultrasound as an echogenic image with acoustic shadowing, which is characteristic but not always present.

Vaginal rhabdomyosarcomas are commonly botryoid and are found almost exclusively in young girls. On ultrasound, a vaginal rhabdomyosarcoma appears as a large, solid, heterogeneous or echo-poor mass posterior to the bladder.

Disorders of puberty

Precocious puberty is defined as complete sexual development (including menarche) before 8 years of age. Precocious puberty may be central or peripheral.

Central precocious puberty is idiopathic or due to a cerebral tumour or another cause of intracranial hypertension (e.g. post-meningitis hydrocephalus); it is gonadotrophin-dependent. Ultrasound shows augmentation of uterine and ovarian volumes (Fig. 5.146).

Peripheral precocious puberty, or precocious pseudopuberty, is gonadotrophin-independent. Autonomous ovarian follicular cysts are the most frequent cause, being more common than oestrogen-secreting neoplasms, such as granulosa-cell tumours and gonadoblastomas. In autonomous ovarian follicular cysts, bone age is often normal, and there is no response to stimulation with luteinizing hormone. Ultrasound shows a stimulated uterus and a unilateral follicular ovary.

Fig. 5.146. True isosexual precocity in a 5-year-old girl. (a) Longitudinal scan shows a pear-shaped pubertal uterus with a thin echo-rich endometrial stripe (arrowheads). (b) Longitudinal scans of the right and left ovary shows multiple follicles (arrows). B, bladder
Primary amenorrhea is defined as no menarche by 16 years of age, no thelarche or adrenarche by 14 years of age, or no menarche more than 3 years after adrenarche and thelarche. The absence of secondary sexual development at clinical examination and Müllerian structures on ultrasound are the basis for selecting laboratory tests. Common causes include gonadal dysgenesis (Turner syndrome with XO karyotype, nonvisualized mosaic or abnormal ovaries; 33% of cases) (Fig. 5.147), Müllerian (uterovaginal) anomalies (Müllerian agenesis, duplication defects with or without obstruction, canalization defects with or without obstruction; 20%), hypothalamic-pituitary causes (15%), constitutional delay (often familial; 10%) and other causes (e.g. systemic, psychiatric; 22%).

Müllerian agenesis or hypoplasia, often termed Mayer-Rokitansky-Küster-Hauser syndrome, is the result of absent or arrested development of both Müllerian ducts. Müllerian agenesis is the commonest cause of primary infertility after gonadal dysgenesis. The ultrasound findings include vaginal atresia, absent or rudimentary uterus (unicornuate or bicornuate) and normal ovaries. The karyotype is normal (46 XX). Renal or skeletal anomalies may be associated. A functioning endometrium may be present within the rudimentary uterus, resulting in unilateral haematometria.

Adolescents with obstructive uterovaginal anomalies present amenorrhea and cyclic abdominal pain. Ultrasound is useful for differentiating the frequent haemato(metro)colpos, which is due to an imperforate hymen or a transverse vaginal septum, from the rare haematometra, which is due to cervical dysgenesis (Fig. 5.148). Cyclic abdominal pain with normal menses and haematocolpos may occur due to an obstructed hemivagina with a double uterus, which is almost always associated with ipsilateral renal agenesis.
Adnexal torsion

In children, torsion of the normal ovary is rare. It is due to excessive mobility of the ovary and may occur when the Fallopian tubes are long and the ovaries are mobile or when there is a predisposing lesion, such as an ovarian cyst or mass (Fig. 5.149). The classical presentation is acute onset of lower abdominal pain, often associated with nausea or vomiting and leukocytosis. Some children have a history of recurrent pain, reflecting intermittent torsion and detorsion. On ultrasound, the involved ovary appears as an enlarged, echo-poor mass with multiple small peripheral follicles and good sound transmission (Fig. 5.150). Doppler ultrasound commonly shows lack of flow in the adnexum, although arterial flow is occasionally seen. The prognosis is poor when surgery is delayed.

Fig. 5.148. Haematocolpos with uterus duplex in a 12-year-old girl with an abdominal mass. (a) Longitudinal and (b) transverse scans show a markedly distended vagina (V) posterior to the bladder (B) and filled with blood. (c) Axial scan through the uterus shows the presence of two uteri (U)
Pelvic inflammatory disease

Pelvic inflammatory disease in sexually active girls is usually due to *Neisseria gonorrhoeae* or *Chlamydia trachomatis*. Less commonly, it is a result of direct extension from an adjacent infection, such as appendicitis, inflammatory bowel disease or post-operative abscess (Fig. 5.151). The clinical features include pelvic pain, fever and adnexal tenderness. The diagnosis is usually established clinically, and imaging is commonly used to identify complications, pyosalpinx or tubo-ovarian abscess, and in assessing response to treatment. The classical sonographic appearance of pyosalpinx is a tubular, fluid-filled adnexal mass containing low-level echoes representing purulent debris. A tubo-ovarian abscess appears as a thick-walled echo-poor mass,
usually containing internal debris, septations or a fluid–debris level. Other sono-
graphic findings include uterine enlargement with poorly defined margins and pelvic
lymphadenopathy. Doppler ultrasound usually shows increased colour signals in the
uterus, adnexa and pelvic soft tissues.

Intersex states
Intersex states are characterized by ambiguous external genitalia and gonads. The
clinical findings include cryptorchidism, labial fusion, clitoromegaly, epispadias
and hypospadias (Fig. 5.152). Ultrasound is useful for demonstrating the presence
or absence of the uterus in neonates with ambiguous genitalia, which is important
for determining the cause of hermaphroditism and for assigning sex.

Most cases of ambiguous genitalia consist of female pseudohermaphroditism due
to congenital adrenal hyperplasia. In these cases, ultrasound shows a normal uterus
and ovaries (Fig. 5.153). Increased size of the adrenal glands has been reported in
neonates and infants with congenital adrenal hyperplasia. Genitography shows ure-
throvaginal confluence and opacification of the uterine cavity.

Fig. 5.151 Pelvic inflammatory disease in a 4-year-old girl secondary to extension in the
Douglas space of a periappendiceal abscess. (a) Transverse scan of the right lower
quadrant shows an enlarged appendix (A) and a loculated heterogeneous fluid
collection (arrows). (b), (c) Transverse scans of the pelvis show extension of the
collection into the Douglas space. R, rectum; B, bladder.
The other intersex states are male pseudohermaphroditism, true hermaphroditism and mixed gonadal dysgenesis. Male pseudohermaphrodites have normal testes, although they may be undescended (Fig. 5.154). True hermaphrodites have
Fig. 5.154. Male pseudohermaphrodism in a 9-month-old infant. (a) Transverse scan of the inguinal region shows an undescended bilateral testis and no uterine cavity. (b) Lateral genitogram shows opacification only of the bladder (B) and urethra.

Fig. 5.155. Gonadal dysgenesis in a newborn. (a) Ambiguous external genitalia. (b) Transverse scan shows a bicornuate (arrows) uterus (U) behind the bladder (B). (c) Transverse scan of the pelvis shows a testis (T) above the bladder (B). (d) Lateral genitogram shows opacification of the bladder (B), vaginal cavity (V) and uterus (U).
an ovary on one side and a contralateral testis or an ovo-testis. The sonographic appearance of the ovo-testis is that of a heterogeneous ovoid mass containing small cysts.

Children with mixed gonadal dysgenesis have a testis on one side and a streak gonad containing ovarian stroma without ovocytes on the other side. A uterus, which may be bicornuate, is sometimes present (Fig. 5.155).

Other pelvic masses

**Ectopic pregnancy** is rare in adolescents, but girls in this age group have the highest reported rate of complications. Ultrasound with quantitative assessment of β-human chorionic gonadotropin is the essential diagnostic test.

A palpable mass in the labial or inguinal region of infants with ambiguous genitalia may be due to **ovarian herniation**. Ultrasound shows an ovoid mass, often containing cystic follicles (Fig. 5.156).

Ovary involvement is a late manifestation of **lymphoma**; it is more common in non-Hodgkin lymphoma than in Hodgkin disease. On ultrasound, ovarian infiltration is typically echo-poor and associated with diffuse bilateral enlargement of the ovaries (Fig. 5.157).

**Primary pelvic hydatid cyst** can be seen in endemic areas but is rare. The ultrasound findings are variable and depend on the age of the cyst (Fig. 5.158).

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**Fig. 5.156.** Ovarian herniation in a 3-month-old girl. Longitudinal scan of the left inguinal region shows a small, irreducible inguinal hernia containing the left ovary and bowel loop.
Fig. 5.157. Ovarian infiltration in a 6-year-old girl with Burkitt lymphoma. Longitudinal scan shows an enlarged, echo-poor ovary (O).

Fig. 5.158. Primary pelvic hydatid cyst in a 9-year-old girl with an abdominal mass. (a) Longitudinal scan shows a large cystic mass (C) extending from the pelvis to the abdomen. (b) Sagittal T2 and (c) sagittal T1-weighted images reveal a pelvic cystic mass (C) located between the uterus and the rectum (R). V, vaginal cavity.
Scrotum

Indications
Ultrasound is useful in most cases of scrotal disease in children. The main indications are in screening for congenital anomalies, cases of acute scrotum, scrotal tumours, trauma and varicocele and systemic diseases involving the scrotum.

Preparation
No specific preparation is needed in urgent and acute situations.

Examination technique
The child is examined in the supine position, with the scrotum supported by a towel placed on the anterior face of the thighs. High-frequency 7- to 10-MHz transducers are used. A large amount of warm gel is applied to minimize pressure on the scrotal skin, and longitudinal and transverse scans are performed. Examination of the spermatic cord is important, particularly in cases of acute scrotum, varicocele and suspected testicular torsion. Doppler is performed with optimized parameters; colour, power and pulsed Doppler are used to investigate extratesticular vascularization and testicular perfusion. The assessment of flow with positional and respiratory movements is limited in small children.

Normal findings
The scrotum is divided by the medial raphe or septum, and each half contains a testis, the epididymis and the scrotal portion of the spermatic cord. The normal testis is ovoid, has uniform low-to-medium echogenicity and is surrounded by an echogenic line, which corresponds to the tunica albuginea (Fig. 5.159). Testicular echogenicity increases with age, from echo-poor in neonates, becoming more echogenic between the ages of 8 years and puberty. In adolescents, the testicular mediastinum is seen as a thin echoic line crossing the testis along the superior–inferior axis (Fig. 5.160). The epididymis is visualized on longitudinal views, in three parts: a triangular head with the same echogenicity as the testis (Fig. 5.161), a narrow body located behind the testis and the tail at the inferior pole. Colour Doppler shows the capsular arteries and the intratesticular vessels (Fig. 5.162). Centripetal arteries are identifiable in 65–85% of prepubertal testes and in all postpubertal testes.

The five testicular appendages are the remnants of the mesonephric and paramesonephric ducts. Three can be seen on ultrasound, particularly in cases of hydrocoele. The appendix testis, also known as the hydatid of Morgagni, is usually seen as an oval structure between the testis and epididymis and is isoechoic to the testis. The appendages of the epididymis and the epididymal tail are rarely seen.
Fig. 5.159. Normal testis in a 2-year-old boy. Longitudinal scan shows the testis (T), which is ovoid, moderately echogenic and homogeneous. The tunica albuginea (arrows) is seen as a peripheral echogenic line.

Fig. 5.160. Normal testicular mediastinum in a 2-year-old boy. Longitudinal scan shows the mediastinum (arrows) as an echogenic band running across the testis (T).

Fig. 5.161. Normal epididymal head in a 2-year-old boy. Longitudinal scan shows the head of the epididymis (E) lying above the testis (T), with similar echogenicity.
The spermatic cord appears as a smooth linear structure limited by an echo-rich band on longitudinal scans and as an ovoid structure on transversal scans. It contains the testicular, deferential and cremasteric arteries and the pampiniform veins (Fig. 5.163). Vascular visualization and the spectral waveform depend on the sensitivity of the probe, optimization of parameters, the experience of the operator and the age of the boy.

The height, length and width of the left and right testes are measured on longitudinal and transversal scans. The testicular volume is derived from the formula \( V = L \times W \times H \times 0.52 \), where \( V = \) volume, \( L = \) length, \( W = \) width and \( H = \) height. It is 1–2 cm\(^3\) before the age of 12 years and reaches 4 cm\(^3\) in pubertal boys. The scrotal wall is 3–6 mm thick.

The normal inguinal canal is obliterated at birth and can be seen on ultrasound only in cases of abnormal peritoneovaginal communication.
Pathological findings
Anomalies of descent of the testes

The cryptorchid testis can be located at any point along the descent route, but 80–90% of undescended testes are in the inguinal canal. Cryptorchidism is more frequent in premature infants (30% of premature newborns and 5% at full term). Descent of the testis may be completed during the 1st year in 10% of boys. Ultrasound is the initial procedure used to demonstrate a testis in the inguinal canal. The cryptorchid testis is usually small and echo-poor to the normally located testis (Fig. 5.164). When the testis is located in the abdominal cavity, it cannot be seen, and laparoscopy may be required because of possible degeneration. Cryptorchidism is bilateral in 10–30% of boys, and associated urological abnormalities are found in 20%. The main complications of undescended testis are malignant degeneration and infertility. After surgical repair, the undescended testis usually remains smaller and echo-poor compared with the normal testis.

Fig. 5.164. Cryptorchidism of the left testis in a 3-year-old boy. Longitudinal scan shows an incompletely descended testis (T) in the left inguinal canal. The testis is small and less echogenic than the normally located testis.

Inguinal scrotal hernia

Intestinal loops and omentum may be found in the scrotal cavity in cases of delayed obliteration of the inguinal canal. In cases of acute scrotum, however, the clinical findings may be inconclusive. Ultrasound examination is effective when it shows gas bubbles in the scrotum. Colour Doppler is useful for assessing the viability of the intestinal loops. The contralateral side is examined to eliminate bilateral inguinal hernia. Peritoneography is rarely indicated.
Hydrocoele

Hydrocoele is the commonest cause of indolent scrotal swelling in children. It consists of an abnormal fluid collection of > 2 ml between the visceral and parietal layers of the tunica vaginalis and or along the spermatic cord. Hydrocoele is a congenital anomaly in neonates and infants, but an inflammatory fluid collection may be acquired in adolescence and in cases of torsion trauma or tumour. An abdomino-scrotal hydrocoele may present as a mass. On ultrasound, congenital hydrocoele appears as an echo-free fluid collection surrounding the anterolateral aspects of the testis and sometimes extending to the inguinal canal (Fig. 5.165). Spermatic cord cysts are a rare form of collection (Fig. 5.166). Most congenital hydrocoele (80%) resolve spontaneously before the age of 2 years; however, surgery is needed for spermatic cord cysts and abdomino-scrotal hydrocoele.

Fig. 5.165. Bilateral hydrocoele in a 2-month-old boy. (a) Longitudinal and (b) axial scans show a fluid collection (F) surrounding the testis (T) and the epididymis (E)

Fig. 5.166. Spermatic cord cyst in a 1-year-old boy. Longitudinal scan shows a cystic lesion (C) in the left spermatic cord with increased sound transmission
Varicocoele

Varicocoele is frequent in adolescence, seen as dilatation of the veins of the pampiniform plexus of the spermatic cord. On ultrasound, the dilated veins are tortuous, echo-free, tubular structures along the spermatic cord (Fig. 5.167). The reflux is demonstrated clearly by colour Doppler during Valsalva manoeuvre (Fig. 5.168). Treatment should be considered when the growth of the testis is affected. A unilateral left varicocoele should be followed up by abdominal ultrasound examination to search for associated anomalies, such as a renal tumour or left renal vein thrombosis.

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Fig. 5.167. Left varicocoele in a 13-year-old boy. Longitudinal scan shows multiple tortuous echo-free structures (arrows) in the supratesticular region (T, testis). Valsalva manoeuvre demonstrates the markedly increased diameter of the peritesticular structures

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Fig. 5.168. Varicocoele in an 11-year-old boy. Colour Doppler scan during a Valsalva manoeuvre shows increased flow in multiple tubular peritesticular vascular structures. T, testis
Acute scrotum

Acute scrotum is defined clinically as a suddenly painful scrotum, with redness, swelling and tenderness. Ultrasound with colour Doppler examination can show the typical signs of hydatid torsion, testicular torsion or orchiepidymitis in cases of evidence of infection. An infectious etiology is, however, rare in children. Surgery is often needed for treatment or investigation if the ultrasound examination is inconclusive.

Testicular torsion

Testicular torsion is a common condition, which can lead to ischaemic necrosis of the testis if not urgently reduced. It can occur at any age but is most frequent in neonates and adolescents. The torsion consists of twisting of the spermatic cord, with constriction of venous and arterial flow. On the basis of surgical findings, testicular torsion can be either extravaginal or intravaginal. Extravaginal torsion is seen mainly in neonates and occurs prenatally in most cases (Fig. 5.169). Intravaginal torsion can occur at any age but is commonest in adolescents. Ultrasound examination at an early stage (< 48 h) may show twisting of the vessels on the spermatic cord. The vitality of the testis depends on the degree and duration of ischaemia. When ultrasound is performed at a late stage, testicular infarct is suggested when there is enlargement, a heterogeneous echo pattern and a silent organ. Scrotal skin thickening and hydroceles are common associated findings. In chronic torsion, ultrasound shows a small, echo-poor testis with peripheral echogenicity corresponding to calcification in the tunica albuginea (Fig. 5.170).

Fig. 5.169. Extravaginal torsion in a newborn boy. (a) Longitudinal and (b) transverse scans show an enlarged, heterogeneous right testis (T) with echo-poor and echo-rich areas, surrounded by the highly echogenic tunica and a complex hydrocoele (H)
Torsion of the hydatid

Torsion of the hydatid is frequent in adolescents. The twisted appendix can be seen on ultrasound in the upper pole of the testis, associated with inflammatory signs and hyperaemia.

Orchiepididymitis

Orchiepididymitis is the result of retrograde spread of infection. It is a rare cause of acute scrotum in neonates and young children. Urinary-tract infection is frequently associated, affecting the epididymal head in particular. The ultrasound findings include a focally or diffusely enlarged, heterogeneous epididymis with increased blood flow in one or both testes. Adjacent scrotal skin thickening and reactive hydrocoele are also common findings. A differential diagnosis may be made from suspected malignancy, such as lymphoma or leukaemia. Biological and clinical findings are decisive in such cases.

Scrotal masses

Extratesticular masses

Paratesticular rhabdomyosarcoma is the most frequent malignant tumour of the epididymis. Metastases of leukaemia and non-Hodgkin lymphoma may be seen. The other masses of epididymis are epididymal cysts, which are seen as echo-free masses on ultrasound.

Testicular tumours

Testicular tumours are more frequent after puberty. They can be germ-cell or non-germ-cell tumours (Table 5.1; Fig. 5.171). They may appear as acute scrotum in cases of haemorrhage or infarction. Primary lymphoma is rare, but secondary lymphoma
involvement is common. On ultrasound, an enlarged, echo-poor, homogeneous or nodular testis is seen, often with hyperaemia simulating infection. Metastases of retinoblastoma, neuroblastoma or nephroblastoma are rarely located in the testis.

**Trauma**

Trauma is common in children, often occurring in association with torsion. Ultrasound is useful for demonstrating:

- testicular haematoma, with changing echogenicity over time
- testicular fracture (Fig. 5.172) or rupture
- haematocoele within the layers of the tunica vaginalis.
For follow-up, demonstration of normal blood flow is useful in cases of conservative treatment.

Involvement of the testis in various diseases

The testes may be involved in Henoch-Schönlein purpura, allergic diseases and congenital adrenal hyperplasia. In these diseases, ultrasound findings include scrotal wall thickening, epididymal enlargement, and reactive hydrocele. Differentiation between them is based on clinical and biological findings.

Testicular microlithiasis (Fig. 5.173) is a condition in which calcifications form in the lumen of the seminiferous tubules. It can occur in otherwise normal individuals, but it also has been reported in patients with Down syndrome, Klinefelter syndrome...
and cryptorchidism. On sonography, the calcifications are seen as fine, bright, non-shadowing echo-rich foci, which tend to be uniform in size and are distributed in a diffuse pattern or in peripheral clusters. Testicular microlithiasis is considered to be a premalignant condition; thus, it is recommended that patients with microlithiasis have sonographic examinations at least at yearly intervals.

**Neck**

**Indications**
Ultrasound is useful for inspecting all the neck organs in children to confirm abnormalities diagnosed antenatally, explore various disorders, perform guided biopsies and treat children. The main indications are:

- congenital anomalies
- palpable cervical masses
- screening and staging cervical lymph nodes
- suspected thyroid disorders
- parathyroid hyperplasia
- salivary gland diseases
- trauma
- suspected tumours (e.g. malignant lymphomas).

**Preparation**
No specific preparation is needed.

**Examination technique**
The child lies on his or her back in the supine position with the neck extended over a 5- to 10-cm-thick pillow under the shoulders, depending on the child’s age and cooperation. Examination is performed mainly by transverse scans and always with a comparison of the left and right sides. It may be necessary to rotate infants’ heads from right to left.

Linear probes should be of as high a frequency as possible (5–12 MHz). Doppler is helpful for demonstrating vascular anomalies and for differentiating thyroid disorders.

**Normal findings**
The examination should start with identification of all the normal structures in the neck (see Fig. 5.63): the carotid arteries and jugular veins, the thyroid and salivary glands, the cervical muscles, the cervical oesophagus posterior to the trachea and the left lobe of the thyroid, the trachea and lymph nodes (Fig. 5.174).
The carotid artery shows typical pulsation, with a round cross-section. The vein has an oval cross-section, with a diameter that depends on the intrathoracic pressure (breathing). The jugular veins increase in size, sometimes hugely, when the infant cries. These vessels are useful for topographical orientation.

The commonest anatomical variation is asymmetrical internal jugular veins, with the right vein larger than the left, presumably due to predominance of right cerebral venous drainage (Fig. 5.175).

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**Fig. 5.174.** Normal structure of the neck. Transverse scan through the midportion of the thyroid gland (Th) shows the right and left lobes of the gland in front of the trachea (T). The isthmus is seen anterior to the trachea (arrows). CE, cervical oesophagus (see Fig. 5.63); CC, common carotid; SCM, sternocleidomastoid muscle

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**Fig. 5.175.** Vascular variant in a 3-year-old boy: asymmetry of internal jugular veins. (a) Axial scans through the right internal jugular vein (RIJV) and the left internal jugular vein (LIJV) show that the RIJV is larger than the LIJV. (b) Longitudinal scan confirms the ectasia of the RIJV. Th, thyroid; CC, common carotid
The muscles are echo-poor and are useful for orientation. The normal thyroid gland is echo-rich to the surrounding muscles (Fig. 5.176). In infants and young children, the lateral lobe measures 1–1.5 cm in diameter, 2–3 cm vertically and 0.2–1.2 cm anteroposteriorly. In adolescents, the lateral lobe is 2–4 cm in diameter, 5–8 cm vertically and 1–2.5 cm anteroposteriorly. The right lobe is usually larger than the left. There are usually four parathyroid glands, the paired superior glands having a fairly consistent position near the upper surface of the thyroid lobes. The inferior parathyroid glands are found in close proximity to the lower pole of the thyroid gland and are isoechoic to the thyroid gland. Normal parathyroid glands are difficult to visualize because of their small size. The trachea behind the thyroid gland is marked by strong echoes arising from the air inside; the oesophagus can be seen as a tubular structure behind the left lobe of the thyroid, most clearly in a longitudinal scan. Movement can be seen when the child swallows.

Occasionally, small lymph nodes are seen in children and adolescents. These nodes are considered normal if they are ≤ 10 mm in the longest axis and are oval (ratio of long axis to short axis, > 1.5). Normal lymph nodes are echo-poor with an echogenic linear hilum (the so-called hilus sign), corresponding partially to vascular structures, as demonstrated with a sensitive colour Doppler probe. The vessels normally branch out from the hilus (Fig. 5.177; see also Fig. 4.8 and Fig. 4.9). They can be seen in the submandibular, jugular, submental and posterior cervical chains but not in the supraclavicular region.
The parotid glands can be demonstrated with a high-frequency transducer placed anterior to the ear lobe and parallel to the base of the mandible. They have the same echo-rich pattern as the normal thyroid and are useful for comparison. The submandibular salivary glands are easily seen below the mandible.

Pathological findings
Congenital cystic malformations
These malformations are the result of abnormal embryogenesis. They are frequent in children and include thyroglossal duct cysts (dermoid cysts and teratomas), branchial cleft cysts, cystic hygromas or lymphangiomas and cervical thymic cysts.

Thyroglossal duct cysts, dermoid cysts and teratomas can be situated midline or off-midline in the anterior part of the neck. About 65% of thyroglossal duct cysts are located below the level of the hyoid bone. On ultrasound, uncomplicated cysts have well-defined walls and water-clear contents. Sometimes, fine echoes are seen within cystic lesions, caused by haemorrhage, infection or proteinaceous fluid and post-aspiration (Fig. 5.178). The presence of fluid and fat or calcifications within a cystic mass should suggest dermoid cysts or teratomas (see below).

Branchial cleft cysts and cystic hygromas may be seen in the lateral neck, whereas cervical thymic cysts can occur anywhere.
Cervical lymphadenitis
Cervical lymphadenitis is common in children. It is usually caused by viral or bacterial infections. The submandibular and jugular nodes are involved in more than 80% of cases. On ultrasound, they typically appear as discretely enlarged, oval, echo-poor nodes, which may conglomerate (Fig. 5.179). Doppler shows hypervascularity but normal branching from the hilus. The major complication of cervical adenitis is abscess formation.

Tuberculous lymph nodes are common in some areas. Demonstration of enlarged, echo-poor, sometimes rounded lymph nodes with central necrosis (small echo-free areas) and flocculent calcifications (strong echoes) should suggest a diagnosis of tuberculosis (Fig. 5.180).

Fig. 5.178. Thyroglossal duct cyst in a 5-year-old girl with a midline cervical mass that moved on swallowing. Transverse scan of the infrahyoid neck shows a midline cyst (C), which is not echo-free, just anterior to the thyroid cartilage (arrows) of the larynx

Fig. 5.179. Cervical adenitis in a 3-year-old boy with fever and a painful cervical mass. (a) Axial scan shows multiple lymph nodes (LN) with heterogeneous echo texture. (b) Colour Doppler scan shows a hypervascular hilum
Thyroid diseases

Thyroid problems are not common in children.

*Hypothyroidism*

Ultrasound is used to establish the absence of the thyroid gland (athyroidism) antenatally or postnatally (Fig. 5.181).

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**Fig. 5.180.** Tuberculous cervical lymph nodes in a 12-year-old girl. (a) Longitudinal and (b) axial scans show an echo-poor lymph node (LN) adjacent to the common carotid (CC) and the internal jugular vein (IJV), with central necrosis (arrows).

**Fig. 5.181.** Thyroid agenesis in a newborn girl with hypothyroidism. Transverse scan shows absence of the thyroid gland, with sternocleidomastoid muscles (M) along the anterior border of the trachea (T) and no structure between them. CC, common carotid
**Thyroiditis**

**Acute purulent thyroiditis** is caused mainly by *Streptococcus* or *Staphylococcus* species. Ultrasound shows a slightly enlarged thyroid with a heterogeneous, echo-poor pattern and small echo-free foci (liquefactions). In symptomatic children, the inflammation is often found in the soft tissue around the thyroid, and the thyroid itself is dislocated.

**Quervain subacute thyroiditis** is rare in children. Ultrasound shows an echo-poor area with blurred limits within the thyroid. Fine-needle puncture may show the pathognomonic giant cells.

**Chronic lymphatic thyroiditis (Hashimoto disease)** is an autoimmune disorder characterized by infiltration of thyroid tissue by small lymphocytes. It is usually seen in girls reaching puberty (Fig. 5.182). In the early stage, the disorder may cause hyperthyroidism, similar to Graves disease (see below); if there is no spontaneous remission, the disease leads to hypothyroidism. Ultrasound shows a diffusely enlarged heterogeneous gland, hypoechoic relative to the normal thyroid; the presence of hypoechoic micronodules with an echogenic halo is considered to have a relatively high positive value. Initially, the gland may appear slightly enlarged, but it becomes smaller with a pseudolobular appearance as the autoimmune process advances. Doppler shows hypervascularity, especially in the early stage.

![Fig. 5.182. Thyroiditis in a 14-year-old girl. Longitudinal scan of the right thyroid lobe (R Th) shows an enlarged, heterogeneous gland with multiple, small, echo-poor foci](image)

**Basedow disease (Graves disease)** This autoimmune disease of the thyroid is the commonest cause of hyperthyroidism in childhood, predominantly in girls reaching puberty. Ultrasound shows a symmetrically enlarged gland with a more or less echo-poor, sometimes inhomogeneous pattern. Colour Doppler shows striking hypervascularity, with a peak velocity in the feeding arteries of up to 100 cm/s. Decreased velocity during treatment is a useful indicator for follow-up.
**Goitre**

‘Goitre’ is the term used for (nonspecific) enlargement of the thyroid. Thyroid enlargement (diffuse goitre) is found mainly in adolescent girls living in areas with insufficient iodine in the drinking-water. Ultrasound shows an enlarged thyroid with a homogeneous, echo-rich (normal) pattern. An inhomogeneous pattern with echo-rich nodules and degenerative alterations is seen after years without treatment and therefore mainly in adults.

An enlarged thyroid gland in a neonate can cause constriction of the trachea. It can be due to a thyroid disorder in the mother, such as Basedow disease, or hormonal treatment of the thyroid. Ultrasound shows an enlarged gland with a normal echo pattern.

**Focal diseases**

**Follicular adenomas** are benign nodules that arise from the thyroid cells and are encapsulated. They grow slowly and are usually endocrine-inactive. Some adenomas, however, are active and cause hyperthyroidism (toxic or hot adenomas). The ultrasound findings are variable, adenomas being round or oval, with a sharp boundary. The echo pattern ranges from echo-poor to echo-rich, like the normal thyroid. Echo-free parts indicate cystic degeneration (Fig. 5.183). A so-called halo, an echo-poor peripheral ring, is often seen, which is caused by a ring of vessels, as demonstrated by colour Doppler. This finding is considered a sign of benignancy. Most endocrine-active adenomas are hypervascular to the surrounding tissue; however, hypervascularity may also be seen in malignant lesions (see below).

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**Fig. 5.183.** Thyroid adenoma in a 15-year-old girl. Longitudinal scan of the right thyroid lobe (R Th) shows a slightly echo-poor solid nodule (N) with a halo.
True **cysts** are rare, and most cystic lesions are degenerated solid lesions. Ultrasound shows one or more well-defined, fluid-filled, echo-free lesions within solid nodules. The presence of a cyst in a nodule does not safely exclude malignancy. Echoes within a cystic lesion indicate bleeding, which may be corroborated by pain. Aspiration in these cases reveals a brownish fluid.

**Thyroid cancer**
Malignant tumours are not uncommon in children, who have 10% of all thyroid cancers. An association has been found with accidental or therapeutic irradiation. Papillary carcinomas, medullary carcinomas and lymphomas are the most frequent types in childhood. Ultrasound shows an echo-poor nodule and, in advanced cases, asymmetric enlargement of the gland. The outline may be irregular, and infiltration of the surrounding tissue or perforation through the capsule of the thyroid may be seen. Microcalcifications are seen as dispersed, intense echoes in the lesion, mainly in papillary carcinomas. Involved cervical lymph nodes show an echo pattern similar to that of the original tumour.

As adenomas and small carcinomas cannot be differentiated on the basis of their ultrasound appearance, any nodule > 10 mm and any nodule that grows rapidly within weeks or months should be biopsied to establish a definite diagnosis.

**Parathyroid glands**
Normal glands cannot be demonstrated by ultrasound. Hyperplastic glands and adenomas are seen as roundish, oval or triangular nodules, usually situated at the dorsolateral surface of the thyroid and median to the large vessels. They can be echo-poor or heterogeneous. Ectopic tumours are difficult to find with ultrasound.

**Salivary gland diseases**
The commonest disease of the salivary gland is parotiditis. Ultrasound shows an enlarged gland with a heterogeneous, dispersed pattern. Dilated ducts and stones (intensive echoes) are rarely found in children. Small reactive lymph nodes may be seen around or in the gland. Tumours (e.g. haemangiomas, see below) cause enlargement, with a nonspecific echo pattern.

**Trauma**
**Fibromatosis colli** is a benign lesion of the sternocleidomastoid muscle, also called haematoma of the sternocleidomastoid muscle. It is usually seen 1 or several weeks after birth and is related to trauma during delivery. Patients usually present with an anterior neck mass, most commonly on the right side. The lesion frequently regresses within 4–8 months with conservative therapy. Ultrasound shows unilateral, heterogeneous, fusiform enlargement of the sternocleidomastoid muscle (Fig. 5.184).
Benign tumours

Haemangioendotheliomas and haemangiomas are congenital vascular abnormalities. Most haemangiomas arise in the parotid gland and typically present as soft cutaneous or subcutaneous masses with bluish discolouration. Haemangiomas often undergo a period of initial growth before spontaneous involution. Ultrasound shows a variable echo pattern, which depends on the diameter of the vessels. Within larger cystic structures, sedimented echoes may be seen. Colour Doppler shows hypervascularity. Capillary haemangiomas appear as more echo-rich, heterogeneous masses (Fig. 5.185).

Fig. 5.184. Fibromatosis colli in a 2-month-old girl with a firm neck mass and torticollis. Longitudinal scan shows fusiform enlargement (arrows) of the sternocleidomastoid muscle (SCM).

Tumours of the neck

Fig. 5.185. Parotid haemangioma in a 5-month-old girl. (a) Axial scan of the left parotid shows a subtly altered echo texture near a heterogeneous, echo-poor mass (the strong echoes with the acoustic shadow correspond to the mandible, Ma). (b) Pulsed Doppler shows hypervascularity and arterial flow.
Cystic lymphangiomas (cystic hygromas) appear as cystic, septated masses; haemorrhage may complicate the ultrasound findings (Fig. 5.186).

Typical neck tumours in newborns are teratomas, which are situated within or close to a thyroid lobe. They may cause asymmetrical enlargement of the thyroid. The echo pattern is inhomogeneous, with echo-free areas, sometimes similar to those of a lymphangioma.

Malignant tumours

Hodgkin disease and non-Hodgkin lymphoma are the most frequent malignant cervical tumours in children; rhabdomyosarcoma and neuroblastoma of the neck are also seen. The lymph nodes involved in malignant lymphomas are enlarged, often conglomerated and very echo-poor. Colour Doppler shows hypervascularity but often normal branching of the vessels. Solid tumours have a heterogeneous but predominantly echo-poor pattern. The ultrasound findings are not specific concerning this type of tumour.

Infectious and parasitic diseases

Abscesses are not rare in children, especially in the retropharyngeal region. The inflamed tissue appears oedematous (little sound attenuation) and heterogeneous, with echo-poor or even echo-free areas, indicating abscess formation. The size and shape of cervical abscesses are variable, and they are often limited by the surrounding structures. Dispersed intense echoes within the affected tissue, with a partial acoustic shadow, indicate gas bubbles. The adjacent muscles may be swollen and have a more echo-poor pattern. Thrombosis of the jugular vein is another complication. Ultrasound shows the dilated vessel filled with echoes.

Hydatid cysts can be located anywhere, even in the neck. The most frequent location in the neck is the thyroid gland.
Chest

Indications
Ultrasound exploration of the thoracic cavity is more useful in children than in adults. The main indications are chest wall abnormalities, pleural effusion, peripheral lung lesions, diaphragm abnormalities and mediastinal lesions. Ultrasound is increasingly used in intensive care units to guide interventions and to follow up pleural effusion and chest wall diseases.

Preparation
Before an ultrasound examination, it is important to review the child’s chest radiograph to locate the area of interest.

Examination technique
The child lies supine or prone or stands erect, depending on the clinical problem. Having the arm raised above the head increases the rib space distance and facilitates parietal and pleural examination. The posterior chest is best imaged with the child sitting up, while the anterior and lateral chest can be assessed with the child in the lateral supine position. The transdiaphragmatic acoustic window is used, as well as the intercostal spaces and a supraclavicular approach. Views of the upper mediastinum should be obtained in the sagittal and axial planes. Transthoracic chest ultrasound can be performed with high-frequency linear or curved 5- to 10-MHz probes. Colour Doppler is useful for assessing mediastinal vascular and parenchymal abnormalities and for distinguishing the great vessels from a mediastinal mass. The gain and velocity range of colour Doppler should be adapted to the region of interest.

Normal findings
The normal chest wall has cutaneous and subcutaneous layers, muscles and fascia. Below the soft tissue of the chest wall, the ribs appear as curvilinear structures on transverse scans, associated with posterior acoustic shadowing. When the ribs are scanned along the long axis, the anterior cortex should appear as a continuous, smooth, echoic line (Fig. 5.187).

The pleura is easily recognized as an echoic line deep to the ribs. It may not be possible to differentiate the visceral and parietal portions in healthy infants, and echoic air reverberation artefacts at the pleura–lung interface prevent further visualization of the normal parenchyma. The aorta, great vessels and superior vena cava can be seen in the suprasternal view of the mediastinum.

The thymus is commonly prominent in children under 3 years of age. Ultrasound shows a characteristic appearance of echogenic foci or septae within echo-poor parenchyma (Fig. 5.188). The thickness of the thymic lobe decreases with
age, from 1.5 ± 0.46 cm for children aged 0–10 years to 1.05 ± 0.36 cm for those aged 10–20 years. The width shows little change with age.

The diaphragm is best examined through the lower intercostal spaces and is seen as a thin echogenic line due to the interface between the diaphragm and the air-containing lung, above the liver and the spleen (Fig. 5.189). Segments that do not border air-containing lung tissue appear echo-poor. The normal downward movement of the diaphragm should be seen on inspiration.
Pathological findings
Soft-tissue abnormalities
Ultrasound is sensitive for detecting anomalies in the chest wall, such as abscesses, haematoma, lipoma, lymphangioma and haemangioma, which are easily diagnosed (Fig. 5.190). Nonspecific aspects, however, may require other imaging modalities, such as conventional X-ray, MRI or CT, especially if an intrathoracic extension of a rib or spinal tumour is suspected.
**Rib fracture**
A fracture after chest trauma appears as an irregularity of the cortex of the rib, associated with a localized haematoma, effusion or soft-tissue swelling. Callus formation can be assessed by ultrasound follow-up.

**Pleural effusion**
Pleural effusion appears as an echo-free layer between the visceral and parietal portions of the pleura. Ultrasound is indicated to assess the mobility of the liquid and its echogenicity (transudate or purulent) (Fig. 5.191, Fig. 5.192) or to guide puncture in case of septations (Fig. 5.193). It is also useful for differentiating effusion from a parenchymal abnormality (Fig. 5.193), pleural thickening or pleural infiltration and for follow-up.

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**Fig. 5.191.** Echo-free simple pleural effusion in a 7-year-old boy. Longitudinal scan of the left lower lobe shows a large amount of echo-free pleural effusion (PE) with an echogenic area of parenchymal consolidation (arrow)

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**Fig. 5.192.** Simple effusion with floating debris in a 5-year-old girl. Longitudinal scan of the left lower lobe shows a large, echo-poor pleural effusion (PE) containing swirling particles (arrows). S, spleen
Hydropneumothorax
In some cases, chest radiographs are difficult to read, and a pneumothorax may be missed in a child in the supine position in an intensive care unit. Pneumothorax can be demonstrated from sonographic signs: the absence of lung sliding, the absence of air artefacts and thickening of the pleural line. Hydropneumothorax can be identified with ultrasound as air artefacts within the pleural effusion.

Diseases of the lung parenchyma and mediastinum
Diseases of the lung parenchyma that connect it to the pleural surface by replacing alveolar air with mucus, haemorrhage or inflammatory or purulent liquid create an acoustic window that allows visualization of abnormal parenchyma.

Pneumonia and lung abscesses
Lobar pneumonia, segmental pneumonia affecting the pleura and pleural consolidation are detectable by ultrasound. In the early phase of consolidation, the lung appears diffusely echogenic, resembling the sonographic texture of the liver (Fig. 5.194). A bronchogram is represented by linear echoes; on colour Doppler, the pulmonary artery branches supplying the segment are clearly seen. Fluid bronchograms are identified as echo-free tubular structures, representing fluid-filled airways. Pulmonary consolidation may be observed in haemorrhage, lymphomatous infiltration or contusion. It is important to consider clinical and biological data as well as other imaging modalities. Ultrasound is useful for follow-up during antibiotic treatment of pneumonia.

Abscess formation resulting from complicated pyogenic pneumonia can be identified with ultrasound as an echo-free, hypoechoic or septated mass. Differential diagnosis from hydatid cyst of the lung in endemic areas and in older children
Neoplasms

Pneumoblastomas are solid, heterogeneous, compressive tumours, which can be explored by ultrasound-guided biopsy of the mass. Extension of the tumour is identified by CT or MRI. Metastases of lymphomas or neuroblastomas are rarely explored by ultrasound.

Mediastinal masses or lymph nodes can be detected by ultrasound. Frequently, a normal or hypertrophied thymus must be differentiated from an anterior mediastinal mass, often by ultrasound. Enlarged, irregular lymph nodes raise suspicion of...
malignancy. Colour Doppler can be used to guide biopsy of mediastinal masses and lymph nodes in the anterior and upper mediastinum.

Diaphragmatic abnormalities

The diaphragm normally moves down on inspiration and up on expiration. In diaphragmatic paralysis, it either remains high and fixed or may show paradoxical movements, so that it moves upwards during inspiration. Movement of the diaphragm is usually observed by fluoroscopic screening during respiration; however, careful ultrasound examination of both hemidiaphragms can provide information on diaphragmatic movement.

Diaphragmatic and hiatus hernia can be demonstrated by ultrasound, as can discrete masses of variable echogenicity. Joining with intra-abdominal organs, Brownian movement and duplicated digestive wall in hernia of the digestive tract can also be seen.

Neonatal cranial ultrasound

Indications

The main indications for exploration of the neonatal brain are haemorrhage, ischaemia, convulsions, malformation, infection or a tumour.

Preparation

No specific preparation is needed. The infant lies in the supine position; one of the parents should be present to calm the infant if necessary.

Examination technique

Equipment

A high-resolution, real-time, two-dimensional machine with dedicated settings for cranial ultrasound and Doppler and colour flow capability should be available. High-frequency transducers (5–10 MHz) with a small footprint to match the size of the fontanelle should be used. Depending on the manufacturer, two probes may be needed: one 5-MHz probe for full-term infants and examination of the posterior fossa and one 7.5-MHz probe for premature infants and examination of periventricular areas. Ideally, a high-frequency (7- to 10-MHz) linear probe should be available to scan the extracranial fluid space and superior sagittal sinus. A hand-held colour ultrasound device is required in intensive care units.
**Technique**
Ultrasound scans are made through the anterior fontanelle with sequential coronal and parasagittal projections. The posterior fontanelle is examined for detailed depiction of the periventricular white matter or small amounts of blood in the lateral ventricles. A scan through the mastoid fontanelle provides optimal visualization of the posterior fossa structures. Coronal, sagittal and parasagittal views should be taken, and oblique, surface and axial views may be needed (Fig. 5.196).

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**Normal findings**

**Normal anatomical structures**
Normal anatomical structures that should be identified are:

- ventricles and fissures: frontal horn, fourth ventricle, third ventricle, lateral ventricles (choroid plexus and atria), Sylvian fissure and extra-axial space (Fig. 5.197);
- brain parenchyma: corpus callosum, caudate nucleus, basal ganglion, thalamus, all the lobes, cerebellar vermis and cerebellar hemispheres (Fig. 5.198);
- arterial structures (colour Doppler): anterior cerebral arteries, middle cerebral arteries at their origin and in the Sylvian fissure, posterior cerebral arteries, basilar artery and internal carotid arteries in the carotid siphon;
- venous structures (colour Doppler): superior sagittal sinus and its draining veins, inferior sagittal sinus, straight sinus, confluence of sinuses, lateral sinuses, internal cerebral veins, vein of Galen and draining veins of the ventricles.
Fig. 5.197. Normal ventricle anatomy in a 3-month-old boy. (a), (b) Coronal scans and (c) sagittal midline scan through the anterior fontanelle show the normal ventricular system. FH, frontal horn; S, Sylvian fissure; LV, lateral ventricle; CP, choroid plexus; V3, third ventricle; V4, fourth ventricle; CC, corpus callosum; CV, cerebellar vermis.

Fig. 5.198. Normal brain anatomy in a newborn boy. Coronal midline scan through the anterior fontanelle, with the thalami (Th), the caudate nucleus (CN) and the basal ganglion (GB) on each side of the ventricular system. FP, frontal parenchyma; TP, temporal parenchyma; S, Sylvian fissure; V3, third ventricle.
Normal variants
A number of normal variants should be recognized. **Cavum septum pellucidum** is an anterior midline cavity located between the two leaves of the septum pellucidum (Fig. 5.199).

*Cavum vergae* is a posterior midline fluid–fluid space which usually communicates with the cavum septi pellucidi and is obliterate from posterior to anterior. **Cavum veli interpositi** is an anatomical variation that may appear as a cyst in the pineal region in neonates. **Connatal cysts** are cysts measuring 3–10 mm adjacent to the suprolateral margin of the frontal horns, with no sign or symptom of infection, haemorrhage or hypoxia. They are due to approximation of the walls of the frontal horns of the lateral ventricles proximal to their external angles. They are found mainly anterior to the foramen of Monro.

In premature infants, the lateral ventricles may be small or invisible. A **lobular choroid plexus** may be seen occasionally and be confused with an adherent clot.

**Calcar avis** is a paramedian protrusion of the calcarine gyrus into the medial segment of the lateral ventricle at the junction of the trigone with the occipital horn. On parasagittal oblique images, these normal parenchymal structures may simulate intraventricular clots. They can be recognized by their characteristic location, their contiguity with the calcarine gyri and the presence of a central echogenic sulcus that has normal perfusion on colour Doppler.

Periventricular hyperechogenicity is a normal variant when it is smooth and less echo-rich on ultrasound than the choroid plexus. It is due to parenchymal immaturity.

**Haemodynamics**
The arterial spectrum shows low resistance and strong, continuous diastolic flow with systolic peaks. The amplitude of the diastolic component of the arterial cerebral blood flow is thus directly related to the distal circulatory resistance (Fig. 5.200). The
resistive index ((peak systole–end diastole)/peak systole) does not always correlate with the cerebral blood flow, and blood-flow velocity and venous velocity should be measured.

Fig. 5.200. Normal haemodynamic study of the anterior cerebral artery of a newborn boy. The systolic velocity is 46 cm/s, the diastolic velocity is 10.7 cm/s, and the medium velocity is 23.5 cm/s. The resistive index is 0.77.

Pathological findings
Premature brain

Cranial ultrasound Doppler is the main screening method for imaging unstable, incubated, ventilated infants in a neonatal intensive care unit. It has good diagnostic sensitivity and some limitations. Use of MRI has been the subject of many prospective studies.

Early perinatal exploration is based on a sonographic examination before the third day of life to examine either an intracranial lesion found on morphological examination or a normal morphological image but an abnormal haemodynamic result.

The morphological examination is pathological. Subependymal germinal matrix haemorrhage has an excellent prognosis when it is identified and must therefore be sought at the first evaluation. Intraventricular haemorrhage is sometimes associated with precocious dilatation, characterized by echo-rich intraluminal images. If the examination is conducted early or if there is a doubt about the images, the examination should be complemented with a colour Doppler analysis of the aqueduct of Sylvius to show intermittent up- and downstream flow, either spontaneous or after pressure on the fontanelle (or abdomen). This examination is useful in daily practice and is highly reliable, even though it is nonspecific.

Intraventricular haemorrhage associated with an ischaemic–haemorrhagic periventricular infarct appears as an echo-rich lesion, which is often globular, sometimes digitiform and generally unilateral. Imaging of periventricular hyperechogenicity should include the intensity. The appearance is massive globularity, sometimes with a speculated periphery and a digitiform aspect extending to the white subcortical
matter, usually containing echo-rich nodules, which are rarely microcystic at this age. The topography is uni- or bilateral and may be limited to the frontal regions or behind the atria or extend to other regions, including the temporal area. Some periventricular hyperechogenicity seen during initial exploration may be transitory.

An echo-rich basal ganglion or thalamus is a rare lesion but can occur in premature infants. Lesions of the basal ganglion seen on initial sonographic examination may be attenuated on follow-up and then reconfirmed.

When analysis of the posterior region of the brain is technically difficult because of a small fontanelle, an overlapping suture or respiratory ventilation that makes access to the anterior fontanelle difficult, or when there is doubt about the normality of the posterior regions of the brain, the examination should be complemented by exploration through the posterior fontanelle, which gives direct access to regions behind the atria and the occipital horns. The temporal regions can also be studied through the temporal bone (mastoid view).

If the morphological examination appears normal but the haemodynamic analysis is pathological, a special pulsed Doppler study should be conducted. The data to be sought include fluctuations of Doppler spectra, usually contemporaneous with haemodynamic instability; low flow, characterized by systolic and average speeds lower than normal; high flow, with high systolic and average speeds; and anomalies of vascular resistance.

**Early follow-up**

Early follow-up (before 10 days of life) is also based on sonography. This examination is performed to screen for intraventricular haemorrhage in an infant with normal morphology but pathological haemodynamics or secondary clinical complications (respiratory complications, ductus arteriosus or enterocolitis) that could lead to haemorrhage. Ultrasound is also used to screen for ischaemic–haemorrhagic infarct in an infant with intraventricular haemorrhage. Early follow-up is necessary to confirm the existence and persistence of periventricular hyperechogenicity, to screen for heterogeneity in the echogenicity and to confirm the existence of another lesion (e.g. in the basal ganglion).

**Follow-up of a haemorrhagic lesion**

Ultrasound will show the classical evolution of an intraventricular clot and is used to screen for ventricular dilatation and its morphological evolution (Fig. 5.201). Complementary pulsed Doppler can show an increase in the resistive index due to intracranial hypertension. The sensitivity of the technique can be increased by fontanelle compression for determination of \( \text{[resistive index after compression – basal resistive index] / basal resistive index} \), which indicates progression of ventricular dilatation. Doppler analysis is particularly useful when cerebrospinal fluid is to be removed, because it can show the efficacy of the therapy and guide the frequency of punctures.
Intermediate follow-up

An intermediate follow-up (between 3 weeks after birth and theoretical term) makes it possible to determine the presence of cysts in the white matter, consisting of rapidly confluent macrocysts, which are rare, or more frequent microcysts. It may be difficult to distinguish real microcysts from normal parenchyma within the echo-rich matter. Use of a high-frequency probe and special acoustic windows (the posterior fontanelle if possible) is useful for diagnosis. Intermediate follow-up can also reveal persistence of prolonged periventricular hyperechogenicity or ventriculomegaly, often manifested only by a rounded aspect of the frontal horns on a coronal scan, or the existence of an undetected white-matter lesion. Ventriculomegaly is stable and can be due to widening of the pericerebral spaces.
Role of MRI

The anomalies found on early MRI are haemorrhage in a ventricle or the germinal matrix; anomalies of the white matter, consisting of cystic images of periventricular leukomalacia, hyperintense T1 punctate lesions, diffuse hypersignal of the white matter and haemorrhagic infarct; and lesions of the basal ganglion, in addition to haemorrhage of the posterior fossa, consisting of cerebellar or extra-axial haemorrhage, which is frequently unilateral.

MRI and ultrasound findings correlate well for severe lesions (85–95% for germinal matrix haemorrhage or intraventricular haemorrhage and 96% for major periventricular hyperechogenicity) but less well for lesions of moderate (55%) or medium (72%) severity. Diffusion-weighted MRI shows the extent of some white matter anomalies more clearly than conventional MRI, and there is a strong correlation with later neurological evolution. Early MRI is considered useful when sono-graphic imaging shows moderate or doubtful anomalies or when there is discordance with the clinical or electrical presentation of the infant.

Long-term follow-up

Long-term follow-up is necessary because of the correlation between anomalies in neuromotor development and peri- or postnatal lesions of the white matter. It is based on MRI, which can indicate ventriculomegaly, ventricular deformity, late myelinization, hypoplasia of the corpus callosum and diminution of the cerebral volume.

Lesions are staged by either ultrasound or MRI. Cranial ultrasound can be used to differentiate intraventricular haemorrhage, white-matter injury and periventricular leukomalacia, basal ganglia lesions and secondary isolated ventriculomegaly.

Intraventricular haemorrhage (Fig. 5.202) is graded as isolated germinal matrix haemorrhage (grade I), moderate haemorrhage without dilatation of the ventricles (grade II), severe haemorrhage, often with hydrocephalus (grade III), and severe haemorrhage with ischaemic–haemorrhagic infarct (grade IV).

White matter injury with periventricular leukomalacia (Fig. 5.203) is graded into localized periventricular hyperechogenicity (grade I), which can be frontal or parietal, located in the post-trigonal regions or punctiform. Extended hyperechogenicity, limited to the periventricular white matter, unilateral, bilateral or even extending into the subcortical white matter but without cystic lesions is classified grade II. Cystic periventricular leukomalacia (grade III) is characterized by small (< 5 mm) or large (> 5 mm) cystic lesions or limited to the periventricular or subcortical white matter.
MRI shows haemorrhagic lesions of the germinal matrix, intraventricular haemorrhage with ischaemic–haemorrhagic infarcts; focal lesions of the periventricular white matter, ranging from a few small grade I lesions to numerous extended, cystic grade III lesions; diffuse echo-rich white matter; basal ganglion lesions; and late anomalies, including ventriculomegaly, delayed myelinization and reduced brain volume.

Ultrasound should thus be performed before the 3rd day, before the 10th day, 1 week later and at full term. Screening is more frequent if progressive lesions are detected. Use of early MRI depends on the sonographic results and a possible discordance between the clinical and electrical data. MRI should be performed at 4 months or 1 year for all premature infants.
Ischaemic lesions
Antenatal cerebral lesions of vascular origin are frequently detected, particularly those associated with malformations, such as porencephaly, multicystic encephalomalacia, hydrocephalus and disorders of neuronal migration. Reducing the risk for ischaemia is essential for preventing intrauterine asphyxia, maintaining ventilation, perfusion and adapted glycaemia and controlling episodes of seizure. Ultrasound exploration of anoxic–ischaemic lesions should be conducted with high-frequency probes (7.5–10 MHz) and colour Doppler (Fig. 5.204). Colour Doppler is useful for diagnosis, whereas haemodynamics assist in establishing a prognosis.
Fig. 5.204. Cerebral anoxic–ischaemic lesions. (a) Coronal scan shows cortical necrosis. (b) Coronal scan shows bilateral parasagittal ischaemia. (c) Coronal scan shows grey nucleus ischaemia. (d) Sagittal scan shows cerebral trunk ischaemia with diffuse hyperechogenicity of the cerebral trunk. (e) Sagittal scan in a normal newborn shows an echo-poor posterior cerebral trunk.
Anoxic–ischaemic encephalopathy

This disorder appears as an ischaemic echo-rich lesion of the white matter, cortex or subcortex, increased cerebral blood flow velocity and decreased vascular resistance due to arteriolar vasoplegia (Fig. 5.205). Decreased resistance with increased diastolic flow is the main sign of immediate danger and guides resuscitation.

Fig. 5.205. Prolonged hypoxia during neonatal surgery for oesophageal atresia. (a) Coronal scan performed 4 days later shows diffuse ischaemia with echogenic white matter (arrowheads). (b) Pulsed Doppler shows decreased blood pressure with a resistive index of 0.47

Arterial ischaemic infarct

This condition is difficult to diagnose clinically in newborns. Perinatal asphyxia is the most frequent cause, but other factors include hypoxia, thrombosis (polyglobuliala, hyperviscosity, meningitis, meningoencephalitis, poisoning) and emboli due to congenital cardiopathy or placental failure. The increasing frequency of neurological sequelae of cardiac surgery is of concern. The hypothermia and complete circulatory arrest that accompany external circulation favour physiopathological mechanisms such as microemboli, hypoxia and insufficient regional cerebral perfusion.

On ultrasound, ischaemic infarct shows early hyperechogenicity near the origin of the middle cerebral artery or the Sylvian fissure; cystic cavitations occur within 3–4 weeks. Colour Doppler can show an arterial thrombus. Thrombosis of the superior sagittal sinus and the profound venous system is rare, and clinical diagnosis is difficult and nonspecific. It is now rarely due to infection, and severe dehydration is the principal cause. The thrombosis usually results in diffuse oedema of the cerebral parenchyma and rarely in venous ischaemic–haemorrhagic infarct, the location and extent of which determine the prognosis. Thrombosis of the superior sagittal sinus is more frequent than that of the profound venous system. Sonographic and colour Doppler examinations give reliable signs (Fig. 5.206): an echo-rich thrombus in the superior sagittal sinus and total or partial interruption of flow in colour Doppler with no spectral analysis.
Severe haemodynamic distress

Neonatal and infant respiratory failure lead to multiple vascular anomalies, including rhythm disorders and flow abnormalities, seen as fluctuating and changed Doppler spectra, and the disappearance or reversal of diastolic flow due to increased vascular resistance (Fig. 5.207, Fig. 5.208).

Fig. 5.206. Thrombosis of the superior sagittal sinus in a newborn. (a) Coronal scan shows a triangular echo-rich image in the midline, corresponding to the superior sagittal sinus; absence of flow on colour Doppler. (b) Coronal T1-weighted magnetic resonance image confirms the venous thrombosis.

Fig. 5.207. Preterm 26-week-old infant. Duplex colour Doppler shows normal arterial velocity, with a systolic flow of 26.5 cm/s and a diastolic flow of 5 cm/s (median, 12.6 cm/s).
Cerebral malformations

Cerebral malformations are now rare in the neonatal period because they are usually identified during the fetal period by ultrasound and MRI. They include anencephaly, exencephaly, inencephaly, lissencephaly, holoprosencephaly, meningocele, meningoencephalocele and myelomeningocele. While diagnosis of an aneurysm of the Galen vein is simple with colour Doppler, evaluating its prognosis requires a complete haemodynamic assessment of afferent vessels and a fetal MRI to detect any anoxic–ischaemic lesions.

The rare malformations that are diagnosed neonatally include lesions of the corpus callosum, anomalies of the posterior fossa and neuronal migration. Complete or partial agenesis and hypoplasia of the corpus callosum are easily diagnosed with ultrasound (Fig. 5.209). No other investigation is necessary, but the assessment should be complemented by MRI to detect associated malformations and particularly those of the central nervous system. The complexity of the pathology of the posterior fossa usually requires several imaging methods. Although the Dandy-Walker complex can be diagnosed by ultrasound alone, other anomalies, such as hypoplasia or atrophy of the vermis and agenesis of the vermis without cystic pathology, require MRI assessment.
Extra-axial fluid
Ultrasound imaging allows accurate localization of extra-axial fluid (Fig. 5.210). Echo-free fluid penetrates the inter-hemispheric region between the grooves in the subarachnoid space. Colour Doppler shows the absence of subdural arteries and their consistent subarachnoid presence.

Fig. 5.209. Agenesis of the corpus callosum in a 4-month-old boy. Coronal scan shows absence of corpus callosum, characteristic Viking horn or bull’s horn configuration of the frontal horns (FH) and third ventricle displaced upwards (V3)

Fig. 5.210. Extra-axial fluid, coronal scans. (a) Enlargement of the subarachnoid spaces in a 3-month-old girl. (b) Subdural collection separated from the cerebral surface by the arachnoid
Infections
Ultrasound should be used to locate intraventricular echoes, echo-rich ependymal thickening, ventriculitis, cerebral abscesses, subdural empyema, ischaemic lesions, sinus thrombosis or secondary ventricular dilatation (Fig. 5.211). Cytomegalovirus infection shows progressive subependymal cysts, the candelabra sign of thalamostriate vasculopathy, anomalous neuronal migration and ventricular dilatation (Fig. 5.212).

Fig. 5.211. Cerebral infections. (a) Sagittal scan shows diffuse ventriculitis in *Pneumococcus* meningitis (arrowheads). (b) Coronal scan shows a right frontal abscess (A) in *Proteus* meningitis. (c) Coronal scan shows a large subdural empyema (arrow). (d) Coronal scan shows an ischaemic cortical area (empty arrow)
Cerebral tumours

Cerebral tumours are exceptional in neonates and young infants. Although cranial ultrasound can demonstrate tumours, CT and MRI remain the modalities of choice. These tumours are frequently associated with hydrocephalus, especially in posterior fossa tumours; the ventricular dilatations are easily seen by ultrasound.

Diagnosis of a papilloma of the choroid plexus is based on specific ultrasound findings. The tumour has an echo-rich aspect, lobulated contours and an intraventricular location. Hydrocephalus results from several complex mechanisms, including obstruction of the ventricle by the tumour, associated intraventricular haemorrhage, decreased absorption of cerebrospinal fluid and increased ventricular pulsation.

Fig. 5.212. Congenital cytomegalovirus infection in a 3-month-old boy. (a) Coronal scan shows parenchymal calcifications (arrows). (b) Coronal and (c) sagittal scans show subependymal cysts (arrowheads). (d) Sagittal scan shows a candelabra image at the level of the thalamostriate vessels (empty arrow)
Spine

Indications
The spinal cord is examined by ultrasound in neonates and infants less than 6 months of age with signs of spinal disease. Typical indications are:

- midline skin masses on the back;
- midline cutaneous malformations on the back, such as a dimple or a haemangiomatous or hairy lesion;
- deformities of the spinal column;
- neurological disturbances;
- spinal cord injury due to traumatic birth or meningeal tear;
- syndromes with associated spinal cord compression.

Ultrasound can be used in the antenatal period to predict the anatomical level of spinal dysraphism in most cases. As sonography can show the entire spectrum of intraspinal anatomy and pathological conditions with high resolution, it should be considered the initial imaging modality of choice for investigating the spinal cord in neonates and for deciding whether CT or MRI should be performed.

Preparation
There is no specific preparation.

Examination technique
Infants are usually examined in the prone position, curved over a pillow. For examination of the craniocervical junction, the neck must be flexed. Sagittal and axial planes of the spinal canal and cord can be examined, from the craniocervical junction to the sacrum. In older children, progressive ossification of the posterior elements of the vertebrae obviates useful examination, and paramedian scans may be sufficient.

Movement of the spinal cord and cauda equina can be evaluated with real-time ultrasound in M-mode. The brain is examined systematically through the fontanelle. Examinations should be performed with high-frequency linear transducers (5–12 MHz).

Normal findings
The normal spinal cord appears on ultrasound as an echo-poor tubular structure containing fine, homogeneous internal echoes, surrounded by a nearly echo-free area corresponding to the cerebrospinal fluid. A well-defined echogenic interface highlights the boundaries of the cord, with a change in acoustic impedance between the spinal cord and surrounding cerebrospinal fluid (Fig. 5.213). The diameter of the
spinal cord varies; it is largest at the cervical and lumbar levels and smallest at the thoracic level. An axial scan of the spinal cord shows an echo-poor, oval or round spinal cord with an echogenic central complex within the echo-free subarachnoid space (Fig. 5.214).

The vertebral bodies of the column are seen as echogenic structures ventral to the spinal cord. The echogenic vertebral arches produce ventral shadows on axial scans. Pulsatile motion of the cord and small vascular structures on the anterior and posterior surfaces of the cord, presumably representing anterior and posterior spinal arteries and veins, are seen routinely with the Doppler technique.
At birth, the spinal cord is relatively straight owing to the straight bony spine. It contains a central canal, which extends from the cervicomedullary junction to the lower end of the spinal cord. Transient dilatation of the central canal can be seen, but it should be no greater than 2 mm in diameter. The conus medullaris should normally end at the level of the L1–L2 vertebrae (Fig. 5.215). It is cone-shaped and may be slightly bulbous, with a low, central cerebrospinal fluid cavity, which is the ventriculus terminalis, a small, ependymal, oval, cystic structure positioned at the transition from the tip of the conus medullaris to the origin of the filum terminale (Fig. 5.216). This structure has a longitudinal diameter of 8 mm and a transverse diameter of 2–4 mm. The ventriculus terminalis develops during embryogenesis as a result of canalization and retrogressive differentiation of the caudal end of the
developing spinal cord and regresses in size during the first weeks after birth. This variant causes no clinical symptoms. The filum terminale is best visualized on the axial view. It should not be greater than 2 mm in diameter; it runs along the posterior wall of the thecal sac (Fig. 5.217).

**Pathological findings**

**Congenital malformations**

Spinal ultrasound is conducted in children with spinal dysraphism in order to recognize associated malformations, such as myelocoele, myelomeningocele, meningocoele, Chiari II syndrome, tight filum terminale syndrome, spinal lipoma, dorsal dermal sinus, syringomyelia, diastematomyelia, arachnoid cyst and caudal regression syndrome. Cranial ultrasound can also show associated malformations of the brain, such as hydrocephalus and hypoplasia or aplasia of the corpus callosum.

Myelocoele or myelomeningocele occurs in 2 of 1000 live births, with a slight female predominance. It results from localized failure of fusion of neural folds dorsally during embryogenesis. These two conditions are associated with Chiari II malformation and tethered spinal cord syndrome. In Chiari II syndrome, the cerebellar vermis herniates through the foramen magnum into the cervical spinal canal, and the fourth ventricle is narrowed and positioned low.

Ultrasound shows a low-lying spinal cord extending into the cystic back mass; the bone abnormalities are clearly seen on CT. The ultrasound appearance of tethering is a low-lying or blunt-ended conus medullaris below L2–L3, which is due to abnormal fixation of the spinal cord. Ultrasound shows an abnormally thickened filum terminale exceeding 2 mm in diameter at the level of L5–S1, sometimes in combination with a centrally located small cyst or lipoma. Typically, the tethered cord is positioned eccentrically, and failure of pulsatile movement of the spinal cord and nerve roots can be demonstrated with M-mode scanning.
Spinal lipoma is an intraspinal mass of fat and fibrous tissue that occurs in continuity with the adjacent spinal cord. It is the commonest type of occult spinal dysraphism and is classified as lipomyelocoele or lipomyelomeningocele, fibrolipoma of the filum terminale or intradural lipoma.

In lipomyelocoele, the lipoma lies adjacent to the cleft spinal cord and extends into the central canal of the cord and into the spinal canal, causing tethering of the neural tissue. Dorsally, the lipoma is continuous with the subcutaneous fat and covered by intact skin. Lipomyelocoele is always associated with spina bifida and anomalies of the vertebrae. Spinal ultrasound shows an echogenic intraspinal mass adjacent to the deformed spinal cord. Dorsally, the mass is contiguous, with slightly echo-poor subcutaneous fat. In children with lipomyelomeningocele, a dilated subarachnoid space can be seen. Associated malformations, such as hydromyelia and syringomyelia, can be detected with spinal ultrasound.

Dorsal dermal sinus, another type of occult dysraphism, is an epithelium-lined tract running from the skin to the spinal cord, cauda equina or arachnoid. Most are located in the lumbosacral region. Scrupulous spinal ultrasound shows the entire length of the tract, from the skin to the spinal space. When the tract is in the subcutaneous fat, it is slightly echo-poor and is sometimes difficult to detect with ultrasound.

Diastematomyelia is characterized by a sagittal cleft in the spinal cord, which is usually divided into two asymmetric hemicords (Fig. 5.218). Each hemicord has a separate arachnoidal and dural sheath if a fibrous, cartilaginous or osseous septum is present. Ultrasound performed in the axial plane typically shows both hemicords in cross-section, each with a central canal and ipsilateral nerve roots. In children with an osseous septum between the hemicords, the spinal cord is rarely seen at the level of the septum because of the shadow it produces. Spinal ultrasound can demonstrate associated malformations such as hydromyelia and syringomyelia (Fig. 5.219) and thickened filum terminale (Fig. 5.220).

![Diastematomyelia in a 3-month-old boy. Transverse scan shows two hemicords (arrows) within the spinal canal, separated by a sagittal septum (spur, empty arrow)](image-url)
Congenital hydromelia or syringomyelia may be the result of deregulation of cerebrospinal fluid circulation or a variant of dysraphism malformation. Spinal ultrasound shows dilatation of the central canal of the spinal cord.

Caudal regression syndrome corresponds to a spectrum of anomalies of the caudal end of the trunk, which vary from isolated partial agenesis of the sacrococcygeal spine to more severe deformities such as sirenomelia. Spinal ultrasound shows a blunt, deformed conus medullaris which terminates above the normal level of L1, with major sacrum deformities and other spinal dysraphism. Associated malformations are imperforate anus, genitourinary anomalies and renal dysplasia.
Neoplasms
Spinal tumours are less common in children than in adults and are extremely rare in infants under 6 months of age. Ultrasound can help to detect neoplasms and in deciding whether MRI should be performed. Neoplasms of the spinal cord are clearly seen with MRI.

Infection and trauma
Ultrasound can also be used as the initial imaging method in suspected birth trauma or infection of the spinal cord. It allows detection of epidural or subdural haemorrhage and complete spinal cord transection. Direct signs, such as oedema, venous congestion and haemorrhage, increase the echogenicity of the spinal cord and an epidural fluid collection; indirect signs, such as displacement of the spinal cord due to haemorrhage, are also used. Follow-up examinations reveal resorption of intraspinal blood collections, changes in cord calibre and persistently increased echogenicity due to early glial proliferation in children with myelomalacia.

In all cases, MRI is the imaging procedure of choice.

Musculoskeletal system
Indications
- musculoskeletal pain
- trauma
- suspected child abuse
- obstetrical trauma
- infectious conditions
- soft-tissue lesions
- foreign bodies
- ganglion cyst
- bursitis
- joint effusion
- neonatal hip dysplasia.

Preparation
No special preparation is needed.

Examination technique
The position of the patient depends on the organ or region to be examined and the pathology. Sagittal and axial scans of the region of interest may be performed. Doppler techniques (colour and pulsed) are helpful for demonstrating the vascular
component of a lesion or deep or superficial vein thrombosis. Dynamic compression with probe and colour Doppler imaging can facilitate detection of superficial vascular masses. Bilateral examination and comparison with the healthy side in various scanning planes may avoid a misdiagnosis.

Ultrasound examination of the musculoskeletal system is best performed with high-frequency linear or curved probes (7–15 MHz), when available.

**Normal findings**

At birth, the cartilaginous epiphysis is clearly seen on ultrasonography. The bone appears as a highly echogenic structure with distal acoustic shadowing, while the cartilage is more echo-poor than the adjacent soft tissue, with sparkling echoes inside it (Fig. 5.221). Ossified elements appear as bright linear or curvilinear structures and can be irregularly shaped (Fig. 5.222).

The sonographic appearance of the tendons and ligaments in children is similar to that in adults. When tendons are examined in the longitudinal plane, they appear as echo-rich structures with well-defined echogenic margins and a fibrillar appearance due to the bundles of tendon fibres. Ligaments appear as echo-rich bands with internal fibrils that join the nonossified echo-poor epiphyses of adjacent bones.

In joints, the capsule has a concave configuration; the distance between the anterior capsule and the bone is normally less than 3 mm.

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**Fig. 5.221.** Normal epiphysis in a 3-month-old boy. Coronal scan of the hip shows the echo-poor cartilaginous epiphysis (E) with scattered internal echoes and the metaphysis (M), appearing as a bright linear structure with distal acoustic shadowing. G, acetabular cartilage
Pathological findings

Bone and joint abnormalities

*Neonatal abnormalities*

Developmental dysplasia of the hip, formerly called congenital hip dislocation, is a spectrum of abnormalities, ranging from mild acetabular dysplasia and reducible subluxation to irreducible subluxation of the femoral head. It is most common in breech infants and fetuses with oligohydramnios. The diagnosis is suspected clinically when physical examination reveals asymmetric skin folds, limited abduction of the hip or abnormal Barlow or Ortolani manoeuvre. Ultrasound is used systematically for diagnosis in newborns aged 1 month. As femoral head ossification centres appear at 3–6 months, simple radiographic examination is not useful in newborns. Ultrasound allows direct visualization of the cartilaginous components of the hip and makes it possible to determine the position of the femoral head and the depth of the acetabulum and to evaluate dynamic instability (Fig. 5.223, Fig. 5.224). The method for hip ultrasound reported by Graf and Harke includes evaluation of acetabular morphology, the angle of the acetabular roof (alpha angle), coverage of the femoral head and dynamic subluxation during stress manoeuvres. A combination of static (anatomical) and dynamic (physiological stress) examinations is now the standard. Colour Doppler is not generally part of the standard examination but is reported to be helpful in assessing femoral head perfusion, especially in children being treated in a Pavlik harness.

*Club foot* or *talipes equinovarus* can be studied relatively simply and noninvasively by ultrasound and should be part of routine assessment of neonatal clubfoot. Particularly in neonates, ultrasound complements current radiographic techniques because it demonstrates the anatomical relations of unossified bones, such as in the talonavicular and calcaneocuboid joints. Congenital limitation of dorsiflexion, the anterior position of the talus in the ankle mortise and the addition of the foot are
easily measured on sonograms. Furthermore, changes in the range of movement resulting from conservative treatment and surgical correction can be quantified. The hip should also be examined systematically, to identify associated hip dysplasia.

**Limping child**

**Irritable hip** is a clinical syndrome that most commonly affects children between the ages of 3 and 8 years. It is most often due to transient synovitis, a self-limiting condition for which no cause has been found. Ultrasound of the hip is recommended to detect echo-free effusions and to exclude other hip anomalies.
In synovial diseases, ultrasound is the method of choice for detecting joint effusions and for differentiating joint fluid from synovial thickening. Colour Doppler can show the extent of the vascular supply of the synovium, providing a qualitative representation of the degree of synovial inflammation. It is particularly effective for mapping the number and distribution of joints involved and has proved to be better than plain film and clinical examination for grading the involvement of joints.

**Legg-Calve-Perthes disease** is an idiopathic, avascular necrosis of the capital femoral epiphysis. The clinical findings include hip or knee pain, limp and limitation of internal rotation. Boys are affected more often than girls. The usual age at onset is 4–8 years. The four identifiable radiographic stages of the disease are ischaemia, revascularization, reossification and healing. Plain radiographic examination is the imaging procedure of choice for diagnosis, and ultrasound is used for staging and confirmation of diagnosis. The capital femoral epiphysis can be normal or show joint effusion.

**Slipped femoral capital epiphysis** is a disorder of adolescence caused by repetitive stress of weight-bearing. It is the commonest chronic Salter-Harris type 1 injury. The characteristic radiographic findings are medial, posterior and inferior positioning of the femoral head with respect to the femoral shaft. Ultrasound is used to identify children for whom improvement of the epiphyseal position by treatment is possible and safe. A new classification into acute, acute-on-chronic and chronic slipped femoral capital epiphysis has been proposed on the basis of objective sonographic data. Joint effusion represents physial instability or regression, and remodelling is a sign of chronicity. Acute slipped femoral capital epiphysis is characterized by effusion, whereas slip without effusion but with remodelling is designated as chronic, and acute-on-chronic is associated with both effusion and remodelling.

**Osgood-Schlatter lesion** is tibial osteochondrosis that affects pre-adolescent and early adolescent athletes. It is due to traction apophysitis of the patellar tendon insertion on the tibia tubercle. Its diagnosis is usually clinical, but radiographs and MRI can be used to exclude other causes of knee pain. Ultrasound may show thickening of the patella tendon, which may appear indistinct and partly echogenic. Fragmentation of the tibial tuberosity and echo-rich surrounding soft-tissue oedema may also be present.

Ultrasound is an effective method for detecting occult fractures in children. It is sensitive and specific for diagnosing small cortical fractures and, later, for demonstrating periosteal formation at the fracture site.

Fracture-separation of the epiphysis in neonates is difficult to diagnose radiologically because the cartilaginous epiphysis is radiolucent. Ultrasound in conjunction with physical examination is the method of choice in diagnostic evaluation, by providing clear differentiation of the bone, the cartilaginous epiphyses and the joint space, recording the direction and extent of displacement and demonstrating the presence of blood and debris in the joint space (Fig. 5.225). Ultrasound is also suitable for detecting, localizing and characterizing a variety of traumatic disorders of the muscles, tendons and ligaments in children. In the context of the battered child, it is useful for diagnosing and following up associated visceral injuries.
Infections
Osteomyelitis

Bone can be infected by extension from contiguous soft-tissue or joint infection or via the bloodstream from a remote source. Acute haematogenous osteomyelitis is frequent in children. Gram-positive cocci are common, but many infectious agents are seen. Haematogenous osteomyelitis usually involves the highly vascularized metaphyses of the fastest growing bones, such as the distal femur, proximal tibia and proximal humerus. The clinical manifestations are pain, fever, swelling and increased inflammatory markers in blood serum. Blood culture is positive in 50% of cases of acute osteomyelitis and is often required to diagnose infection accurately.

At the earliest stage of acute osteomyelitis, all imaging modalities show soft-tissue swelling and hyperaemia adjacent to the affected bone. Ultrasound is accurate in showing these nonspecific abnormalities and must be performed as soon as possible, before antibiotic therapy is established. The diagnosis is confirmed by MRI, if available, and bone scintigraphy with technicium-99m. MRI shows marrow alteration and the extent of disease in bone, soft tissue and adjacent joint at the same time. The most characteristic ultrasonic feature of osteomyelitis is subperiosteal fluid collection contiguous with the bone (Fig. 5.226). When the initial study does not show these features, it must be repeated regularly, at best daily during the 1st week. Ultrasound is the modality of choice for diagnosing subperiosteal and superficial abscesses and for guiding aspiration of these collections. MRI, nuclear medicine and CT are indicated to demonstrate intraosseous sequestering or collection during follow-up, and also for profound localization. Nuclear medicine is useful in multifocal forms. Early diagnosis and treatment of acute osteomyelitis preclude chronicity.
Septic arthritis

Septic arthritis results from haematogenous inoculation of joints in septicaemia or contiguous extension from a focus of osteomyelitis. Group B streptococcus is the commonest causative organism in neonates, while *Staphylococcus aureus* is the commonest in infants. Treatment is urgent because of the high risk for progression toward destructive joints. Radiographs are usually normal in the early stages, and ultrasound is sensitive for confirming joint effusion (Fig. 5.227) and for evaluating periarticular soft tissues. The capsule-to-bone width and echogenicity of the fluid are variable (Fig. 5.228). Fluid aspiration must be conducted with care, regardless of the ultrasound findings. Colour Doppler helps to eliminate venous thrombosis, which is frequently associated.

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**Fig. 5.226.** Acute osteomyelitis with subperiosteal abscess in a 6-year-old boy. (a) Longitudinal and (b) axial scans show a spindle-shaped (arrows) subperiosteal fluid collection (C) contiguous with the bone (B)

**Fig. 5.227.** Septic arthritis in a 4-year-old girl. Sagittal scan of the right hip shows fluid (F) distending the joint capsule, which has a convex margin (arrows)
Soft-tissue abnormalities

**Vascular lesions**

**Haemangioma** or capillary haemangioma is one of the more common soft-tissue lesions in children. It contains vascular and nonvascular elements, such as fat, fibrous tissue and smooth muscle. Typically, it appears shortly after birth, initially with rapid growth and then usually undergoing spontaneous involution. The lesion can arise within superficial or deep soft tissues. Greyscale ultrasound shows a homogeneous or heterogeneous mass, which is usually predominantly echo-poor. Ultrasound is useful in diagnosis because it can demonstrate a pattern of low internal reflectivity and may also show compressibility of the lesion. The characteristic marked internal blood flow can easily be seen on colour Doppler, which also shows high vessel density.

**Vascular malformations** include arteriovenous, venous, capillary and lymphatic malformations. They are not often present at birth but become apparent as the child develops. Vascular malformations are usually sporadic but can be associated with genetic disorders, including Maffucci syndrome, Klippel-Trenaunay syndrome and Parker-Weber syndrome.

**Arteriovenous malformation** is a high-flow vascular lesion characterized by multiple blood vessels with direct arteriovenous connections and shunting. The sonographic findings include enlarged, tortuous vessels, turbulent blood flow with high systolic arterial flow, and reversed flow or pulsatile waveforms in the systemic vein. Colour Doppler imaging, CT and MRI after injection of contrast agents can show direct communication between the vessels involved.

**Venous malformation** is a slow-flow vascular lesion characterized by abnormal venous space and a normal arterial component. Clinically, it presents as a soft, compressible mass, usually of bluish colour. The sonographic findings include an echo-poor or echo-rich mass with low monophasic flow or no flow at all. The vein often contains phleboliths, characterized by echogenic foci with posterior acoustic
shadowing (Fig. 5.229). Colour Doppler shows the presence of large feeding vessels, and the probe may have to press onto the skin to confirm the vascularity.

**Capillary malformation** is characterized by a collection of small vascular channels in the dermis. Images are usually normal, although increased thickness of the subcutaneous fat and prominent venous channels may be seen in some children.

**Lymphatic malformations**, also known as **lymphangiomas** and **cystic hygromas**, are composed of dilated lymphatic channels. They are rarer than haemangiomas. About 75% are found in the neck, and 50–60% are found at birth. Cystic lymphangioma can readily be examined by high-resolution ultrasonography. As expected from their cystic nature, they typically appear as thin-walled, multilocular, predominantly fluid-filled masses.

![Fig. 5.229. Venous malformation in a 3-year-old girl. Transverse scan shows an ill-defined, echo-poor mass (M) containing phleboliths (arrows) within the muscles](image)

**Benign nonvascular lesions**

**Lymph nodes** may be found in a variety of locations in children, especially in the cervical region. On ultrasound, they are well-defined, homogeneous lesions, usually near vascular bundles. They have a characteristic vascular pattern, with extensive vascularity centrally; if they are benign and reactive, they often have a highly echogenic hilum (hilus sign). Benign nodes are small, with a greater longitudinal axis. Malignant lymph nodes are rounded, enlarged, of lower echogenicity and may have identifiable peripheral vascularity on colour Doppler, depending on the primary tumour; the resistivity index of malignant lymph nodes is higher (> 0.80) than that of reactive ones.

**Fibromatosis colli** (see also section on Neck Trauma, above) is a benign lesion of the sternocleidomastoid muscle, which is postulated to be due to birth trauma or peripartum injury. Infants usually present with an anterior neck mass by 2 weeks of life. The lesion frequently regresses over 4–8 months with conservative therapy. Greyscale ultrasound shows a subtle alteration of the echo structure and muscular enlargement within the sternal or clavicular head of the sternocleidomastoid. An
echo-poor mass, an echo-rich mass and mixed echo texture have all been described in fibromatosis coli.

**Fibromatosis** is a histologically benign but locally aggressive lesion. It usually occurs after puberty but has been reported in younger children. On ultrasound, the echogenicity and homogeneity of the lesion are nonspecific.

**Lipomas** are the commonest fat-containing soft-tissue masses in children. They are composed of mature adipose tissue. On sonography, they appear as oval, usually well-defined, homogeneous masses, which in general are echo-rich with no detectable blood flow on colour Doppler.

**Lipoblastoma** is a rare fatty tumour that occurs almost exclusively in children under 3 years of age. It contains multiple lobules of immature fatty tissue separated by fibrous septa. Sonography often does not allow differentiation between lipoma and lipoblastoma.

**Neurofibromas** are the commonest neural tumours in children. They arise within peripheral nerve fibres, occurring either sporadically or in association with neurofibromatosis type 1. On ultrasound, benign neurofibromas are homogeneous, well-defined, round or oval echo-poor lesions with a characteristic location in the neurovascular bundle.

**Dermoid and epidermoid cysts** are benign developmental choristomas. The lesions have a smooth contour and variable internal echogenicity on ultrasound. Most appear as oval, well-defined echo-free masses, with calcifications or fatty components.

Soft-tissue **haematoma** is usually caused by a myotendinous injury or a direct blow and tends to resorb after 6–8 weeks. The ultrasound findings depend on the time of imaging after the injury. In the acute phase, a haematoma may appear as a cloud of fine echoes and is sometimes difficult to differentiate from normal or swollen muscle. Later, ultrasound may show a complex ovoid mass with internal echoes and septations, which eventually becomes echo-free. The surrounding subcutaneous soft tissues usually show no inflammatory change.

**Popliteal cyst** occurs behind the knee and is less common in children than in adults. It is an echo-free lesion with acoustic enhancement behind and between the semimembranosus tendon and the medial head of the gastrocnemius muscle.

**A chronic foreign body** may cause inflammation in the surrounding tissue and present as a soft-tissue mass well after a traumatic event. Children in particular may not remember introduction of the foreign body. Wood splinters are common and are not seen on plain radiographs. Ultrasound may identify chronic or acute foreign bodies in subcutaneous tissues (Fig. 5.230). Most appear as an echo-rich focus associated with acoustic shadowing or reverberating comet-tail artefacts, surrounded by an echo-poor area due to surrounding oedema. If ultrasound is performed after an attempt has been made to remove the foreign body, the examination can be difficult. Ultrasound can be used to guide removal.
Malignant tumours

Malignant tumours are rare in children; they are generally considered to represent about 1% of all soft-tissue tumours. The commonest lesion is rhabdomyosarcoma, and the next commonest is synovial sarcoma. Rare sarcomas include fibrosarcoma, neurofibrosarcoma, malignant histiocytoma, leiomyosarcoma, alveolar part sarcoma and liposarcoma.

The imaging features of these malignant soft-tissue tumours are nonspecific. They can be homogeneous or heterogeneous and well circumscribed or poorly defined and infiltrative. On sonography, they may be echo-poor, isoechic or echo-rich to the adjacent soft tissues. The role of ultrasound in the initial diagnosis of a soft-tissue malignancy is to determine whether the lesion is solid and then to define those lesions for which a clear diagnosis can be made by ultrasound alone. Ultrasound is useful for guiding biopsy once staging with MRI has been performed. Core needle or surgical biopsy is often necessary for a definitive diagnosis.

Soft-tissue infections

Cellulitis is an infection of the subcutaneous soft tissues. Staphylococcus aureus and Streptococcus pyogenes are the commonest organisms involved. The clinical findings are erythema, cutaneous oedema and tenderness. Ultrasound shows increased echogenicity of the subcutaneous fat, often with fluid in the fascial layers (Fig. 5.231). A differential diagnosis can be made from osteomyelitis and deep venous thrombosis. Skeletal scintigraphy and MRI can be used to distinguish between cellulites and osteomyelitis.

Abscesses are suppurative fluid collections circumscribed by a wall. Ultrasound shows an echo-poor or echo-free fluid collection with internal mobile echoes, septations and a hyperaemic wall. Colour Doppler demonstrates
the absence of blood flow in the lesion. Ultrasound may be used to guide aspiration. A haematoma or necrotic tumoral lesion is suspected on the basis of the clinical background.

**Soft-tissue inflammatory disorders**

**Juvenile rheumatoid arthritis** is the commonest cause of arthritis in children. The cause is unknown. Ultrasound can show echo-rich tenosynovitis, echo-poor joint fluid, synovial thickening, pannus or a synovial cyst.

**Dermatomyositis** or juvenile dermatomyositis is an idiopathic inflammatory myopathy with diffuse nonsuppurative inflammation of striated muscle and skin. Ultrasound can show a diffuse echo-rich muscle with subcutaneous calcifications or muscle atrophy.

**Special clinical situations**

**Abdominal pain**

Abdominal pain is a frequent symptom in children, and in 80% of cases no diagnosis is made. Minimum exploration should, however, be done to exclude an organic disorder. Before imaging is begun, the medical history of the child should be recorded carefully. Acute or chronic, generalized or localized pain, fever, a palpable mass and the age of the child are the main aspects to be considered.

Ultrasound is a suitable imaging tool in such situations, because it is harmless and versatile. Other modalities, such as chest radiography, are necessary to complement ultrasound in some situations.
Acute abdominal pain
In acute abdominal pain, ultrasound is used to demonstrate or exclude the following mechanical and inflammatory disorders:

- Abdomen: ascites, masses, abscesses, inguinal hernia;
- Liver and bile ducts: focal lesions, dilatation of the bile ducts, cholecystitis;
- Pancreas: pancreatitis;
- Spleen: enlargement, focal lesions;
- Digestive tract: appendicitis, regional lymphadenitis, gastroenteritis, colitis, ileal intussusception, ileal volvulus (bowel malrotation), rheumatoid purpura with intestinal wall haematoma, gastroduodenal ulcer;
- Urinary tract: dilatation of the renal pelvis and ureters;
- Chest: pleural effusion, pneumonia.

Chronic abdominal pain
In chronic pain, in addition to the disorders listed above, the following should be considered:

- Abdomen: tumours, enlarged (mesenteric) lymph nodes, intestinal parasitosis, hydatid cysts, hernias;
- Gall bladder: abnormalities (choledochal cysts), stones;
- Digestive tract: tumours, enlarged mesenteric lymph nodes, foreign bodies (bezoars), bowel malrotation;
- Urinary tract: obstructive syndromes, calculi, pyelonephritis, tumours;
- Genitalia: pelvic or scrotal mass, ovary cysts, haematocolpos, hydrometrocolpos, pregnancy in older girls;
- Outside the abdomen: pneumonia, spinal anomalies, tuberculosis, psoas muscle abscess.

Neonatal intestinal obstruction
Duodenal obstruction
Intrinsic obstruction: atresia, stenosis, diaphragm
The usual diagnostic approach in neonatal digestive pathology has changed in the past few years. Digestive malformations have become more common, and ultrasonic exploration or digestive MRI, if available, allow precise assessment of the malformation and clear etiological orientation. Neonatal bowel obstruction has multiple causes. Duodenal obstructions are easy to recognize and always require radical surgery. Therapeutic decisions can be made only after a precise differential diagnosis. Once the presence of an obstruction has been established, its cause must be determined. Plain abdominal films are usually essential to localize the obstruction but cannot always identify an intestinal perforation. Ultrasonography is therefore an essential complement to plain abdominal films, leading to increasingly precise
categorical diagnosis of an organic occlusion, continual visualization of the colon and precise localization of the obstruction, indicating use of a contrast enema in low small-bowel obstruction.

There are multiple causes of duodenal obstruction, including obliteration of the duodenal lumen (due to duodenal atresia, stenosis or diaphragm), obstructive complications of malrotation, with obstruction by Ladd bands, and midgut volvulus. Rarely, it is due to obstructive duodenal duplication. The obstructive role of a preduodenal portal vein or an annular pancreas is not clear.

The pathophysiology of duodenal atresia or stenosis is incompletely understood, but absent recanalization of the digestive lumen between the 8th and the 10th week is the most likely explanation. It thus consists of an early disorder of organogenesis, with biliopancreatic regional anomalies and many other malformations, including oesophageal atresia, renal abnormalities, vertebral malformations and congenital heart disease. Duodenal atresia or stenosis is also commonly associated with trisomy 21.

Intrinsic congenital obstruction of the duodenum is relatively rare, occurring in 1/10 000 to 1/40 000 births. It is now frequently diagnosed prenatally, with hydramnios in 50% of cases. It is located exclusively in the second part of the duodenum, and in 80% of cases the obstruction occurs below the ampulla of Vater.

The typical presentation is a flat abdomen and early bilious vomiting. Plain radiography reveals the double-bubble sign, representing air in the stomach and proximal duodenum, contrasting with the absence of gas in the intestine distal to the duodenum (Fig. 5.232). Most clinicians consider this radiological aspect sufficient to make a diagnosis and to refer the newborn to a paediatric surgeon; however, the surgeon should be given a more precise pretherapeutic ultrasonographic assessment, based on both the double liquid bubble and an annular pancreas. Early ultrasound can also distinguish a diaphragm from atresia (Fig. 5.233). The absence of malrotation must be verified by studying the position of the mesenteric vessels by ultrasound (Fig. 5.234). Ultrasonographic study of the colon and rectum is essential: if the atresia
is single, the colon diameter is normal (Fig. 5.235); if there are multiple atresias, there is a microcolon. Associated malformations of the heart, kidneys and bile ducts should also be sought by ultrasound.

If the duodenal dilatation is severe with no gas distal to the obstruction, atresia or a tight diaphragm should be suspected; however, complete obstruction due to malrotation cannot be ruled out. When there is less duodenal dilatation and especially when gas is seen distal to the duodenal obstruction, a precise diagnosis cannot be made, as it could be due to duodenal atresia with biliary duct bifidity, a diaphragm, malrotation with duodenal compression by a Ladd band or malrotation with midgut volvulus, which is the most important differential diagnosis.
Obstructive complications of malrotation

Malrotation in neonates, which is seldom asymptomatic, usually presents as obstructive complications, such as Ladd band obstruction or malrotation with midgut volvulus, which requires urgent surgical intervention because of the risk for digestive ischaemia.

Rotation anomalies are not a distinct entity but a continuum of malformations, reflecting an embryological attack at any time during development of the primitive intestinal gut. Interruption of intestinal rotation at 90° (nonrotation) does not incur a major risk for volvulus because the mesentery root is long enough; however, if rotation stops at 180°, the jejunum follows the duodenum and occupies the right lower quadrant, and there is no duodenojejunal flexure. The ileocaecal junction joins the subhepatic area abnormally through peritoneal duodenocolic bands, and Ladd bands pre-cross the duodenum, frequently causing greater or lesser extrinsic compression. The first jejunal loop and the last ileal loop are close to each other, and the mesenteric root is extremely short, resulting in a high risk for volvulus. The presence of green vomiting in a newborn must therefore be considered a sign of malrotation with midgut volvulus, pending proof of a different cause.

The typical plain abdominal radiological image is of incomplete duodenal obstruction, with little distal digestive gas. When the obstruction is complete, the volvulus cannot be distinguished from duodenal atresia, and the plain radiograph may appear normal, which is dangerous if it halts the investigation. Therefore, an upper gastrointestinal series should always be conducted to show the abnormal position of the duodenojejunal flexure and the torsion whirl. Even so, if obstruction is complete and the whirl tight, the volvulus will not be seen. Axial imagery and ultrasound show the position of the mesenteric vessels. Ultrasound detection of inversion of the mesenteric vessels in malrotation must sometimes be confirmed in an upper-gastrointestinal series, while volvulus can be diagnosed by ultrasound.
alone. In this urgent context, ultrasonographic diagnosis should be used to confirm the malrotation (Fig. 5.236) and localize the volvulus mass (Fig. 5.237), and the torsion should be visualized by colour Doppler.

The mesenteric whirl is seen as a prevertebral mass 15–20 mm in diameter located in front of the aortic axis, with clear ultrasonic characteristics: the superior mesenteric artery is surrounded by the whirl built up by the superior mesenteric vein, which is usually turgescent, and by the mesentery and the digestive loops. Colour Doppler shows the clockwise direction of the whirl and sometimes the number of whorls.

Fig. 5.236. Digestive malrotation in a newborn girl. Transverse scan shows inverted positioning of the mesenteric vessels (arrows), with the superior mesenteric artery (SMA) lying to the right of the superior mesenteric vein (SMV). Ao, abdominal aorta

Fig. 5.237. Malrotation with midgut volvulus in a newborn boy with bilious vomiting. Transverse scan (colour Doppler) shows a prevertebral mass 19 mm in diameter in front of the aortic axis; swirl pattern of the superior mesenteric vein (SMV) as it twists around the superior mesenteric artery (SMA)
This diagnosis must always be accompanied by an ultrasonic evaluation of the prognosis, particularly if there are clinical signs of digestive ischaemia, such as shock, bloody diarrhoea or abdominal distension. The evaluation should include a search for thickening or thinning of the digestive wall, motionless loops, peritoneal fluid, haemodynamic anomaly of the superior mesenteric artery and absence of flow in colour Doppler in the whorl of torsion (Fig. 5.238).

**Small-bowel obstruction**

Postnatal small-bowel obstruction can usually be confirmed on the basis of clinical and radiological assessments. The cause is more difficult to determine and is the true diagnostic challenge of a paediatric radiologist. The mechanism of these obstructive lesions varies, from jejunoileal atresia to multiple atresias; an abnormal meconium consistency, as in meconium ileus in cystic fibrosis; or abnormal small-bowel peristalsis, as in megacystis-microcolon-intestinal hypoperistalsis syndrome. To identify the mechanism, the imaging method must show intestinal peristalsis, allow measurement of the loops on both sides of the site of obstruction and specify the intraluminal contents of the proximal and distal loops.

A plain abdominal film shows proximal bowel distension, while contrast enema shows the consequences of a digestive obstruction on the distal bowel and its contents. Ultrasound shows digestive motility, proximal loop dilatation, and distal digestive collapse and provides details of the fluid or meconial content on both sides of the obstructive site. As the gas content of the digestive bowel is sometimes dangerous, an ultrasound should be conducted immediately after birth.
**Small-bowel atresia**

Small-bowel atresia and stenosis account for 40% of organic obstructions. Atresia is responsible for 95% of neonatal obstructive syndrome, and screening by ultrasound and MRI is frequently performed at the fetal stage. Small-bowel atresia is the result of a mechanical ischaemic accident occurring after week 12 of gestation in the region of the superior mesenteric artery. Ischaemic necrosis of variable severity leads to resorption of the digestive segment in aseptic media and fibrous scarring or disappearance. This can be due to a primary vascular accident near the superior mesenteric artery or secondary to a volvulus, an internal hernia, intussusception or parietal narrowing (laparoschisis).

The clinical findings of jejunoileal atresia are characteristic and appear within the first hours of life. Bilious emesis is constant and the more proximal the obstacle, the earlier and more abundant is the vomiting; the more distal the object, the greater the abdominal distension. Usually there is an inability to pass meconium.

The diagnosis is based on a combination of plain abdominal films and ultrasound. The radiological examination shows bowel loops dilated with air and fluid, especially when the atresia is located low in the bowel. There is no distal bowel gas, the colon is not seen, and there is no gas in the rectum. Radiological evaluation of a neonatal obstructive syndrome can be difficult. With a distal obstruction, it is not always easy to differentiate the small from the large bowel, and the obstructive site is difficult to evaluate because of the liquid content distal to it. As fetal screening indicates imaging immediately after birth, the diagnostic efficacy of plain abdominal films is reduced. Radiological data should therefore be complemented by neonatal ultrasound for diagnosis of small-bowel obstruction (Fig. 5.239). On sonography, fluid dilatation is seen up to the obstruction, and the loops of the thin-walled small bowel show increased hyperperistalsis. The transition zone is clearly seen, from the presence of collapsed, gasless distal loops of the small bowel if the obstructive site is in the jejunum or the middle small bowel or a microcolon if the atresia is located in the distal small bowel. Peritoneal effusion is seen frequently.

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**Fig. 5.239.** Ileal atresia in a newborn girl. Transverse scans shows (a) fluid-filled, dilated, hyperperistaltic segments of the small bowel and (b) a small microcolon (arrow)
Meconium ileus

Meconium ileus is an obstruction in the final ileum due to an intraluminal obstacle made up of meconium of anomalous consistency. This condition occurs in 10–20% of newborns with cystic fibrosis, which is an anomaly of secretion of the exocrine glands. Thus, the composition of the meconium is abnormal, with low water content and high albumin content, and it adheres to the mucosa of the digestive tract. Pellets of desiccated meconium are found in the distal ileum below a collection of viscous meconium in dilated loops. The meconium ileus results in abdominal distension, bilious vomiting and failure to pass meconium.

The suggestive radiological findings are no air–fluid level, asymmetrical dilatation of the bowel loops and a granular pattern in the right iliac fossa, but they are seldom present. Generally, meconium ileus appears as a nonspecific low obstruction and is difficult to differentiate from low small-bowel atresia on clinical and radiological grounds. This differential diagnosis is, however, essential because uncomplicated meconium ileus can be treated effectively by hyperosmolar contrast enema.

Contrast enema generally allows a differential diagnosis. In distal small-bowel atresia, the microcolon opacifies quickly and there is a frank backward flow into the distal small-bowel loops. In meconium ileus, the colon fills slowly and with difficulty to reveal the meconium pellets impacted in the distal ileum (Fig. 5.240). Contrast enema is not always diagnostic, as there may be no opacification of the distal small-bowel loops due to perforation during filling.

Fig. 5.240. Meconium ileus in a newborn boy. Contrast enema demonstrates a microcolon, with a dilated distal ileum containing multiple pellets of meconium (arrows)

Ultrasound is useful in the diagnosis of meconium ileus (Fig. 5.241). In order to confirm an organic obstruction, dilatation of all the small-bowel loops and marked microcolon must be demonstrated. The appearance of the bowel loop content is diagnostic: dilated loops with an echogenic content (contrasting with the echo-free, fluid-filled loops in small-bowel atresia), a pseudo-thickened layer secondary to concentric layers of
inspissated meconium in contact with the mucosa, an echographic granular pattern of bowel gas trapped in the echogenic meconium and echogenic pellets within the distal ileum.

**Megacystis-microcolon-intestinal hypoperistalsis syndrome**

This syndrome consists of intestinal obstruction associated with nonobstructive megacystis, probably of myopathic origin. At the digestive level, there is a short small bowel, a microcolon, no or ineffective peristalsis and, frequently, malrotation. The prognosis is poor without effective treatment, and death occurs before 6 months.

The physiopathology of this syndrome is poorly understood. The hypoperistalsis is attributed to various factors, such as ganglionic immaturity of the intestinal tract, axonal dystrophy, a degenerative disease of the smooth muscles or destruction of the smooth muscle and the neurogenic environment with fibrosis of the digestive wall.

Clinically, the newborn presents with severe abdominal distension secondary to megacystis and failure to pass meconium. On ultrasound, the infant has a large bladder, often with pelvic ureter and calyx dilatation. The digestive anomalies that confirm the diagnosis are moderate dilatation of nonperistaltic loops, major microcolon and malrotation (Fig. 5.242).
Complications of bowel obstructions

Meconium peritonitis is a frequent complication of meconium ileus (30%) and small-bowel atresia (45%). It results from antenatal digestive perforation, generally above an obstacle (atresia or volvulus). It evolves towards sterile plastic organization of the fluid and the appearance of peritoneal calcifications. The diagnosis is made antenatally by ultrasound from the presence of peritoneal and sometimes scrotal calcifications of irregular form.
Meconium peritonitis can present as a meconium (pseudo)cyst. The meconium bursts into the peritoneal cavity and initiates an intense fibroblastic reaction. The meconium is then gradually circumscribed by fibrous adherences in contact with the gathered loops. A capsule is formed by fibrous granulation, which is then calcified and encircles the fluid. A diagnosis can be made during fetal ultrasonography and confirmed by fetal MRI, which shows a cyst with a hypersignal (meconium), a microcolon and proximal small-bowel dilatation. Meconium cysts are sometimes found postnatally as an obstructive syndrome or abdominal mass. Plain abdominal film and ultrasound are necessary and sufficient to show cysts, peripheral calcifications, a microcolon and dilated small-bowel loops (Fig. 5.243, Fig. 5.244). Cystic fibrosis should be suspected.

Fig. 5.243. Meconium pseudocyst in a newborn boy. Supine radiograph shows a large meconium pseudocyst with calcified walls (arrows)

Fig. 5.244. Meconium pseudocyst in a newborn boy. Axial scans of the left quadrant show a large cystic mass (C) with calcified rim (arrow) containing internal debris, a dilated small bowel (SB) and a microcolon (MC)