14 Intraoperative Ultrasound During Biliary Tract Surgery

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Introduction

The use of ultrasonography during biliary surgery was first proposed in the mid-1960s by Knight in the UK and Eiseman in the United States [1, 2]. These pioneers made use of A-mode ultrasonography which is unidirectional with the signal displayed on an oscilloscope. These were notoriously difficult to interpret with Eiseman noting:

> Small stones may be overlooked unless the surgeon is alert to rescan any suspicious "pips" and to observe the oscilloscopic deflection as the probe closes on the point under question.

Yet, many of the difficulties described are similar to those faced today, with duodenal air making it "particularly difficult to interpret signals from the ampullary region of the duct" and the need for care "in using the intraluminal probe to avoid air bubbles within the duct … [as] the sonar reflections of intraductile bubbles are similar to calculi". The development of B-mode ultrasonography in the 1980s saw a dramatic improvement in quality, with two-dimensional images conveying for the first time the structure of the underlying organs [3]. This aided interpretation and allowed the recording of findings with Polaroid images. While the main driver of these innovations was the need to identify common bile duct calculi, the low resolution of preoperative imaging left the surgeon making important intraoperative decisions regarding the nature of common bile duct lesions and the nature or degree of infiltration of pancreatic lesions. Intraoperative cholangiography was in common use, was effective and was usually straightforward to perform. It may not be surprising that intraoperative ultrasonography was not widely employed, given the relative ease with which the anatomy could be delineated with cholangiography.

In more recent years, two factors have acted to rekindle an interest in operative ultrasonography: the development of hepato-pancreaticobiliary surgery as a specialty with a widening range of operative procedures and aggressive strategies to manage cancer, and the development of laparoscopic surgery including cholecystectomy, pancreatectomy and liver resection. The requirement for the surgeon to accurately delineate the position of lesions in the biliary system has provided a stimulus for the development of this technique.

The aim of this chapter is to describe the anatomy of the normal biliary tract with specific reference to intraoperative ultrasonography. Using images and video, the assessment of the biliary tract is described and the influence of ultrasonography on the management of common pathologies is highlighted.

Anatomy of the Biliary Tree

The biliary tract is a set of anatomical structures that convey bile secreted from the liver to the duodenum. Small intrahepatic biliary radicles coalesce into larger segmental ducts, which form the left and right hepatic ducts (Fig. 14.1). The course of the left duct is extrahepatic to its confluence with the right duct, where the common hepatic duct is formed (Fig. 14.1a). This lies within the hepatoduodenal ligament and runs anterior and to the right of the portal vein. The anatomy of the portal pedicle is highly variable, hence the importance of ultrasonography in delineating it. The lower part of the common hepatic duct lies to the right of the proper hepatic artery, with the right hepatic artery branch usually running behind the common hepatic duct (Fig. 14.1a). The right hepatic artery can run over the anterior surface of the common hepatic duct, which is an important variation to identify to avoid injury to this vessel.

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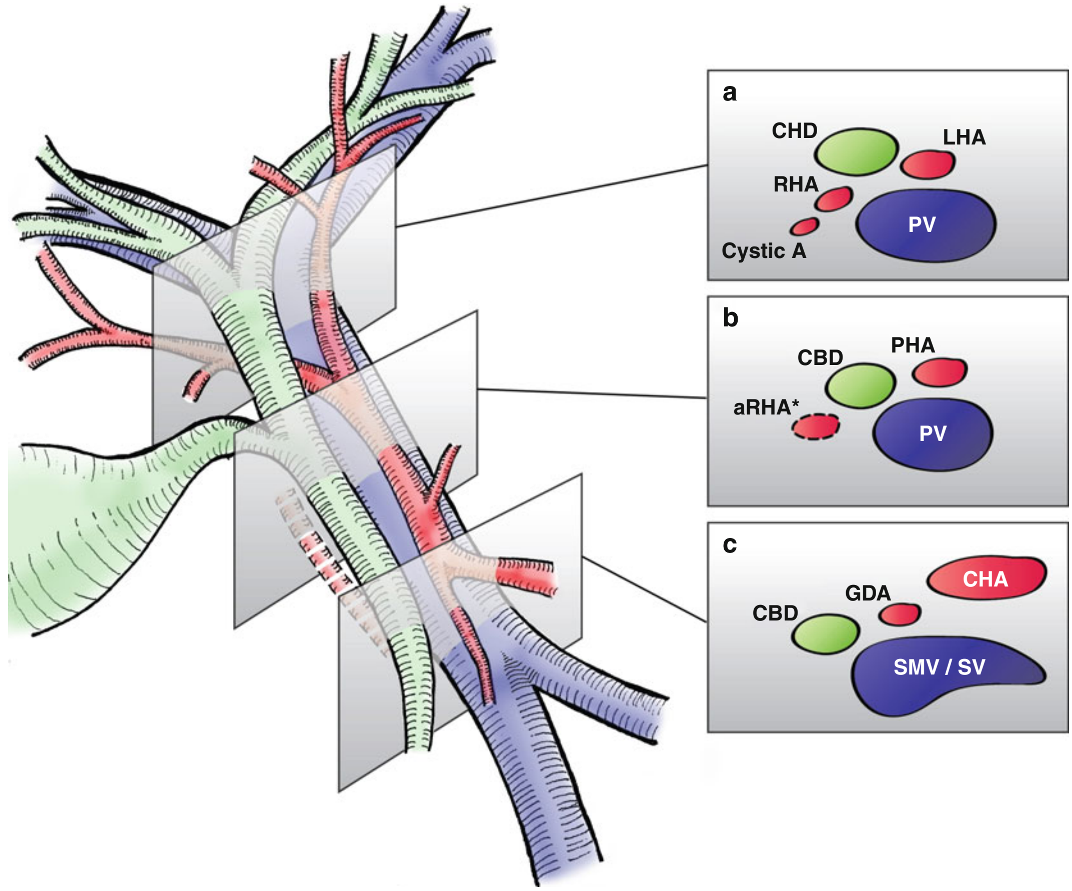

Fig. 14.1 Anatomy of the extrahepatic biliary tree with typical transverse ultrasonographic planes through the portal pedicle. The right hepatic artery (*RHA*) usually runs behind the common hepatic duct (*CHD*), with the origin of the cystic artery (*Cystic A*) being variable (**a**). An important variant is an accessory right hepatic artery (*aRHA*) arising from the superior mesenteric artery present in 15 % of patients (**b**). The superior mesenteric vein/splenic vein confluence is tear-shaped and often easy to identify (**c**). *LHA* left hepatic artery, *PHA* proper hepatic artery, *CHA* common hepatic artery, *GDA* gastroduodenal artery, *CBD* common bile duct

The cystic artery arises from a variable origin along the length of the proper and right hepatic arteries. Similarly, the insertion of the cystic duct into the common bile duct varies, either running a short course and inserting directly or, more commonly, travelling beside the common hepatic duct for a length prior to insertion. The posterior sectoral duct can also insert low into the common hepatic duct or, rarely, directly into the cystic duct. An uncommon configuration in posterior sectoral duct anatomy is sometimes implicated in the occurrence of bile duct injury at laparoscopic cholecystectomy.

An anatomical variant occurring in 15 % of patients is an accessory or replaced right hepatic artery arising from the superior mesenteric artery (Fig. 14.1b) [4]. Identifying and protecting aberrant vessels is important, particularly during resectional surgery such as extrahepatic bile duct resection and pancreaticoduodenectomy. An accessory left hepatic artery arising from the left gastric artery crosses the lesser omentum in a position out with the portal pedicle. This vessel will not usually be seen on standard sonography of the portal pedicle, unless the probe is moved left and the vessel looked for specifically.

The common hepatic artery is prominent in transverse planes low in the pedicle, appearing greater than its size given the angle of approach (Fig. 14.1c). It can be used to identify the gastroduodenal artery which usually arises at the same level and should not be confused with the right gastric artery (see Fig. 14.4b). The coeliac trunk can usually be visualised dropping behind the pancreas, with the splenic and left gastric artery origins usually visible.

The confluence of the splenic vein and superior mesenteric vein can be identified by its tear-shaped appearance in the transverse plane on ultrasound. Potentially troublesome venous tributaries can often be identified in this area, prior to dissection in pancreaticoduodenectomy. The portal vein can be followed up behind the pancreas towards the liver, a manoeuvre which can often aid the assessment of resectability of malignant disease.

Lymph nodes are present throughout the portal pedicle and may be enlarged as a consequence of disease (see discussion of section "Benign obstruction of the biliary tree"). These are easily identified and measured.

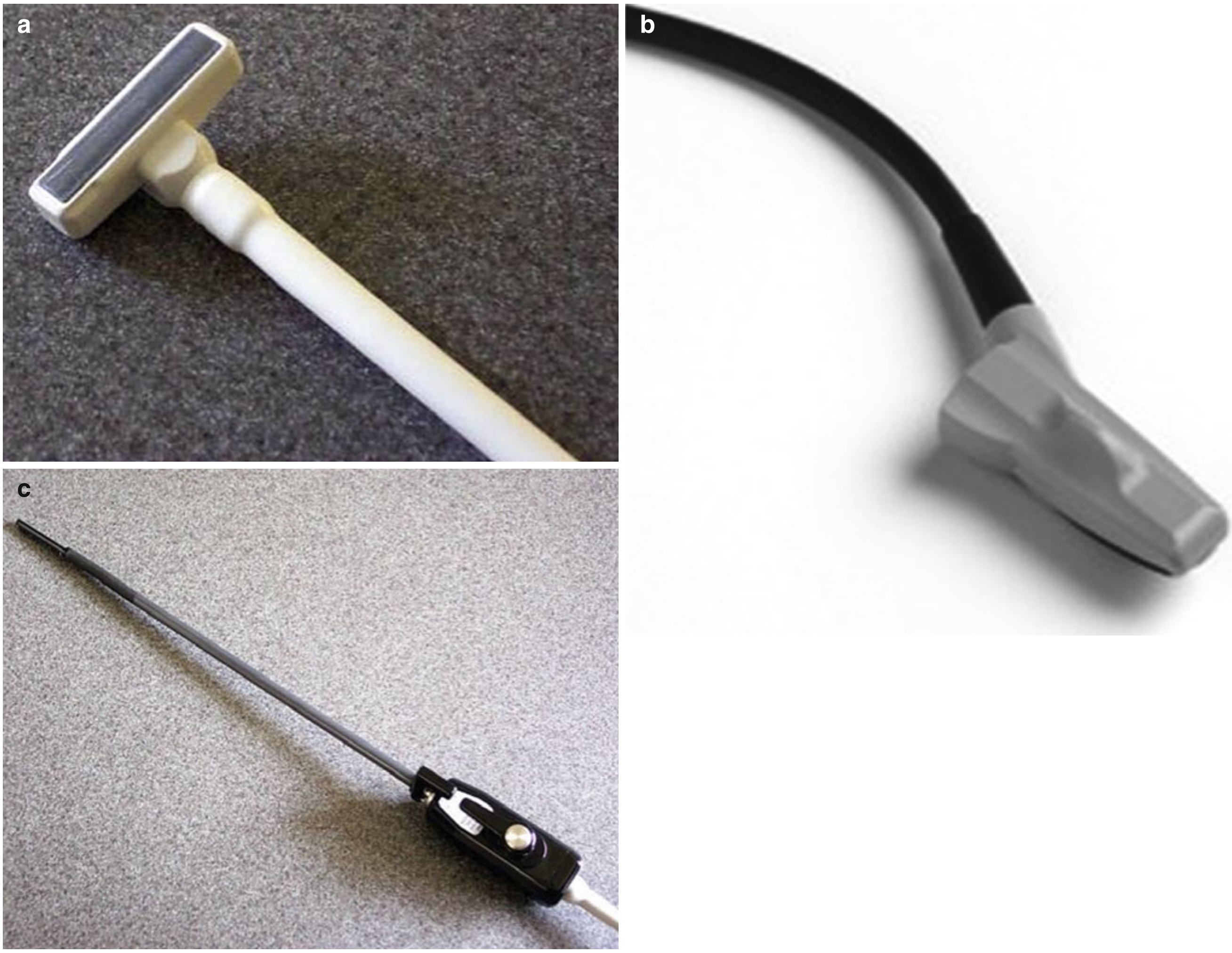

Fig. 14.2 Ultrasound transducers designed for use in surgery: (**a**) T-style linear probe, (**b**) I-style convex probe, and (**c**) laparoscopic probe

Equipment

A number of different companies now produce versatile high-resolution equipment providing excellent image quality. Real-time B-mode ultrasound images are of course essential, but the ability to add colour flow, power flow and spectral Doppler is now standard. This allows visualisation of blood flow in vessels, which at its simplest can be used in the initial orientation of structures. The technology is now such that even flow in the smallest vessels can be visualised with high sensitivity and resolution. Facilities on the most advanced systems include multi-planar image reconstruction and 3D automated volume measurement.

Various probe options are available including the authors' preferred T-transducer (Fig. 14.2a) and the I-style finger-grip transducer (Fig. 14.2b). These can be configured with linear or convex arrays, with the former providing a rectangular field of view and the best spatial resolution at the tissue depths typically encountered in hepatobiliary and pancreatic surgery. Laparoscopic probes in the past required to be placed within a sterile plastic sheath containing conductive gel which was awkward and yielded poor image quality. Probes can now be sterilised in ethylene oxide, allowing direct organ contact with improved image in quality. A 12-mm port is required for use and port placement is described below. The tip of the probe is flexible in two planes, allowing most required angles to be achieved through one port (Fig. 14.2c).

Remote control units are available for sterile use and image/video storage can be integrated with institution picture archiving and communication systems (PACS). Specialised probes have been designed that include a needle guide and come with specific software to aid accurate placement for radiofrequency/microwave ablation.

Technique in Open Surgery

The access to the organs of the abdomen afforded by open surgery provides an ideal opportunity for contact ultrasonography. The high-frequency, compact equipment now available

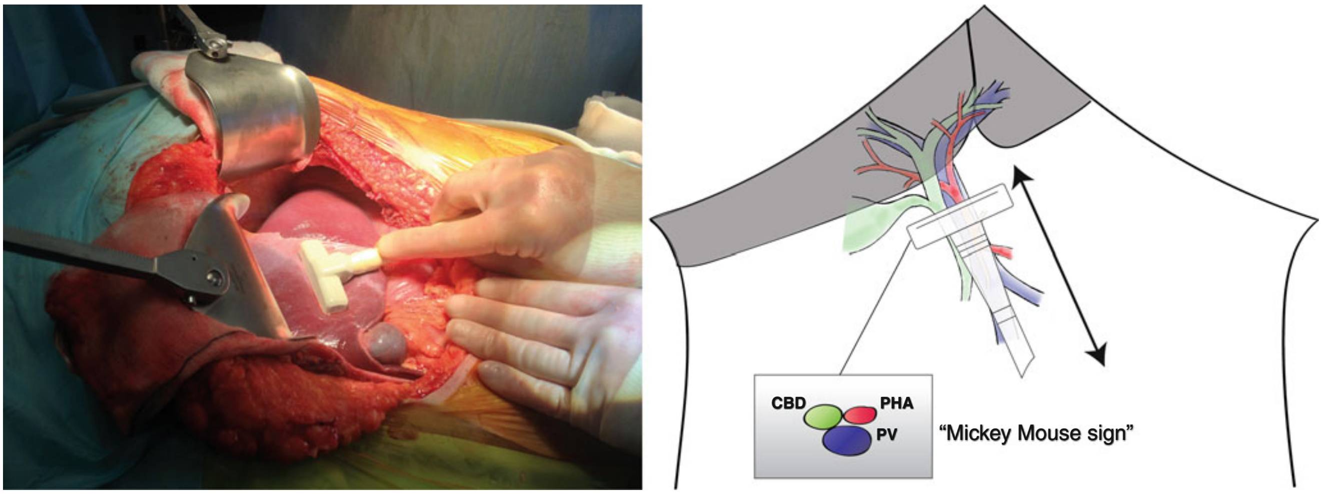

Fig. 14.3 Ultrasonography of the portal pedicle starts with identification of "Mickey Mouse", formed by the larger portal vein (*PV*) sitting posteriorly with the common bile duct (*CBD*) and proper hepatic artery (*PHA*) in front

can be fully sterilised and placed directly on abdominal viscera to obtain high-resolution real-time images of intra-abdominal structures. This gives the operating surgeon an accurate and flexible tool to assess the anatomy, the nature and the extent of disease, aiding operative decision-making.

Intraoperative ultrasound may be useful in surgery for benign or malignant disease and in both cases the approach is the same. A full visual inspection and manual examination is useful and should be performed initially at laparotomy [5]. Together with the preoperative imaging, this will provide valuable information about the nature and extent of disease. Ultrasonography starts at the hepatoduodenal ligament with examination of the structures of the portal pedicle. Placement of fixed surgical retractors including a specific liver retractor on segment IV may aid access. The use of warm saline around the ligament can help if image quality is poor, but is not always required. It often helps if the operator retracts gently on the duodenum, placing the hepatoduodenal ligament under some tension.

To aid initial orientation, the "Mickey Mouse sign" can be useful (Fig. 14.3). The larger portal vein sitting posteriorly, with the bile duct and hepatic artery in front are reminiscent of the face and ears of the famous cartoon character. "Mickey" can be followed up and down, which acts to keep the probe at right angles to the structures. Care must be taken not to compress structures with the probe. The common bile duct is normally around 8 mm in diameter and can be difficult to visualise when not dilated. It can be differentiated from other portal structures by its hyperechoic wall and absence of flow on Doppler.

Benign Obstruction of the Biliary Tree

Non-malignant obstruction of the biliary tree can result from congenital abnormalities but is more commonly associated with gallstones, benign biliary strictures or a consequence of acute or chronic pancreatitis. In 997 consecutive patients selected for laparoscopic cholecystectomy, operative cholangiography was accomplished in 962 (96 %) [6]. Forty-six patients (4.6 %) had at least one filling defect in the common bile duct, although 12 of these patients had a normal cholangiogram within 48 h (26 % possible false-positive rate) and a further 12 (26 %) had spontaneously passed a stone by 12 weeks. Twenty-two patients (2.2 % of total population) had persistent CBD stones 6 weeks after laparoscopic cholecystectomy.

Figures 14.4 and 14.5 and accompanying videos (Videos 14.1, 14.2 and 14.3, respectively) show typical images obtained with ultrasonography during open surgery. This patient presented with obstructive jaundice and cholangitis on a background of upper abdominal pain. A CT showed dilatation of the extra- and intrahepatic biliary tree with no pancreatic duct dilatation and an obstructing 1.5 cm gallstone in the distal common bile duct. Endoscopic retrograde cholangiopancreatography (ERCP) with sphincterotomy was performed and a biliary stent placed. The bilirubin remained elevated and the cholangitis persisted and a second ERCP was performed, with placement of a second biliary stent. The stone was impacted and could not be removed at ERCP. Drainage was achieved and the symptoms of sepsis settled. Given the size and position of stone, clearance by open exploration was performed.

"Mickey Mouse" is identified and the common bile duct seen to be significantly distended at 1.5 cm (Fig. 14.4a). What initially appears to be the proper hepatic artery is actually a prominent gastroduodenal artery. This is followed up and the origin of the right gastric artery is seen (Fig. 14.4b), just before a large common hepatic artery is visualised (Fig. 14.4c). The cystic duct is long and clearly inserts in a low position (Fig. 14.4b). A lymph node is seen behind the common bile duct which does not look enlarged on ultrasonography and is not suspicious on palpation. Towards the confluence of the left and right hepatic duct, plastic stents are seen within the common hepatic duct, with associated acoustic shadowing (Fig. 14.4d). Some debris can be seen at different levels in the duct.

Longitudinal views are seen in Fig. 14.5. With the right side of the images being the anatomical superior position, the pancreas and pancreatic duct are seen anterior to the confluence of the superior mesenteric/splenic vein (Fig. 14.5a). The bile duct is abnormally thickened and a large stone is present just superior to the neck of the pancreas (Fig. 14.5b). A prominent acoustic shadow is cast behind the stone, obscuring the view of structures in this area. Moving superiorly, two plastic

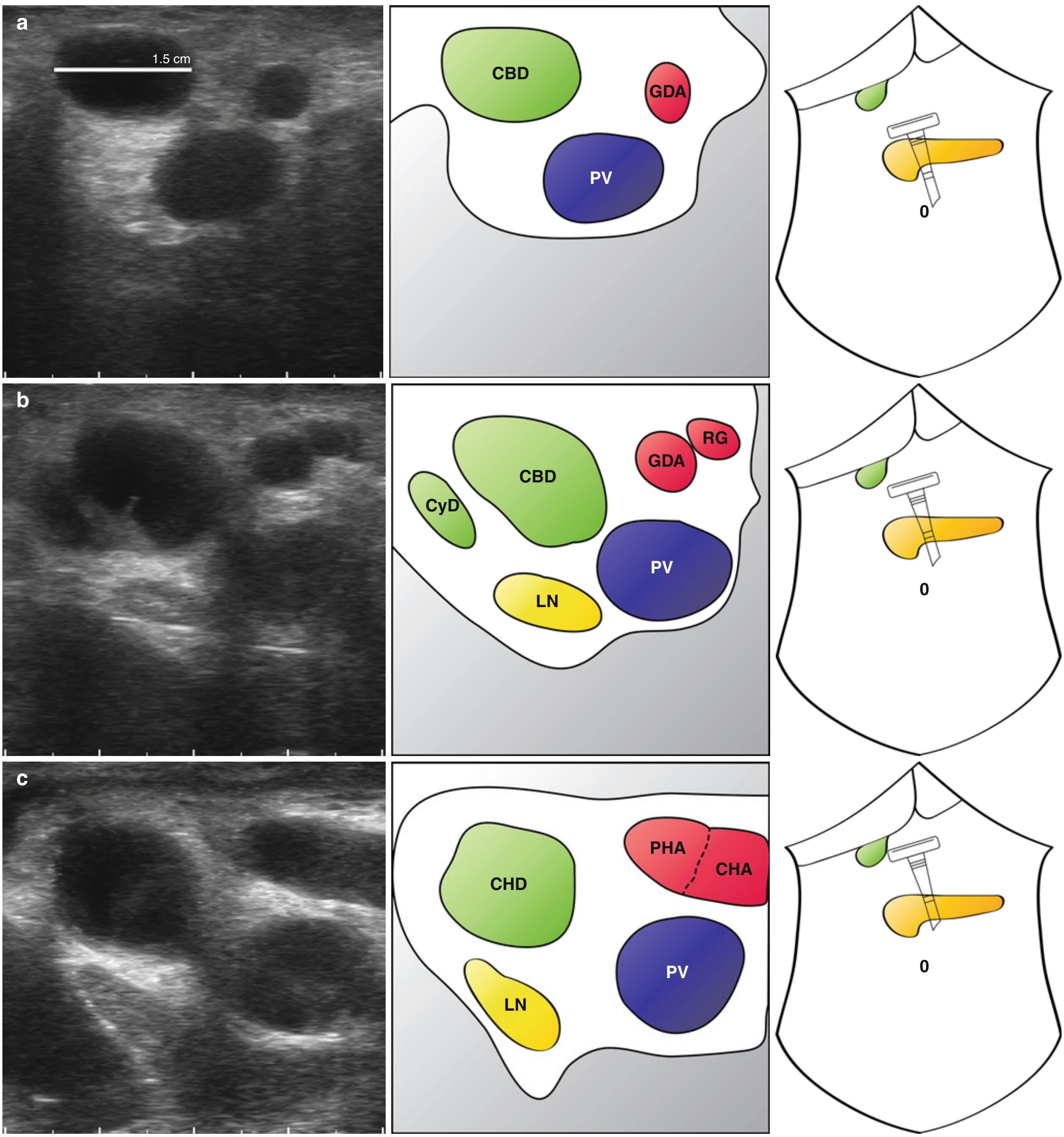

Fig. 14.4 Transverse views of portal pedicle in a patient with biliary obstruction. A full description is provided in the main text. A dilated common bile duct (*CBD*) is followed up with the portal pedicle (**a**). The arterial anatomy is clearly seen (**a**–**d**) and two plastic stents can be seen within the common hepatic duct (**d**) (Also see accompanying Video 14.1) *GDA* gastroduodenal artery, *PV* portal vein, *CHD* common hepatic duct, *RG* right gastric artery, *CyD* cystic duct, *LN* lymph node, *PHA* proper hepatic artery, *CHA* common hepatic artery

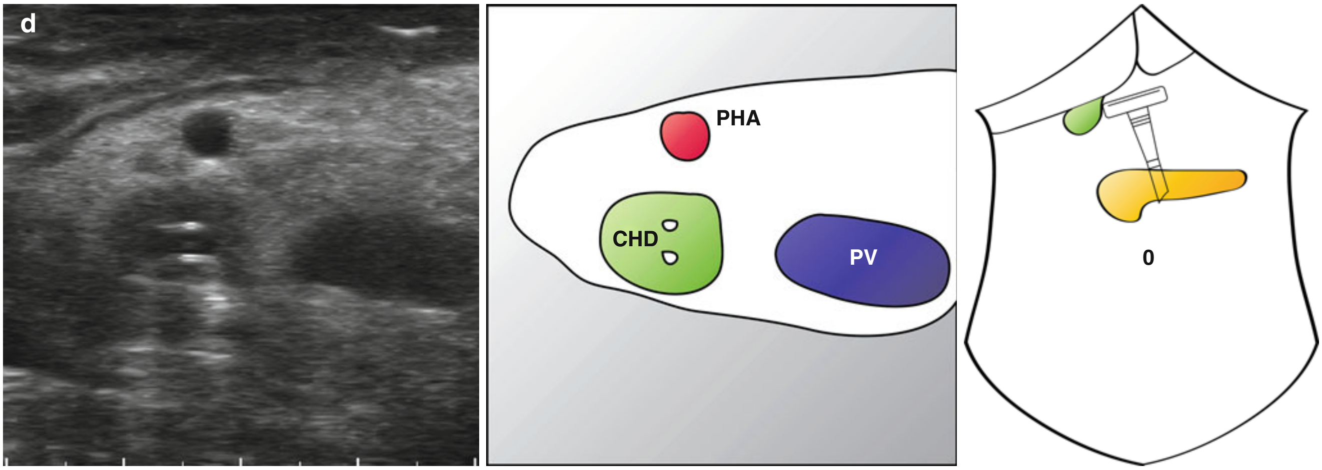

Fig. 14.4 (continued)

stents are seen in the common bile duct (Fig. 14.5c). With careful manipulation of the probe, the stents are seen to pass the stone into the distal CBD (Fig. 14.5d).

An open common bile duct exploration was performed and the stone removed in fragments. The duct was visualised with a choledochoscope, and the operating surgeon was satisfied that all stone fragments had been cleared. The duct was primarily closed without a t-tube and the patient discharged from hospital 6 days later.

Malignant Obstruction of the Distal Biliary Tree

Malignant obstruction of the distal biliary tree is most commonly caused by adenocarcinoma of the head of the pancreas. Other causes include cholangiocarcinoma arising in the distal common bile duct, duodenal or ampullary adenocarcinoma and obstruction resulting from malignant portal lymph nodes.

Figure 14.6 with the accompanying video (Videos 14.4 and 14.5) shows images obtained with ultrasonography during open exploration of a patient who presented with painless jaundice and weight loss. A CT showed dilatation of the extra- and intrahepatic biliary tree and pancreatic duct. No gallstones or large mass were seen on cross-sectional imaging and a presumed diagnosis of distal/ampullary cholangiocarcinoma was made. No evidence of locally advanced disease or distant metastases was seen on CT. Endoscopic retrograde cholangiopancreatography (ERCP) was performed and a short metal stent inserted. Brushings of the bile duct showed cellular atypia but no frankly malignant cells.

At open exploration, ultrasonography in the transverse plane showed a grossly dilated pancreatic duct (Fig. 14.6a). The metal stent was clearly visualised in the CBD and an inhomogeneous mass seen in the head of the pancreas. The dilated pancreatic duct could be followed into the tail of the pancreas (Fig. 14.6b). The confluence of the SMV/SV and SMA were well visualised and did not appear involved in the mass. In the longitudinal plane, the portal vein was followed up through the head of the pancreas and the wall appeared smooth and regular with no suggestion of malignant involvement. No large nodes were seen around the coeliac trunk or in the aortocaval window.

The patient went on to have a pancreaticoduodenectomy and was found to have a T3N1 ductal adenocarcinoma of the head of pancreas which was completely excised.

Malignant Obstruction of the Proximal Biliary Tree

Hilar and intrahepatic cholangiocarcinoma remain difficult tumours to treat with poor outcomes. A spectrum of tumours of the biliary tree exist which is summarised in Table 14.1. Risk factors for cholangiocarcinoma include age (65 % cases are greater than 65 years old), smoking, primary sclerosing cholangitis (PSC, lifetime risk 5–15 %), Caroli's disease (lifetime risk 7 %), choledochal cysts (5 % will transform) and chronic intraductal inflammation (from gallstones, liver fluke and typhoid) [7]. The origin of the tumour is most commonly the perihilar biliary tree (50–60 %) but can also arise within the liver (20–25 %) and in the distal bile duct (20–25 %) or can be multifocal (5 %).

Fewer than 20 % of patients presenting with hilar cholangiocarcinoma are suitable for a potentially curative resection. Of those that undergo surgery with curative intent, 30 % are shown to have an incomplete resection. The recently updated British Society of Gastroenterology guidelines are a useful resource for the diagnosis and treatment of cholangiocarcinoma [7]. Laparoscopic ultrasound may be considered in the staging of cholangiocarcinoma and this is discussed in Chap. 10.

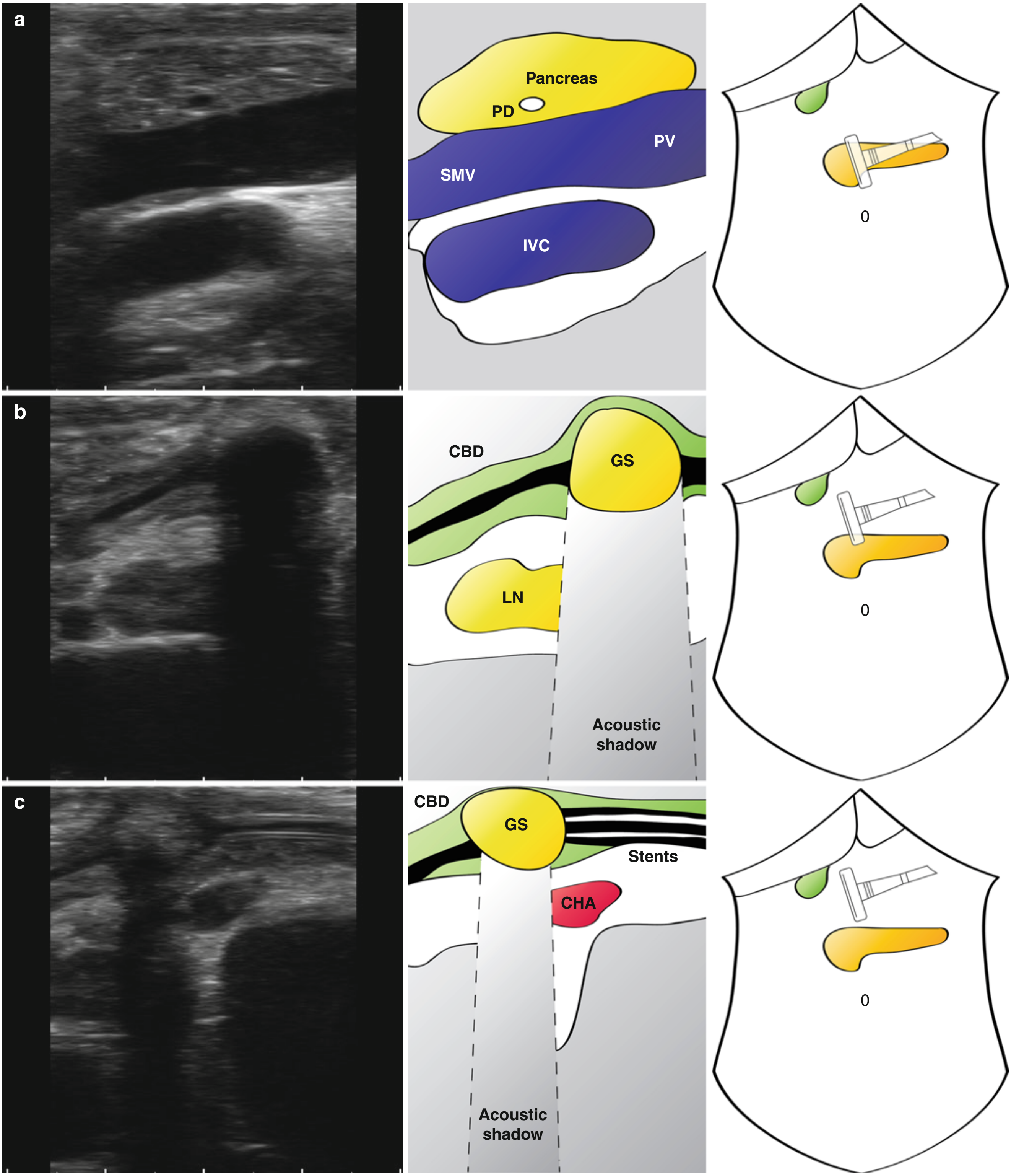

Fig. 14.5 Longitudinal views of portal pedicle in patient with biliary obstruction. The neck of the pancreas can be seen with a visible but non-dilated pancreatic duct (**a**; *PD*). A large gallstone (*GS*) is seen in a thickened common bile duct (**b**; *CBD*) (note the prominent acoustic shadow). Stents can be seen in the CBD (**c**) extending below the level of the stone (**d**) (Also see accompanying Videos 14.2 and 14.3). *SMV* superior mesenteric vein, *PV* portal vein, *LN* lymph node, *CHA* common hepatic artery

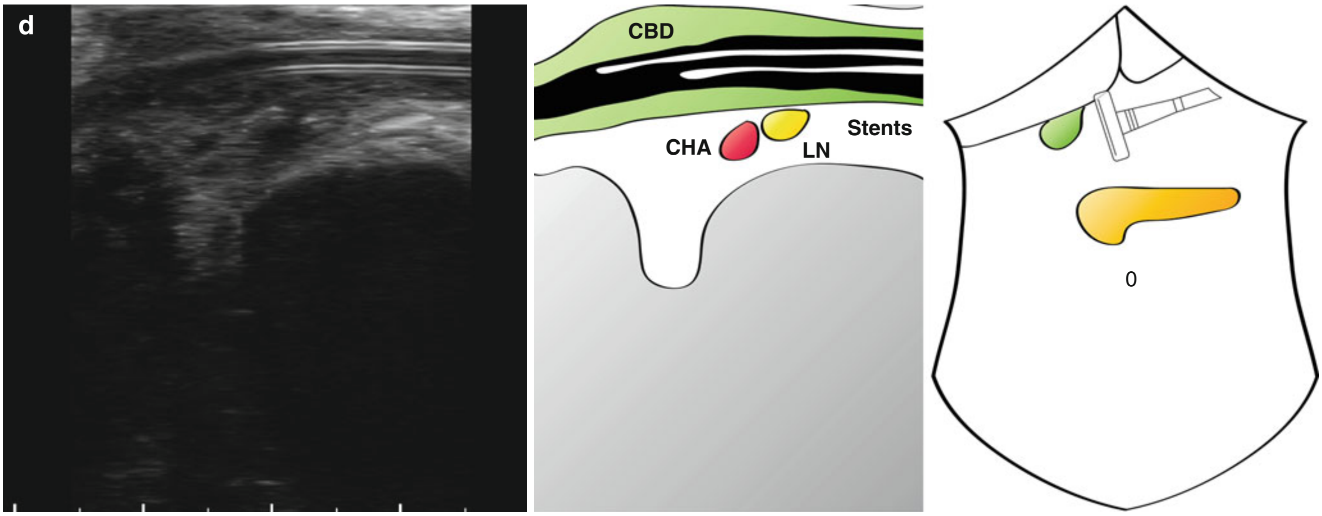

Fig. 14.5 (continued)

Accurate assessment of the extent of tumour within the biliary tree is essential prior to attempted resection. This assessment is now primarily performed using magnetic resonance cholangiopancreatography (MRCP). Triple-phase CT is also essential for assessing arterial and portal venous involvement, as well as determining the presence of distant metastases. If biliary drainage is required, then this should be performed by a percutaneous transhepatic technique to the side of the liver with least disease. The Bismuth-Corlette classification of biliary strictures provides a useful taxonomy for describing and treating hilar cholangiocarcinoma (Fig. 14.7). At laparoscopy/laparotomy, intraoperative ultrasound may be used to assess extent of disease, guiding which resection is appropriate [7]. For types I and II, en bloc resection of the extrahepatic bile ducts and gallbladder, regional lymphadenectomy and Roux-en-Y hepaticojejunostomy are appropriate. In type III disease, these approaches can be extended to include a right (IIIa) or left (IIIb) hepatectomy, which may require resection of two or three liver sections. Type IV is often not resectable, but an extended right or left hepatectomy may be possible.

Other malignant causes of high biliary obstruction include metastatic liver disease and hepatocellular carcinoma (HCC). Figure 14.8 shows images from a 52-year-old male patient presenting with segmental biliary obstruction as a result of a large HCC. The patient had no apparent background liver disease and was not jaundiced. The position of the tumour just anterior and superior to the liver hilus resulted in compression to the segment V (Fig. 14.8a) and IV (Fig. 14.8b) ducts. See also Video 14.6.

Given the position of the tumour, a portal vein embolisation was performed preoperatively with significant hypertrophy of the left lateral section. An extended right hepatectomy was able to be performed with preservation of the extrahepatic biliary tree.

Intraoperative Ultrasound in Laparoscopic Surgery

Assessment of the biliary tree by laparoscopic ultrasonography (LUS) may be required in the context of benign or malignant disease. The former is dominated by the complications of gallstones, typically when choledocholithiasis is suspected during cholecystectomy. LUS may be useful in the staging of biliary tract malignancies (see Chap. 10). The current standard of management should be to perform staging laparoscopy with LUS prior to proceeding to resection for patients with cholangiocarcinoma, as it will prevent unnecessary laparotomies in up to 30 % of patients [7]. Laparoscopic resection of bile duct cancers is still rare, although laparoscopic pancreaticoduodenectomy is now performed by enthusiastic individuals. LUS can be useful in the assessment of gallbladder wall thickening or polyps in the presence of gallstones, when malignancy has not been excluded by preoperative imaging. With confident use of LUS to exclude an infiltrating mass in the gallbladder wall, a laparoscopic cholecystectomy can be performed, avoiding an open radical cholecystectomy.

Port position is important and should be based on the most likely operative procedure to be performed. Modern laparoscopic ultrasound probes (Fig. 14.2c) have a flexible tip that can be manipulated in two planes allowing most necessary positions to be obtained from a single 12 mm port and all positions from two 12 mm ports. A common situation faced by the surgeon is using LUS to image the common bile duct during gallbladder surgery with laparoscopic bile duct

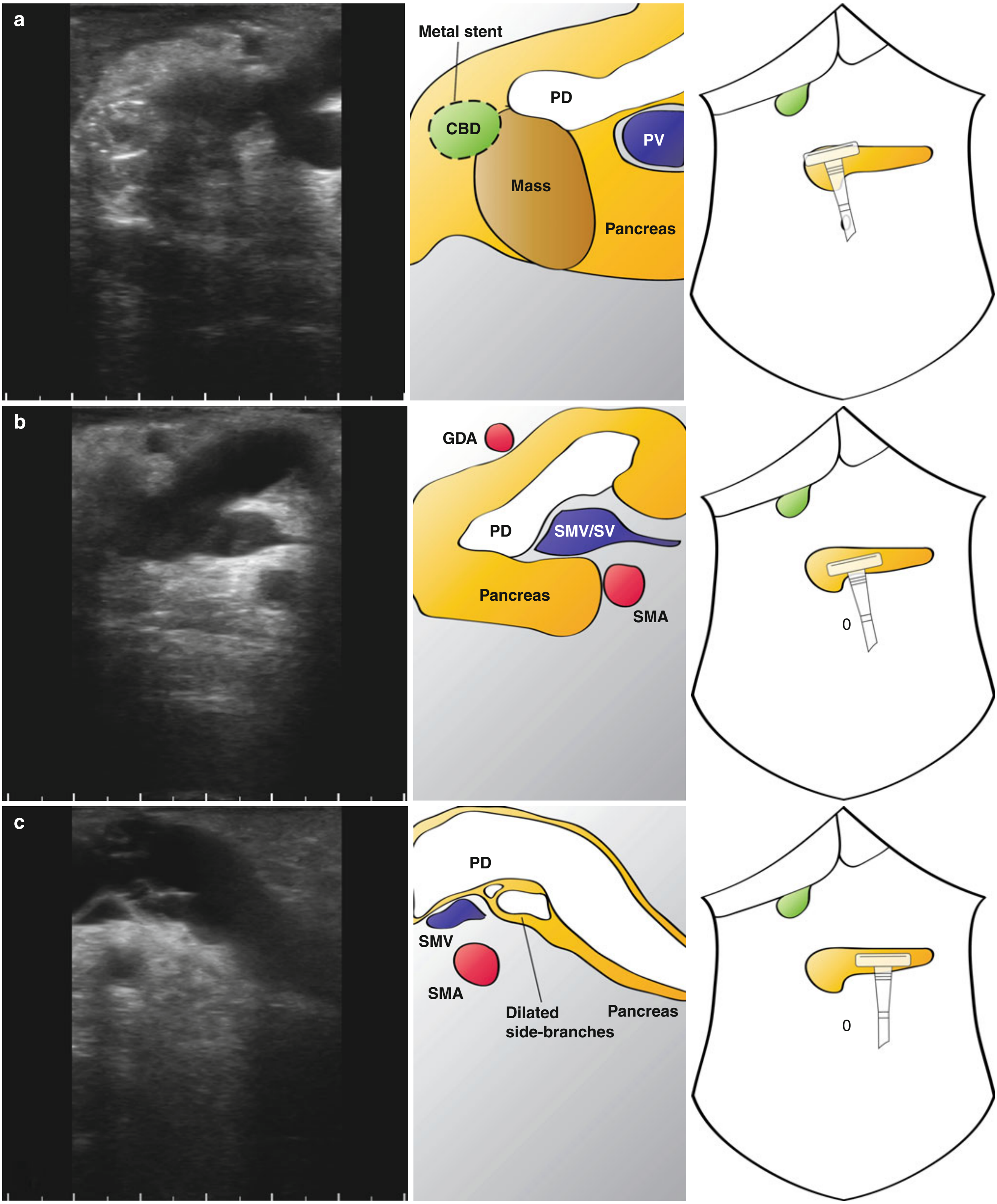

Fig. 14.6 Malignant obstruction of the biliary tree. An indistinct mass is seen in the head of the pancreas with dilatation of the pancreatic duct (*PD*) and a metal stent in the common bile duct (*CBD*; **a**). The confluence of the superior mesenteric vein (**b**; *SMV*) and splenic vein (*SV*) becomes the portal vein (**d**; *PV*) which can be followed beneath the neck of the pancreas. Both the vein and the superior mesenteric artery (**c**; *SMA*) appear free of tumour (Also see accompanying Videos 14.4 and 14.5)

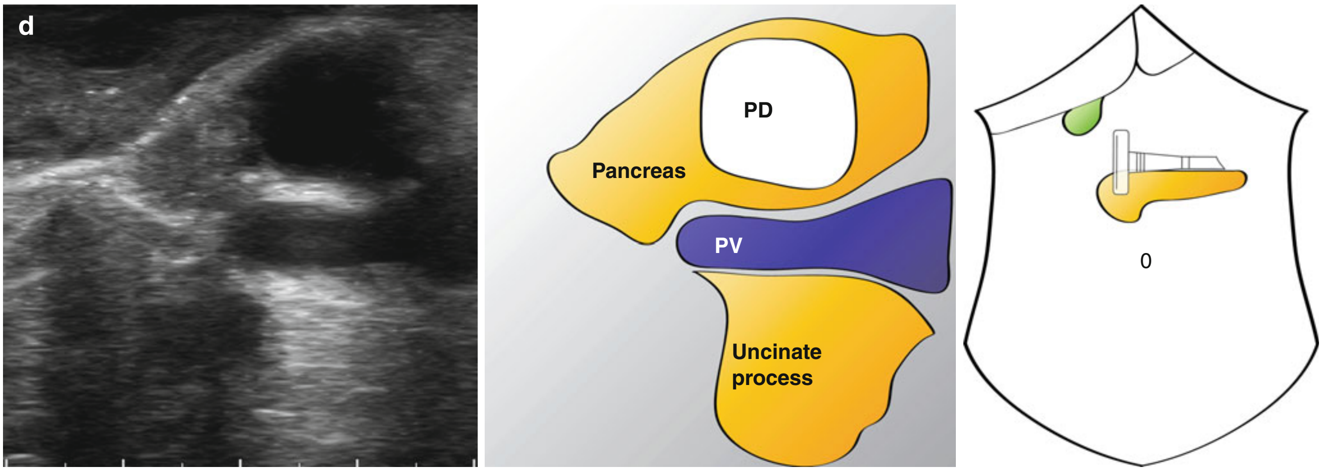

Fig. 14.6 (continued)

Table 14.1 World Health Organization (WHO) classification of biliary malignancies

	Benign	Premalignant	Malignant
Tumours of intrahepatic ducts	Bile duct adenoma	Biliary adenofibroma	Intrahepatic cholangiocarcinoma
	Microcystic adenoma	Biliary adenofibroma	Intraductal papillary neoplasm with associated invasive neoplasia
	Biliary adenofibroma	Mucinous cystic neoplasm	Mucinous cystic neoplasm with associated invasive neoplasia
Tumours of extrahepatic bile ducts		Adenoma	Adenocarcinoma
		Biliary intraepithelial neoplasia	Adenosquamous carcinoma
		Intracystic (gall bladder) or intraductal (bile duct) papillary neoplasm	Intracystic (gall bladder) or intraductal (bile duct) papillary neoplasm + associated invasive neoplasia
		Mucinous cystic neoplasm	Mucinous cystic neoplasm with associated invasive neoplasia
			Squamous cell carcinoma
			Undifferentiated carcinoma

Modified from Khan et al. [7]

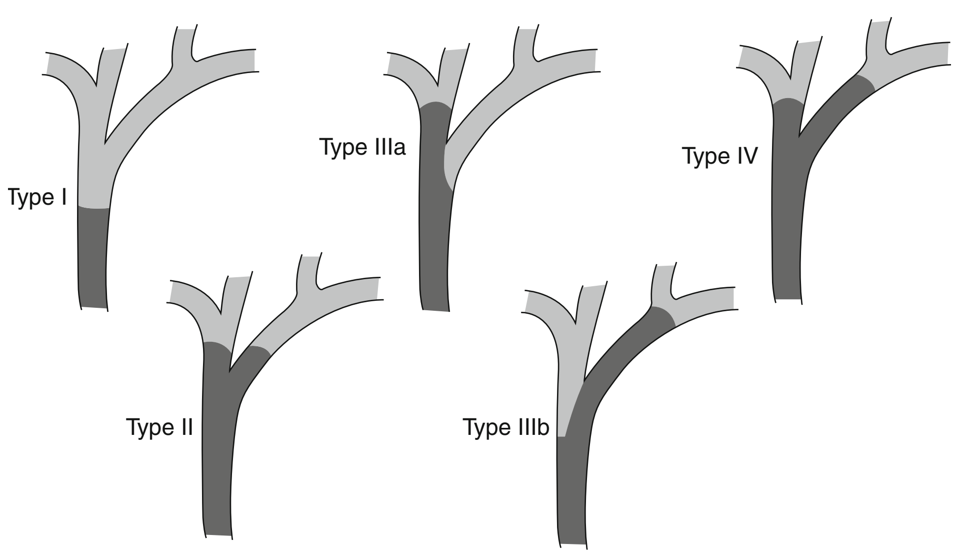

Fig. 14.7 Bismuth-Corlette classification of biliary strictures (From Khan et al. [7])

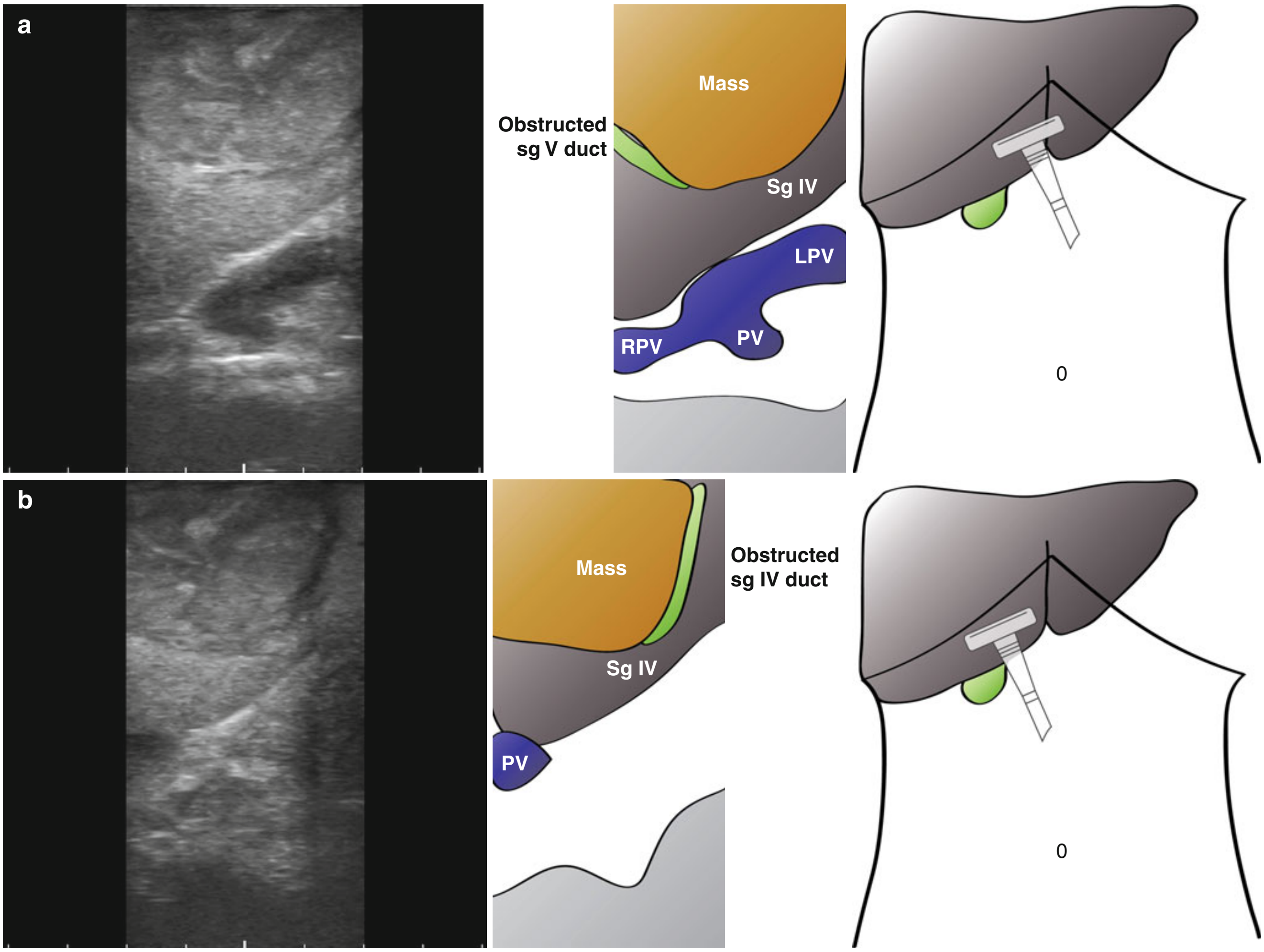

Fig. 14.8 Segmental obstruction of biliary tree by large hepatocellular carcinoma (HCC). The tumour sits anterior and superior to the liver hilus resulting in compression to the segment V (**a**) and IV (**b**) ducts. See also Video 14.6

exploration. When it is expected that a choledochotomy will be performed, the midline epigastric port site should be placed slightly lower than normal (~3 cm) to aid the laparoscopic placement of sutures to close the duct.

Figure 14.7 demonstrates a common approach to obtaining longitudinal (left panel) and transverse (right panel) views of the hepatoduodenal ligament from two 12 mm ports placed in the epigastrium and below the umbilicus. Rotation of the probe is useful and will ensure good contact with tissues. Instilling saline into the peritoneal cavity may help to improve image quality, although is usually not required. Particularly during cholecystectomy for gallstones, it is the authors' usual practice to perform ultrasonography prior to any dissection. Maintaining complete tissue planes initially ensures unimpeded views of the biliary tree. In operators with good experience of LUS, demonstrating a non-dilated biliary tree without stones usually obviates a requirement for cholangiography.

Early prospective studies showed laparoscopic ultrasound compared favourably with intraoperative cholangiography in the detection of ductal stones [8]. Contemporary series have confirmed these findings [9], suggesting that routine use of laparoscopic ultrasound can reduce the need for cholangiography [10]. It has been proposed that LUS should be considered the primary method of imaging the bile duct during laparoscopic cholecystectomy [11] and using LUS to define anatomy may reduce the incidence of bile duct injury [12]. It is accepted, however, that neither operative cholangiography nor ultrasonography obviates the need for safe dissection and neither eliminates the risk of injury to the main bile duct (Fig. 14.9).

Abnormal Gallbladder Wall Thickening with Gallstones

A 45-year-old female patient presented with longstanding right upper quadrant pain associated with eating. She had never been jaundiced and had no weight loss. A transabdominal ultrasound of the gallbladder had raised the possibility of an underlying neoplasm and revealed significant thickening of the gallbladder wall on the liver side in the absence of

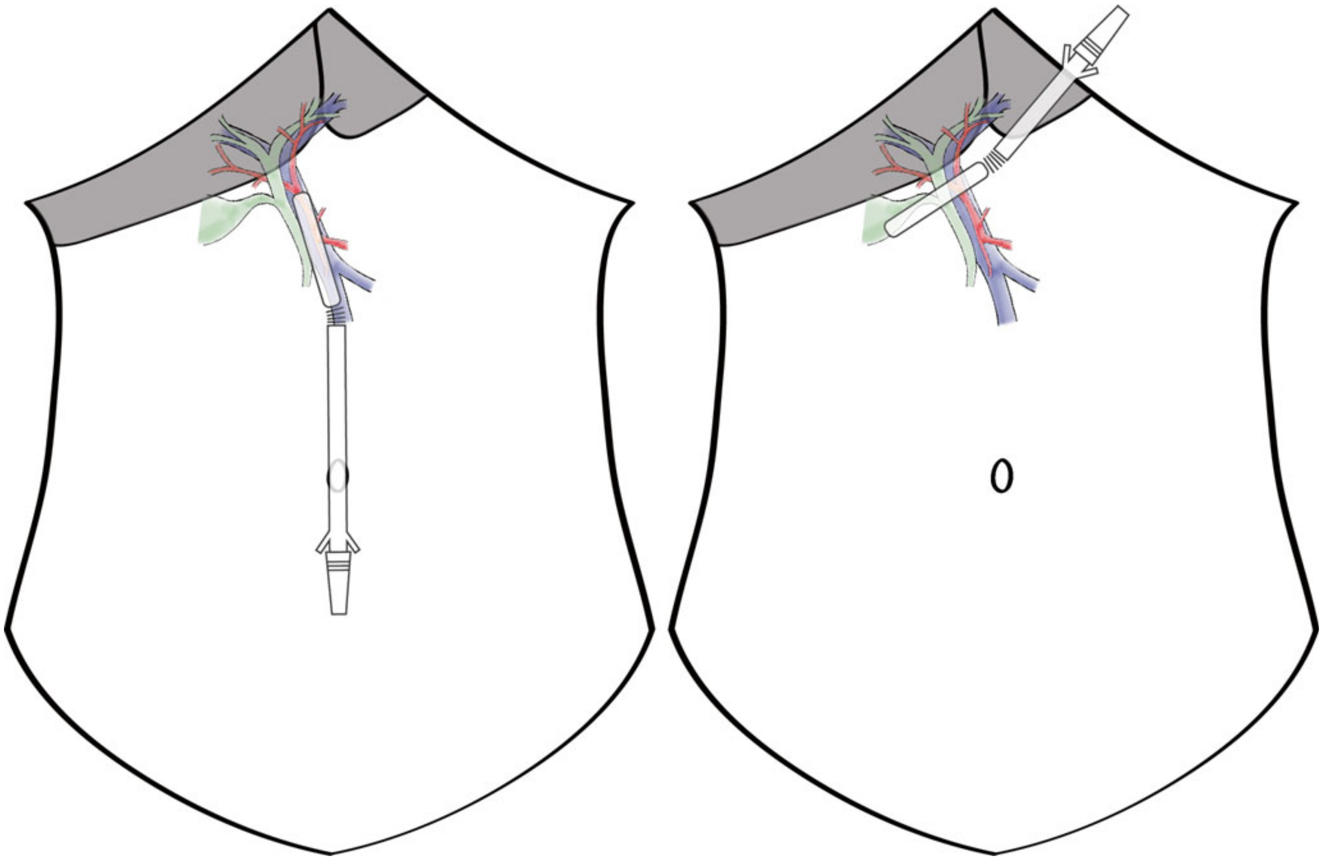

Fig. 14.9 Obtaining longitudinal (*left panel*) and transverse (*right panel*) views of the portal pedicle through a 10–12 mm umbilical and epigastric laparoscopic port

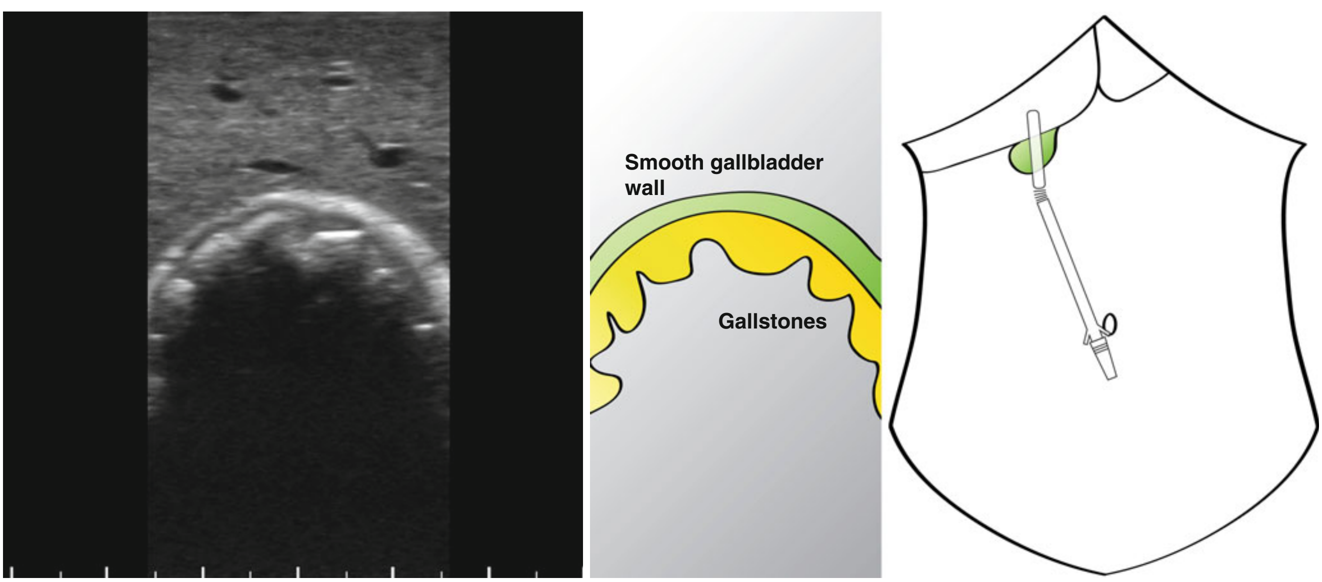

Fig. 14.10 Laparoscopic ultrasound examination of gallbladder described as suspicious on preoperative imaging. The gallbladder is seen to be smooth and relatively thin walled, with multiple gallstones present within the lumen. No infiltrating lesion was seen (Also see Video 14.7)

evidence of acute inflammation. No definite infiltrating lesion was seen and no other evidence of malignancy was present.

Laparoscopic ultrasound of the gallbladder was performed (Fig. 14.9). The gallbladder was seen to be smooth with multiple gallstones present. On careful LUS, it was clear there was no gallbladder wall lesion and a laparoscopic cholecystectomy was performed. Pathological examination confirmed no malignant lesion (Fig. 14.10; see also Video 14.7).

Conclusions

Intraoperative ultrasonography of the biliary tree remains an essential part of the armamentarium of the hepatobiliary surgeon. It allows the operating surgeon to clearly delineate anatomy (bile ducts and vessels) and make judgements on the nature and extent of disease. It is efficacious in the detection of common bile duct stones and in experienced hands obviates the need for cholangiography, avoiding exposure to ionising radiation and the potential introduction of infection to the biliary tree.

Intraoperative ultrasonography has high success rates in published studies and the advantage of the ability to repeat the examination during dissection. In general, it is quicker than alternative imaging modalities and has a lower overall cost.

There is a learning curve and the surgeon will require specific training in technique and interpretation of images. It can be technically difficult in certain patients and can be limited by the presence of air in the duodenum. In experienced hands, intraoperative laparoscopic ultrasonography can be as good as cholangiography in delineating anatomy and detecting bile duct stones. There is some evidence that it may be associated with a reduction in the risk of bile duct injury (Level II, Grade B).

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