13 Intraoperative Ultrasound During Laparoscopic Cholecystectomy

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Abbreviations

CBD	Common bile duct
ERCP	Endoscopic retrograde cholangiopancreatography
IOC	Intraoperative cholangiography
LUS	Laparoscopic ultrasound

Introduction

Ultrasound has long been used as an anatomic and diagnostic guide during surgery of the liver and biliary tree. The introduction of B-mode ultrasound technology in the 1970s allowed for real-time viewing of two-dimensional sonographic images, which facilitated its use in a variety of contexts including open cholecystectomy to evaluate the common bile duct (CBD) for stones and define ductal and vascular anatomy [1–3]. However, due to the relative ease of access to tactile manipulation and exploration of the CBD, neither ultrasound nor intraoperative cholangiography (IOC) was routinely employed during cholecystectomy in the open surgical era. The rapid adoption of laparoscopic cholecystectomy in the early 1990s was initially associated with a sharp increase in the rate of CBD injury [4]. A call to remedy this increase in severe complications, in addition to the need for a reliable method for assessing for choledocholithiasis laparoscopically, brought about a renewed interest in both intraoperative laparoscopic ultrasound (LUS) and IOC. While debate still exists regarding the utility of these modalities in decreasing rates of CBD injury, there is no doubt that they are valuable tools that have advanced surgeons' understanding and appreciation of the anatomic relationships of the biliary tree when viewed and approached laparoscopically.

Currently, LUS and IOC each exist as excellent options for both detecting CBD stones and delineating anatomy during laparoscopic cholecystectomy. LUS offers several distinct advantages including a lack of radiation and contrast dye, the ability to perform repeat examinations without the need to cannulate the cystic duct, and comparatively superior time and cost-effectiveness. Additionally, because laparoscopy is a surface imaging modality, LUS allows an assessment of structures beyond the visible surface. This chapter describes the techniques for performing LUS during laparoscopic cholecystectomy and interpreting the resulting sonographic images and additionally provides a review of the available clinical data regarding its effectiveness in comparison with IOC.

Indications

The use of ultrasound during laparoscopic cholecystectomy serves two main functions: the identification of CBD stones and the examination and confirmation of biliary and vascular anatomy. LUS can be used selectively or in a routine fashion in regard to both functions. When applied in a selective manner (similar to selective IOC), LUS is employed when there is a preoperative or intraoperative suspicion of choledocholithiasis. This evaluation can be based on a number of preoperative factors, including jaundice, elevated bilirubin or transaminase levels, a dilated CBD or common duct stones seen on transabdominal ultrasound, or an elevated lipase level or history of gallstone pancreatitis. Intraoperatively, observation of a dilated CBD or cystic duct, and/or the presence of stones within the cystic duct, can also alert to the presence of choledocholithiasis. When applied selectively for anatomic identification, LUS is used when a question exists regarding the anatomic orientation of the hepatocystic triangle, to confirm the location of the CBD and common hepatic duct in relation to the plane of dissection, or to

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confirm an aberrant ductal or vascular configuration that is identified during initial dissection.

We advocate a routine approach to the use of LUS during laparoscopic cholecystectomy, in which a LUS examination is performed during every case regardless of preoperative suspicion of choledocholithiasis or the ease of intraoperative anatomic identification. There are several advantages to a routine usage approach. It allows the surgeon to more quickly amass an extensive LUS experience and gain familiarity with the sonographic appearance of normal ductal anatomy. This allows for greater confidence in interpreting LUS images during difficult and potentially stressful cases, such as those with inflammatory conditions or aberrant anatomy. If surgical residents are assisting in the cases, routine use gives them increased exposure to the techniques of LUS and allows for enhanced cognitive correlation of the anatomy seen laparoscopically with a second visualization modality. Additionally, a protocol of routine LUS use allows the other operating room staff to become familiar with the procedure and guarantees that the necessary equipment will be available for every case.

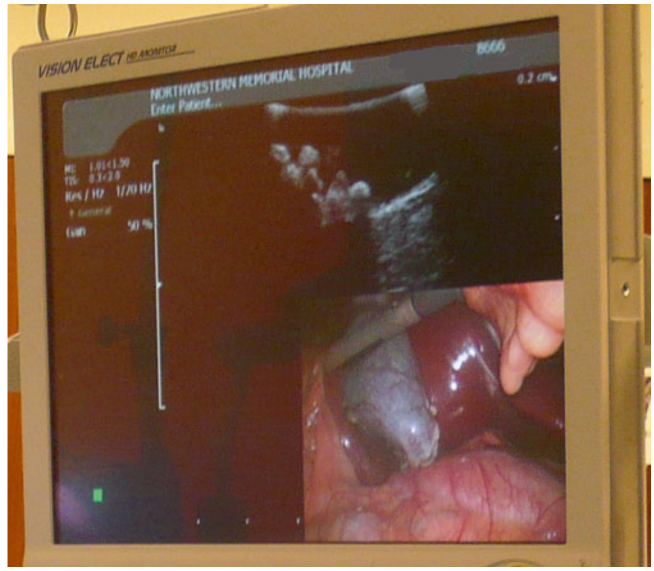

Fig. 13.1 The operating room monitor is configured to show the sonographic and laparoscopic images simultaneously in a "picture-in-picture" view

Equipment

Modern laparoscopic ultrasound probes are designed to enable efficient and reliable intraoperative use. Several probes with a 10 mm diameter that can be inserted through standard 10 or 11 mm laparoscopic trocars are commercially available [5]. These probes use primarily B-mode (i.e., two-dimensional) ultrasound with frequencies between 5 and 10 MHz [6]. Seven and 7.5 MHz are the most commonly used frequencies during laparoscopic evaluation of the biliary system. A linear or curvilinear ultrasound array between 3 and 7 cm in length is optimal.

Probes with both vertically and horizontally deflectable tips are helpful in obtaining variable viewing angles and most incorporate Doppler sonography to simultaneously overlay flow measurements onto the primary sonographic image. This feature is useful in differentiating between bile ducts and adjacent vasculature, especially when imaging the biliary tree proximal to the bifurcation of the common hepatic duct and proper hepatic artery. Modern probes can be sterilized after each usage, obviating the need for sterile probe covers, which can tear causing contamination of the operative field and are often difficult to introduce through laparoscopic trocars.

Essential to efficient use of LUS is an endoscopic operating suite equipped to transmit two images to the viewing monitors simultaneously, in a "picture-in-picture" display (Fig. 13.1). This allows the surgeon to correlate the ultrasound images with their anatomic position laparoscopically, as well as efficiently maneuver the LUS probe in the operative field. Additionally, the ability to record both the laparoscopic and sonographic images is helpful for medical documentation and retrospective teaching purposes.

LUS Technique

Initial Dissection

Although some authors have described the use of LUS during laparoscopic cholecystectomy immediately upon establishment of pneumoperitoneum, during routine cases we prefer to perform an initial dissection of the hepatocystic triangle prior to sonographic examination. Using a standard four-port technique, a combination of blunt and electrocautery dissection is used to remove all of the fibrous and fatty tissue from the hepatocystic triangle in order to establish a "critical view of safety" [7]. Reserving use of LUS until after this dissection has been performed offers several advantages. The most important is that a meticulous and thorough dissection is the most essential means to preventing CBD injury [4]. By completing this dissection prior to the LUS examination, the surgeon does not run the risk of being misled by a seemingly normal anatomic configuration on ultrasound. Additionally, opening the hepatocystic triangle via dissection allows for an easier and more complete LUS examination. The gallbladder is freed from the inferior aspects of its peritoneal attachments to the liver bed, enabling retraction of the infundibulum further laterally from the cystic duct-CBD junction. This allows for easier LUS identification and delineation of the ductal structures and enables the surgeon to manipulate the infundibulum with more mobility during LUS to create a variety of viewing angles.

If there is uncertainty regarding the anatomy during the course of the dissection to create a "critical view," LUS can be employed earlier to examine the ducts in relation to the area in question. In the case of a difficult or confusing dissection, LUS and IOC can be employed conjointly to establish a more robust anatomic examination. However, LUS and IOC should be only considered tools that provide additional information, rather than definitive evaluations. If any uncertainty exists regarding the anatomic relationships of the critical ductal and/or vascular structures after the use of these modalities, the surgeon should not hesitate to convert to an open procedure in order to ensure optimal safety.

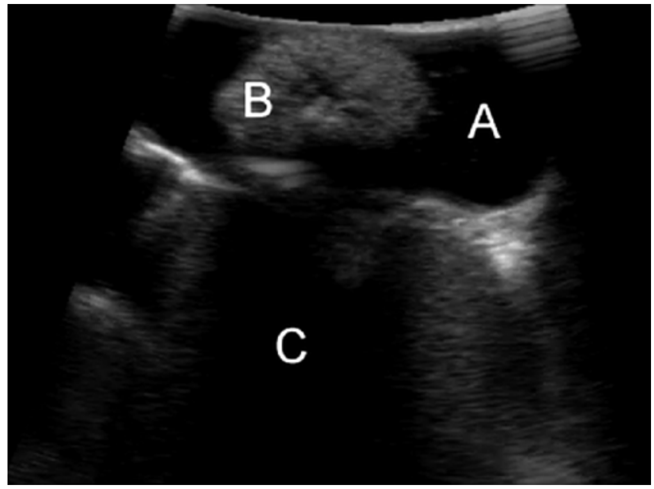

Fig. 13.2 The gallbladder is imaged, showing anechoic gallbladder fluid (*A*), a large hyperechoic stone (*B*), and sonographic shadowing (*C*) created by the stone

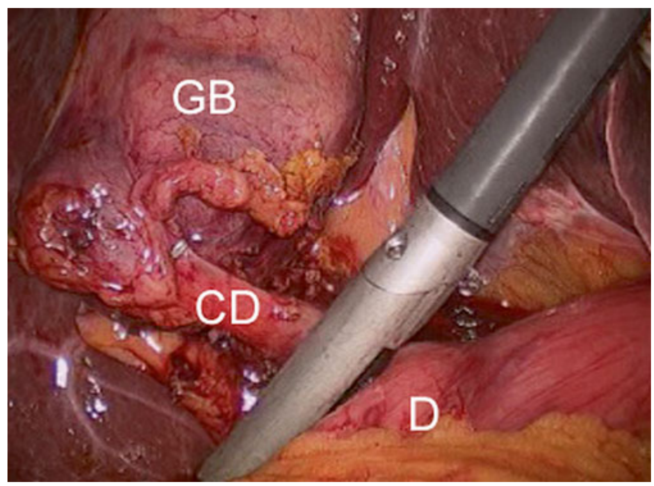

Fig. 13.3 The starting position for imaging the biliary tree when scanning through the epigastric trocar. The probe is placed over the midportion of hepatoduodenal ligament, superior to the duodenum (*D*) and inferior to the cystic duct (*CD*) and gallbladder (*GB*)

Intraoperative Scanning

Once a dissection to a "critical view" has been completed, the ultrasound probe is connected to the scanner and the monitors are switched to a "picture-in-picture" view. Using the standard "American" four-port configuration, the ultrasound probe can be introduced through either the epigastric or umbilical trocar. While we prefer the epigastric technique, each method has its own advantages and disadvantages. Often when a certain structure or segment of the CBD cannot be visualized via one trocar, the probe position must be switched, and some authors have advocated routine imaging from both orientations in every case. While we have found this to be infrequently necessary, surgeons must have a good familiarity with both techniques.

Epigastric Scanning Technique

When scanning through the epigastric trocar, the surgeon stands on the patient's left side and manipulates the probe with his or her right hand while the left hand retracts the gallbladder infundibulum using a grasper placed through the more medial of the two right-subcostal trocars. The assistant retracts the gallbladder fundus superiorly over the liver through the lateral subcostal trocar and operates the camera. The probe is inserted in the direction of the gallbladder, with the scanning array facing posteriorly. It is helpful to hold the probe with your index finger positioned on the side opposite to the scanning array in order to maintain spatial orientation during subsequent probe maneuvering.

The probe is first positioned directly over the gallbladder wall. The sonographic depth of field and gain can then be adjusted to optimize the image. Fluid inside the gallbladder should appear anechoic (i.e., black), and any stones should be hyperechoic (i.e., white) and create "shadowing" in the sonographic field beyond their location (Fig. 13.2). When scanning through the gallbladder, other pathology such as polyps can be identified. In contrast to stones, polyps will appear less hyperechoic, will not create shadowing, and will not fall to a dependent location within the gallbladder. (Refer to Chap. 5 for more detail.)

Once the sonographic view has been fine-tuned and the gallbladder inspected, the probe is placed over the midportion of the hepatoduodenal ligament with the scanning array facing posteriorly (Fig. 13.3). The probe is then manipulated in order to visualize the portal triad structures: the CBD, proper hepatic artery, and portal vein. The probe is positioned perpendicular to the hepatoduodenal ligament, and as a result, all three structures are seen in a transverse orientation and appear as circles on the sonographic image. The CBD and

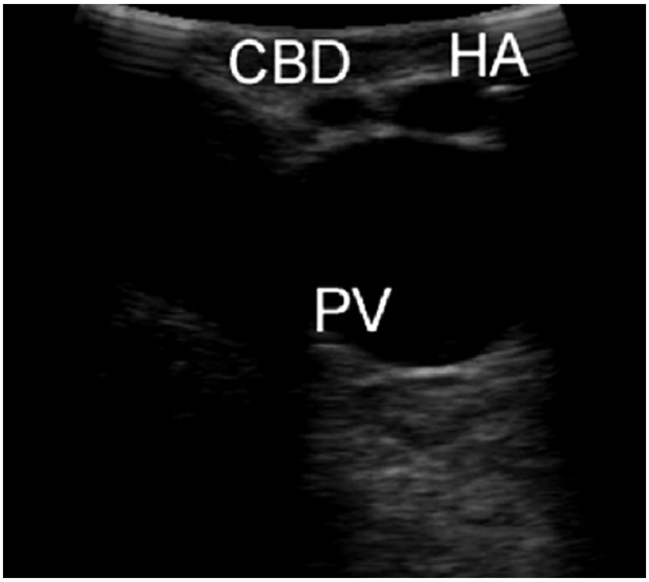

Fig. 13.4 The portal triad is visualized, creating a "Mickey Mouse head" appearance of the common bile duct (*CBD*) and proper hepatic artery (*HA*) anteriorly and portal vein (*PV*) posteriorly, all seen in transverse section

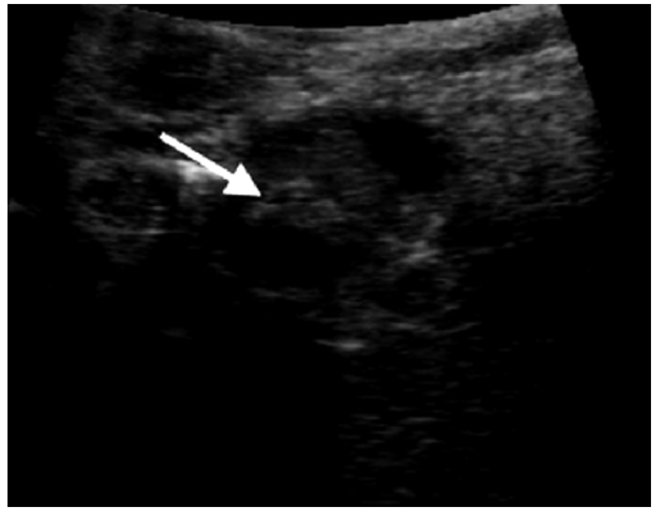

Fig. 13.5 A hyperechoic stone (*arrow*) visualized within the common bile duct

hepatic artery are usually smaller in diameter and aligned in the same anterior-posterior plane, ventral to the larger portal vein. This normal configuration creates a so-called Mickey Mouse head sonographic appearance (Fig. 13.4).

The probe is then moved caudad down the hepatoduodenal ligament and toward the duodenum in order to scan the length of the CBD. During this step the surgeon should manipulate the probe slowly, while only moving in a single plane without rotation. This will allow for visualization of the entire length of the suprapancreatic CBD and minimize the risk of skipping over a segment of duct that contains a stone. The probe should rest gently on the hepatoduodenal ligament during this step. If too much pressure is applied, the CBD will be compressed and obscured from view. Conversely, if the probe is lifted off the surface of the ligament, the acoustic window and sonographic image will be lost. This can be an issue in very thin patients in whom the hepatoduodenal ligament is devoid of fat. To remedy this problem, saline can be infused to flood the right upper quadrant and act as an acoustic coupler in order to create a better acoustic window [8]. However, in actual practice we have found this to be rarely necessary, as well as additionally time consuming.

As the CBD is sequentially imaged, the surgeon should be primarily looking for intraductal stones and sludge. Stones appear intensely hyperechoic and create acoustic shadowing on the side opposite to the scanning array (i.e., toward the bottom side of the sonographic image) (Fig. 13.5). Once detected, the diameter of a stone can be measured using the sonographic calipers function. This can be helpful in determining the most effective means of stone removal via laparoscopic or open CBD exploration or endoscopic retrograde cholangiopancreatography (ERCP). Sludge is defined as echogenic intraductal debris consisting of particles less than 1 mm in diameter and does not usually result in shadowing [9]. During our initial experience with LUS, we would attempt to treat all findings of CBD sludge with flushing via a catheter introduced into the cystic duct [10]. However, we have found this sludge to most often be of no clinical consequence and now reserve intervention for cases in which it is causing biliary obstruction or pancreatitis [11].

After imaging of its suprapancreatic portion, the CBD is followed distally as it enters the pancreatic parenchyma. As the CBD enters the pancreas, its path deviates to the patient's right side, toward the ampulla of Vater. In order to follow the duct along this course, the LUS probe is held in a stationary position abutting the superior edge of the duodenum and slowly rotated in a clockwise direction. With this motion, the CBD should be kept in a transverse orientation on the sonographic image (Fig. 13.6). The duct should be followed until its entrance into the duodenum. The muscular sphincter of the ampulla can be seen as a hypoechoic ring surrounding the distal most segment of the duct (Fig. 13.7). Additionally, the pancreatic duct can often be seen traversing the pancreas inferior to the CBD. In certain patients a long common segment of CBD-pancreatic duct exists and can be documented sonographically, which may predispose to the development of gallstone pancreatitis.

Pancreatic tissue is relatively hyperechoic compared with the fatty tissue of the hepatoduodenal ligament. This can make detection of CBD stones more difficult in the ductal segment within the pancreas. In many series, rates of complete visualization and stone detection in the intrapancreatic (distal) CBD are lower than the suprapancreatic portion, and

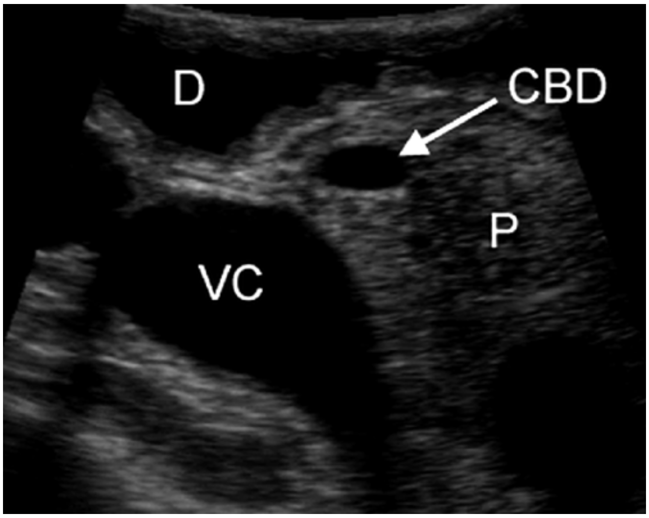

Fig. 13.6 The common bile duct (*CBD*) is seen transversing the relatively hyperechoic pancreatic parenchyma (*P*). The duodenum (*D*) anteriorly and inferior vena cava (*VC*) posteriorly are also visualized

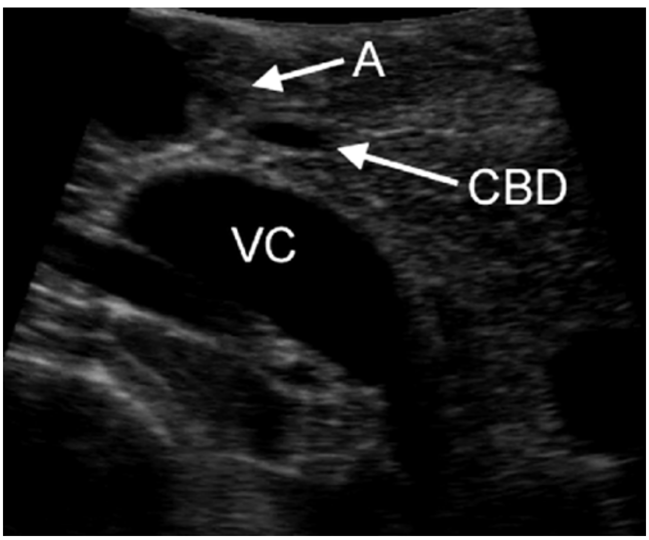

Fig. 13.7 The distal common bile duct (*CBD*) is seen just as it enters the duodenum through the ampulla of Vater (*A*). The inferior vena cava (*VC*) is seen posterior to the pancreas

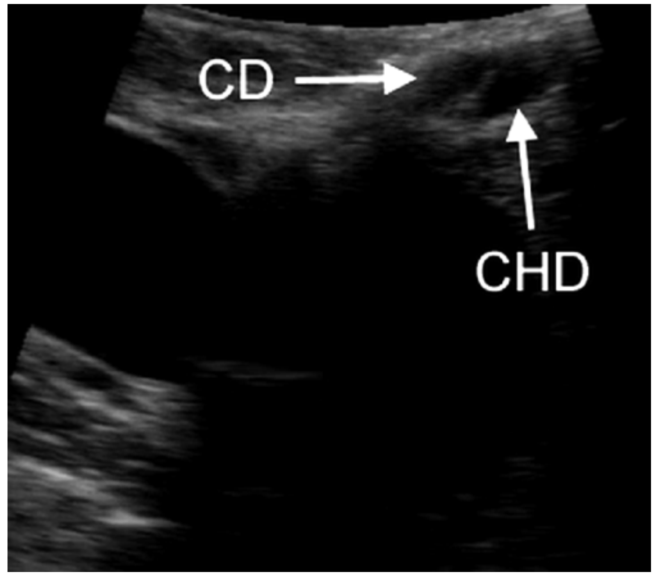

Fig. 13.8 The cystic duct (*CD*) and common hepatic duct (*CHD*) are imaged just as they join to form the common bile duct

some authors have described imaging of the distal CBD as the "Achilles heel" of LUS during laparoscopic cholecystectomy [12–14]. If visualization of the distal CBD is inadequate, several maneuvers can be performed to improve the image quality. Usually, simply placing the LUS probe directly on the duodenum with the transducer directed posteriorly and scanning while exerting gentle downward pressure (to displace air) will result in excellent imaging of the intrapancreatic CBD. If this maneuver does not provide adequate visualization, saline can be instilled into the stomach and duodenum via a nasogastric tube, creating a better acoustic window. The probe can also be repositioned through the umbilical trocar if epigastric visualization is insufficient. In patients with a narrow CBD, saline can be injected into the duct via a catheter introduced through a cystic ductotomy. This acts to dilate the CBD and may enable better visualization of distal CBD stones but requires the same ductotomy and cannulation as an IOC.

After the entire length of the CBD has been satisfactorily evaluated for the presence of stones, attention is turned to examining the anatomy of the hepatocystic triangle. The probe is returned to its original position above the hepatoduodenal ligament and then moved cephalad until the junction between the CBD and cystic duct is visualized (Fig. 13.8). The location of this junction is noted on the laparoscopic image to ensure that the anatomic assumptions made after the initial dissection to a "critical view of safety" were in fact correct. LUS can also be used to measure the length of the cystic duct, to ensure adequate space for clip application. To do this, the gallbladder infundibulum is retracted laterally, to orient the cystic duct perpendicular to the CBD. A longitudinal image of the cystic duct can occasionally be obtained and its length measured directly using the sonographic caliper function. If the anatomy does not allow for a longitudinal view, the cystic duct length can be estimated by flooding the right upper quadrant with saline and scanning down the gallbladder in transverse section until the transition from infundibulum to narrow cystic duct is observed. The distance from this point (i.e., the origin of the cystic duct) to the transverse image of the CBD to the right of the sonographic image is then measured. Using this technique, a study determined the measured cystic duct length to be within 5 mm of the length determined by either IOC or complete dissection of the cystic duct to the CBD junction in 87 % of cases [15].

After examining the cystic duct and cystic-CBD junction, the probe is slid further cephalad to visualize the common hepatic duct and right and left hepatic ducts. Often during this step the liver edge obstructs the probe when scanning through the epigastric trocar. If this occurs, the probe tip can be flexed to the right to create a longitudinal view of the hepatic ducts.

Umbilical Scanning Technique

In contrast to the transverse views seen when scanning through the epigastric trocar, the umbilical technique creates longitudinal images of the CBD. This allows for entire segments of the duct to be viewed simultaneously, and for this reason it is the preferred technique of many authors [12, 13]. However, scanning from an umbilical position requires removal and reinsertion of the laparoscope through the epigastric trocar. With the laparoscope viewing cephalad to caudad and the monitors positioned toward the head of the table, the movements of the probe are seen in a "mirror image" and are counterintuitive. This makes probe maneuvering awkward, especially for those new to the technique, and can therefore lengthen the time required to perform the examination. For this reason we prefer epigastric scanning, although surgeons should become proficient in both techniques as often a certain segment of the CBD cannot be viewed via the initial approach.

Umbilical scanning begins with the gallbladder released from both fundal and infundibular retraction. The probe is positioned over the liver and the gallbladder is visualized using segment V as an acoustic window. As in the epigastric technique, this view is used to adjust the sonographic image and the gallbladder is examined for stones and polyps. The probe is then moved medially over liver segment IV and the confluence of the hepatic ducts and hepatic arteries is visualized. Use of Doppler mode to identify arterial flow can be helpful in orienting the anatomy proximal to the branching of these structures.

Once the common hepatic duct has been identified, it is examined for stones and sludge. With the probe entering through the umbilical trocar, the hepatic duct and CBD will be seen in longitudinal section (Fig. 13.9). The more proximal portion of the duct will appear toward the left side of the sonographic image using typical settings. In order to examine the entire width of the ducts, the probe is slowly rotated back and forth. Once a segment of the duct has been scanned in its entirety, the probe is slid caudad in order to scan distally. As the CBD enters the pancreatic head, its sonographic image will switch from longitudinal to oblique, as the duct curves to the patient's right side and into the duodenum.

Once the CBD has been scanned completely for stones, the anatomy of the cystic duct-CBD junction is examined. To obtain this view, the gallbladder should be regrasped and the infundibulum retracted laterally. From the umbilical trocar, the cystic duct can be seen in transverse section and followed along its length. It can be more difficult to identify the cystic-CBD junction using the umbilical scanning technique because often the two structures cannot be visualized concurrently. This can be remedied by deflecting the probe tip to the left in order to obtain an image of both the cystic duct and CBD in transverse section, in a sense replicating the view obtained via epigastric scanning.

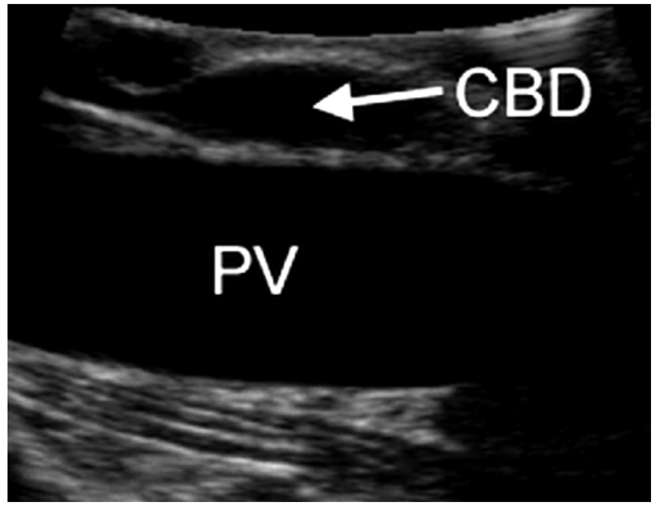

Fig. 13.9 The common bile duct (*CBD*) and portal vein (*PV*) seen in longitudinal section when scanning through the umbilical trocar

Clinical Outcomes and Comparison with IOC

As LUS and IOC are generally used for the same two purposes, detecting CBD stones and identifying biliary anatomy, it is natural that the two modalities should be compared in regard to their efficacy in these tasks. However, while it is necessary to know the relative strengths and weaknesses of each technique, surgeons should not become solely reliant on one or the other. In many instances it is necessary to use both imaging methods during a single operation in order to confirm the presence of choledocholithiasis or interpret confusing or aberrant anatomy. For this reason, routine practice with both methods is recommended, especially during a surgeon's early experience and when teaching surgical trainees.

LUS has several discrete advantages as compared with IOC. LUS does not use x-rays and thus can be performed safely during pregnancy, does not expose operating room personnel to potentially harmful radiation, and does not require assistance from a dedicated radiology technician. No contrast dye is used, which may contraindicate IOC for patients with iodine allergies. IOC also requires cannulation

Table 13.1 Success rates, LUS vs. IOC

Study	Number	Success rate (%)		Time (min)	
		LUS	IOC	LUS	IOC
Siperstein et al. [16]	300	100	94	–	–
Thompson et al. [17]	306	–	–	7	11
Machi et al. [14]	100	95	92	9	16
Birth et al. [12]	518	>99	92	7	16
Catheline et al. [18]	900	100	85	10	18
Tranter et al. [19]	135	98	90	–	–

Table 13.2 Success rates, detection of CBD stones

Study	Number	Sensitivity (%)		Specificity (%)	
		LUS	IOC	LUS	IOC
Siperstein et al. [16]	300	96	96	100	100
Thompson et al. [17]	360	90	98	100	98
Machi et al. [14]	100	89	88	100	98
Birth et al. [12]	518	83	100	100	99
Catheline et al. [18]	900	80	75	99	99
Tranter et al. [19]	135	96	86	100	99

of the cystic duct and therefore poses a risk of CBD injury if the biliary anatomy has been misinterpreted on initial dissection. LUS, on the other hand, is essentially without complication risk and unlike IOC can easily be performed multiple times during an operation to reassess the anatomy as dissection proceeds. In contrast, IOC generally affords a more comprehensive "road map" of biliary anatomy and is the first technical step in performing a laparoscopic common bile duct exploration.

In general, LUS has greater feasibility than IOC, with rates of scanning success approaching 100 % with experience (Table 13.1). Reported failures are generally due only to malfunctioning equipment, whereas IOC has a defined failure rate of approximately 10 % due to inability to cannulate small cystic ducts and obstruction of contrast passage due to cystic duct valves or tortuosity. In studies comparing the two modalities, LUS has been shown uniformly to have shorter completion times [12, 14, 17, 18].

Detection of CBD Stones

Several studies have evaluated the relative success of LUS and IOC for detecting CBD stones (Table 13.2). While both LUS and IOC were performed on each patient in these studies and the findings compared, there are still several methodological issues that must be taken into account when evaluating their results. The most important is the absence of a gold standard examination with which to compare the respective modalities and verify either the true presence or absence of stones. These authors assumed that a negative result on both LUS and IOC is indicative of a true absence of CBD stones, barring later clinical presentation of a missed stone. This assumption has the potential to underestimate the number of false-negative exams, as missed stones can pass without causing symptoms. In most studies, a positive exam (on either LUS or IOC) was investigated via either surgical CBD exploration or ERCP, in order to confirm the result and clear the duct. This methodology however has the potential to overestimate the number of false positives, as CBD stones detected intraoperatively may have passed by the time of the CBD exploration or ERCP. Additionally, in the majority of studies, the surgeon viewed both exams without blinding, thus potentially influencing the performance and interpretation of the second test (in most cases IOC) in the instance of a positive initial result. One should evaluate the following data with these limitations in mind.

Sensitivity for detecting CBD stones ranges from 80 to 96 % for LUS and 75–100 % for IOC depending on the study [12, 14, 16–19]. It is instructive to take a closer look at several of the series that found LUS to be less sensitive than IOC. Thompson and colleagues found a cumulative sensitivity of 90 % with LUS, as compared with 98 % for IOC [17]. However, when the authors subdivided their series into three time periods, they found a sensitivity of 77 % for LUS in the first cohort of 140 patients, as compared to 100 and 96 % in the latter 78 and 142 patients. This improvement was primarily due to better detection of stones in the intrapancreatic portion of the distal CBD. During the second patient cohort, the authors routinely cannulated the cystic duct and injected saline in order to dilate the CBD. In the third group of patients, the authors performed this maneuver on a selective basis, only when the distal CBD could not be adequately visualized on initial examination.

Birth and colleagues found a sensitivity of 83 % for LUS, as opposed to 100 % for IOC [12]. Similar to the previously discussed study, all of the four stones missed by LUS were in a preampullary position in the distal CBD. Three of these missed stones were visualizable by LUS after instilling 400 ml of saline into the stomach and duodenum via a nasogastric tube. However, the authors still counted these as false negatives, as they were initially missed by LUS and only discovered after performing an IOC. The results of these two studies show that both increased operator experience and adjunct maneuvers to improve distal CBD imaging can increase LUS sensitivity to a level equal or superior to IOC. However, surgeons should keep in mind that imaging the distal CBD can be a challenging aspect of LUS. If the intrapancreatic portion of the duct cannot be clearly examined, an IOC should be performed to confirm the absence of stones.

Although both modalities are highly specific in the detection of CBD stones, LUS is superior to IOC in this respect, with a nearly zero incidence of false positives. Although rare, false-positive results do occur during IOC, primarily due to the misinterpretation of air bubbles in the CBD as stones. For this reason, some authors have proposed using LUS as a confirmatory test when a CBD stone is detected on IOC [20].

Examination of Anatomy

In general, IOC provides a better delineation of biliary anatomy than LUS. This is because IOC allows the surgeon to simultaneously visualize the entire biliary tree, so that presumed relationship of the cystic duct with the hepatic and common bile ducts can be confirmed. In contrast, LUS is only able to visualize a single cross-sectional plane at a time. A complete view of the biliary anatomy must therefore be mentally constructed by correlating these two-dimensional images with their position laparoscopically. This can be challenging, especially in cases with severe inflammation or aberrant anatomic configurations. One study found that LUS was only able to detect 82 % of the anatomic anomalies found on IOC [21]. Another showed that IOC showed variant anatomy in 14 % of cases, but LUS was unable to visualize any of these [22]. While most of these variants were in the proximal biliary tree, above the cystic duct-CBD junction, these findings caution the use of LUS for interpretation of unknown or confusing anatomy. Our preference is to use IOC during cases in which a difficult dissection or unusual anatomy makes identification of the ductal relationships uncertain.

LUS does however provide several advantages over IOC with regard to anatomic examination. The ability to overlay color Doppler signaling on the sonographic image can be extremely helpful in delineating vascular from ductal structures. This can aid in confirming variations in arterial anatomy, such as a replaced right hepatic artery, that could be potentially injured during dissection of the hepatocystic triangle. LUS also provides a more accurate measure of distance than IOC, important in reliably determining ductal diameters, stone size, and the interval between two anatomic structures. In general, IOC tends to overestimate the true diameter of the CBD due to dilation after contrast injection, blurring of duct edges, and the lack of a reliable reference length on the same plane as the duct [12]. Lastly, LUS does not require cystic duct cannulation and can be used multiple times throughout an operation. These characteristics often make its use advantageous to IOC during cases of severe cholecystitis, if the ductal structures cannot be easily identified early in the dissection [23].

Several studies have addressed the issue of whether the use of routine LUS for anatomic identification leads to a decrease in rates of CBD injury and other biliary complications. Similar to IOC, there is only circumstantial evidence regarding this assertion, and the ability of either routine imaging modality to decrease CBD injury remains controversial even after 20 years of debate and study. Biffl and colleagues compared rates of biliary complications at a single institution in which two surgeons used LUS on a routine basis while the other three surgeons used IOC selectively [24]. The routine LUS group had no biliary complications, whereas the non-LUS surgeons had a 2.5 % biliary complication rate, including a 0.8 % rate of CBD injury and 0.7 % rate of retained CBD stones. This disparity occurred despite the fact that the non-LUS surgeons performed more operations on average, with a lower percentage of patients operated on for acute cholecystitis. Another multicenter study showed that over a series of 1,381 laparoscopic cholecystectomies with routine LUS, no CBD injuries occurred [25]. In these cases, use of LUS to delineate biliary anatomy was able to prevent conversion to open surgery in 6 % of cases. Additionally, the authors found that supplementary IOC was only truly necessary in 2 % of the cases.

Cost

While patient safety and the avoidance of biliary complications should be the primary concerns when evaluating the use of LUS or IOC, the cost associated with these modalities is an important secondary consideration, especially if they are to be employed on a routine basis. Although the initial purchase cost of an ultrasound scanner is substantial, it can be used during a multitude of operations across several surgical subspecialties. Several studies have shown LUS to be less expensive than IOC on a per-case basis, primarily due to the use of disposable catheters and the cost of a radiology technician during IOC. One study found that LUS cost on average $131, as opposed to $408 for IOC [26]. The authors calculated that even if IOC was used on a selective basis, its cost would average out to $157 per cholecystectomy performed and thus still be more expensive than routine LUS. Another study found a per-case cost of $362 and $665 for LUS and IOC, respectively, and that based on this differential, the cost of the ultrasound scanner itself would be recouped after 95 uses [27]. An examination of our own data based on disposable equipment and additional operating time required showed a cost savings of $145 per case with LUS as compared with IOC [10].

Conclusion

LUS provides an excellent means of examining the biliary tree during laparoscopic cholecystectomy, with the primary goals of defining anatomic relationships and detecting choledocholithiasis. Beyond achieving these objectives, LUS allows the surgeon to look within the hepatocystic triangle and the hepatoduodenal ligament prior to and during the progression of surgical dissection. This allows for a more in depth understanding of the often disorienting and potentially dangerous two-dimensional laparoscopic view of these complex anatomic structures. For this reason, we employ LUS in a routine fashion and make a point of incorporating its use into the curriculum for medical students and surgical residents. While LUS offers many advantages over IOC, the two modalities should be seen as complementary. Whether utilized in a routine or selective manner, it is essential for the modern laparoscopic surgeon to have a familiarity and facility with both techniques, in order to optimize patient safety and streamline the detection and treatment of CBD stones during laparoscopic cholecystectomy.

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