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Utility of intraoperative liver ultrasound

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Intraoperative ultrasound has become an essential component in oncologic hepatobiliary surgery. Based on this evaluation, tumor characteristics and resectability can be defined according to their sonographic appearance and their relationship to intrahepatic vasculature. This article outlines sonographic technique and its application, with the pertinent pearls and pitfalls encountered during a systematic evaluation of the liver.

The concept of intraoperative ultrasound (IOUS) was first introduced in the mid-1960s and was used primarily in evaluating choledocholithiasis. More advanced applications were not pursued until the early 1980s, secondary to the limitations of ultrasound technology, which involved large bulky transducers and a relatively poor image quality [1]. The modern concept of IOUS was first described in the mid-1980s by several authors demonstrating its clinical utility as an adjunct to biliary and pancreatic surgery [2]. One of these seminal reports included the use of IOUS for hepatectomy [3]. Since then, there has been an exponential growth in the applications of IOUS, including percutaneous ablative techniques and laparoscopic applications. Presently, IOUS is a mainstay in all oncologic hepatobiliary procedures. This article evaluates the role, technique, and recent advances in applications of IOUS.

Advantage of intraoperative ultrasound over other preoperative studies

There are many approaches available for preoperative imaging of liver tumors. Transabdominal ultrasound is noninvasive, fast, the least expensive, and the modality of choice to distinguish between obstructive and nonobstructive causes of jaundice. Transabdominal ultrasound also

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provides general information regarding the overall condition of the liver parenchyma. CT scan of the abdomen and pelvis is used widely because it provides valuable anatomic information and evaluates for the presence of extrahepatic disease. The sensitivity of detecting hepatic lesions is modest at 34% to 76%, however [4]. Spiral CT with the adjunct of arterial portography provides a better sensitivity (approximately 86%), but it subjects patients to an invasive procedure and has the same shortcomings as standard spiral CT in that neither can reliably detect lesions less than 2 cm in diameter. In addition, CT arterial portography is associated with a high incidence of false positives [5]. MRI is more sensitive and specific when compared with CT in detecting small lesions; it is also good in delineating whether a lesion is a hemangioma or a solid mass. The shortcomings of MRI include expense and longer scanning times [4].

Despite all of these technical advances, preoperative detection of preoperative liver lesions remains 60% to 80% [6–9]. As a reflection of these shortcomings, false negative rates with CT and MRI range from 40% to 70% [10,11]. Table 1 summarizes these findings [12,13], the significance of which are demonstrated by several groups citing that in 27% to 49% of cases the operative plan will be changed based on new IOUS findings [8,12,14–17]. These conclusions hold true even in the modern era of advanced preoperative staging [18]. As a result, IOUS has now become a standard part of almost all hepatobiliary cases.

Hepatic ultrasound anatomy

Normal anatomy

An understanding of normal ultrasound anatomy is essential in performing IOUS because it enables the surgeon to plan segmental resection and define resectability. Definition of the location of lesions is based on their relationship to the major portal and hepatic veins, which are used to define segmental boundaries. As described by Healy and Schroy [19], hepatic territories are defined as *Glissonian segments*, which are based on intrahepatic bile ducts. Alternatively, Couinaud [20] describes numbered liver segments. As shown in Fig. 1, the four cranial liver segments are separated by the three major hepatic veins (left, middle and right). The more

Table 1
Comparison of imaging modalities available in evaluating liver tumors

	Arteriography	CT	Preoperative ultrasound	IOUS	Exploration
Sensitivity	38%	49%–66%	41%–68%	78%–93.8%	66%–77%
Specificity	57%	94%–93%	96%–97%	94.4%–100%	94%–95%
Accuracy	39%	58%–75.8%	73%–75%	84%–94.2%	81%–94%

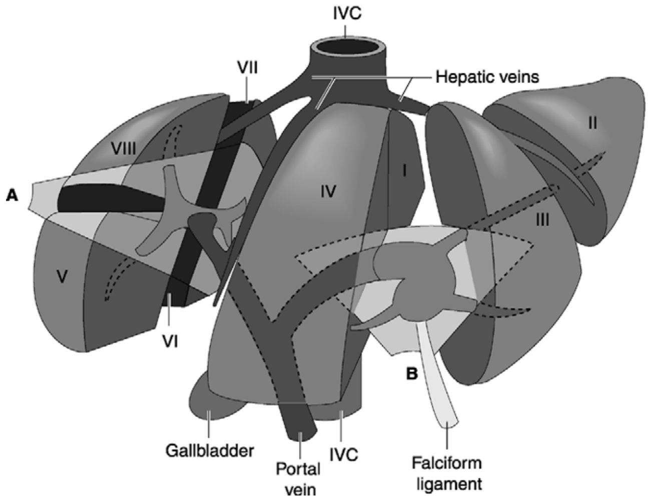

Fig. 1. Three-dimensional depiction of Couinaud segmental anatomy with its relation to the portal and hepatic veins. (Division of Physiologic Imaging, Department of Radiology, University of Iowa. Ultrasound correlation. Available at: http://everest.radiology.uiowa.edu/nlm/app/livertoc/liver/ultrasnd.html. Accessed January 2, 2004; with permission.)

caudal segments are defined by the main, left, and right portal veins as well as their major branches. There is no advantage of one system versus the other; within an institution, however, it is imperative that all members of the team (surgeon and radiologist) remain consistent in their definitions.

Aberrant anatomy

As a whole, the definitions of segments and hepatic territories may differ among institutions, but their relation to these vascular structures remains consistent. This point reiterates the value of a systematic approach in identifying and localizing lesions, similar to the manner described above. At the same time, a thorough awareness of anatomic variants is also required. Ordinarily, the hepatic veins lie in the fissures that divide the hepatic segments and do not follow the distribution of the hepatic arteries, portal veins, or bile ducts. On rare occasions, the three veins enter the inferior vena cava as a single trunk; more often, the right hepatic vein enters the cava separately while the middle and left form a single trunk or enter separately. Other occasional variants include a separate right superior hepatic vein that drains the upper portion of the liver bound by the coronary ligament, or an accessory inferior right hepatic vein that drains into the cava 2 to 3 cm distal to the hepatic vein confluence. On occasion the portal vein may be ventral to the hepatic artery, duplicated, congenitally absent, or branch intrahepatically.

Ultrasound signs of hepatic tumors

Identification of hepatic tumors by IOUS is possible because of their altered echogenicity in comparison to normal liver parenchyma. Homogeneous lesions are the most difficult to identify and may be identified only by their mass effect on neighboring vascular structures. Most tumors are either homo- or heterogeneous in comparison to normal parenchyma, and the ultrasound beam beyond the lesion may be attenuated, increased, or completely absent. Tumors are best characterized as being an-, hyper-, or hypoechoic when compared with normal hepatic parenchyma (Table 2).

Anechoic tumors may be simple biliary cysts that are round and completely anechoic with a thin, regular wall and posterior intensification of echos. Hydatid cysts also are often sonolucent lesions and they can contain multiple liquid-filled compartments, which are daughter cysts. The walls of hydatid cysts can be quite thick and IOUS will detect communication with the biliary tree. Hyperechoic tumors are most commonly benign tumors such as angiomas, but they may also represent gastrointestinal tract metastases. Less frequently, hepatocellular carcinomas (HCC) may appear hyperechoic. Finally, hypoechoic lesions are usually malignant lesions, such as metastatic lesions from extra-abdominal origin or primary HCCs. HCCs are often heterogeneous and locally extensive, with thrombosis of the portal vein branch draining the region. These lesions may be hard to identify because they often appear in cirrhotic livers that produce a markedly heterogenous image. IOUS remains superior to palpation alone, however, in that new lesions will be found in about 30% to 40% of cases [21–23]. The difficulty remains in distinguishing these lesions from dysplastic nodules and regenerative nodules [24]. Furthermore, the echogenicity of HCC lesions has been shown to correlate with histiologic findings and may guide therapy further [25,26].

Recently, ultrasound appearance of liver metastases has been correlated with prognosis following curative resection for colorectal carcinoma. In a review of 143 consecutive patients, Gruenberger and colleagues [27] demonstrated that patients with hyperechoic colorectal metastases had a significantly longer overall ($P < 0.001$) and disease-free survival ($P = 0.004$)

Table 2
Differential diagnosis of hepatic lesions based on echogenicity

Hypoechoic lesions	Hyperechoic lesions	Anechoic lesions
Hepatocellular carcinoma	Most commonly benign	Biliary cyst
Metastases of extra-abdominal origin	Gastrointestinal metastases	Hydatid cysts
Hyperplastic nodule	Hepatocellular carcinoma	
Regenerative nodule	Hemangioma	
Adenomatous hyperplasia	Fatty metamorphosis	
Small cysts		
Areas without fatty infiltration in a fatty liver		

when compared with patients with hypoechoic lesions. The authors concluded that the echogenicity of tumors may correlate with biologic tumor factors such as mucin production, vascularity, and stromal content [27]. A similar conclusion was drawn in those patients undergoing hepatic cryotherapy and receiving adjuvant therapy for hepatic metastases [28]. These data suggest that IOUS may serve as more than a diagnostic tool and emphasize the importance of echogenicity when considering resection of hepatic metastases.

Technical aspects of intraoperative ultrasound

A complete evaluation of the liver can be performed through most incisions and with minimal mobilization of the liver. There are a variety of IOUS systems available. It is also possible to use standard transabdominal equipment, but it has limitations in resolution, the near field of view, and the bulkiness of the probe [1]. IOUS is best performed using a real-time B-mode electronic scanner system with a 5-MHz or 7.5-MHz side-fire T-shaped linear array probe or a convex-array end-fire probe. Either probe can be cradled in the palm of the hand and directly applied to the surface of the liver without gel or acoustic coupling agent. The convex probe reaches all areas of the liver even if full mobilization has not been performed, and allows greater visualization of the deep liver as compared with the linear array.

Regardless of the type of system used, a methodical, systematic approach must be used in all cases. The use of overlapping fields is essential to assess completely the entire liver. We scan the liver with overlapping fields from the dome to the caudal edge, proceeding from left to right through the entire organ in a sequential manner. Scanning at a frequency of 5 MHz allows a depth of penetration of up to 10 to 12 cm, while the 7.5-MHz probe provides a shallower depth of penetration. For deeper lesions, the probe can be placed on the posterior surface of the liver. During the entire survey, the transducer is palmed in the hand of the surgeon such that it never loses contact with the surface of the liver and the surgeon is able to maintain tactile sense of location and prevent skipping areas.

To ensure thorough examination of the liver parenchyma, a systematic approach based on the intrahepatic vascular anatomy is mandatory. This examination is broken into four steps, with each stage sharing three objectives: (1) identify tumors, (2) identify tumor thrombi and vascular invasion, and (3) define the relation of these lesions with respect to the vascular anatomy. The examination starts with identifying the hepatic veins as they arise from the inferior vena cava and following each vein out to its peripheral tributary branches (Fig. 2). The next step is to identify the left portal pedical to segments 2, 3, and 4 (Fig. 3) and the right portal pedicles to segments 5, 6, 7, and 8 (Fig. 4). Finally, the porta hepatis is evaluated. By

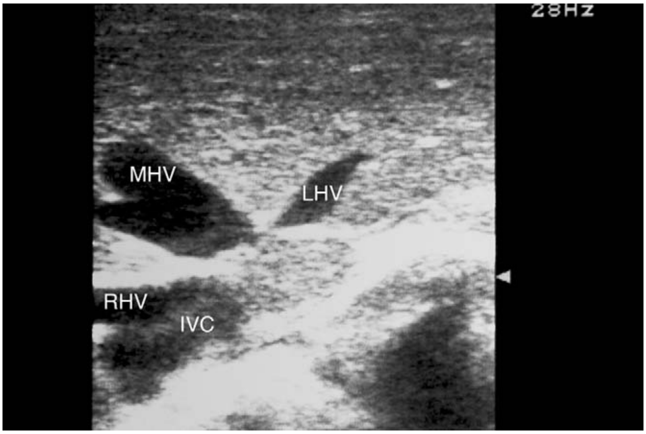

Fig. 2. Ultrasonographic view of the confluence of the right (*RHV*), middle (*MHV*), and left (*LHV*) hepatic veins with the inferior vena cava (*IVC*).

adhering to this regimen, a thorough examination of the entire liver will be accomplished. With intraoperative Doppler and color flow studies, one is able to differentiate dilated bile ducts from adjacent vascular structures during the survey. This technology can identify smaller thrombi that are frequently missed by preoperative studies [1].

If a lesion is encountered, it should be examined in both transverse and longitudinal directions to determine its full extent. Its proximity and extension to neighboring vessels should be determined, as well as the best ‘‘window’’ to visualize the lesion. Such windows are useful for guidance of

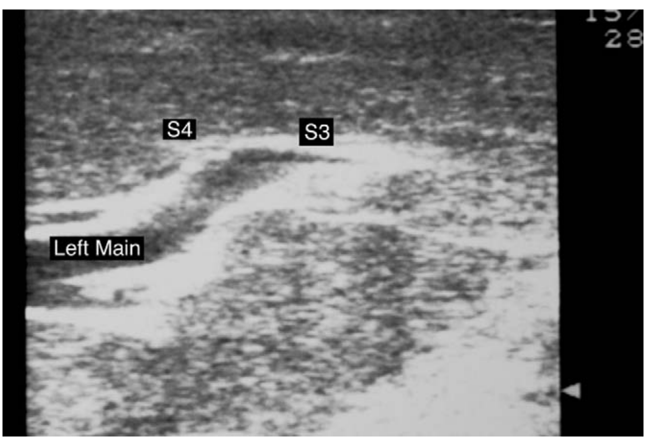

Fig. 3. Ultrasonographic view of the left portal vessel (*left main*) and its branches to the Couinaud segments 3 (*S3*) and 4 (*S4*).

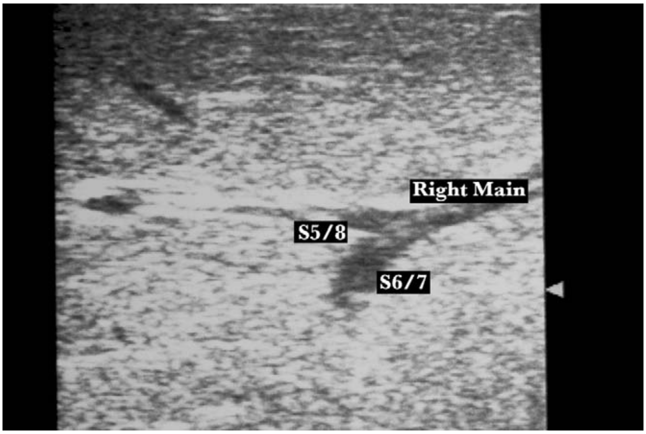

Fig. 4. Ultrasonographic view of the right portal vein (*right main*) and its branches to the Couinaud segments 5 and 8 (*S5,8*) and 6 and 7 (*S6,7*).

ablative techniques and biopsy instruments. Careful inspection of the lesion will also help differentiate malignant lesions from nonmalignant lesions. Nonmalignant lesions are typically soft, and will be deformable visually by palpation and compression when using a bimanual technique.

Particular care should be given to the detection of superficial lesions that may be missed with a 5-MHz probe because of near-field artifacts in the first 1 cm of the image. Use of higher frequency probes (7.5–10 MHz) may help compensate for this; another approach, however, is to examine the superficial surface of the dome and anterior liver surface by placing the probe posteriorly, increasing the depth of penetration, and performing a complete examination using overlapping fields. An additional method would be to place the probe in a sterile glove filled with saline to serve as a water standoff. Subcapsular lesions may still be difficult to image, but in most cases they are palpable and easily biopsied, making excessive attempts of imaging unnecessary [1].

Applications of intraoperative ultrasound

Assessment of tumor burden and localization of occult lesions

The wide acceptance of IOUS in hepatobiliary surgery is based on its sensitivity in identifying lesions and defining their relation to vital intrahepatic structures. Despite adequate imaging preoperatively, localization of lesions intraoperatively may be difficult in identifying HCC lesions and in cases of recurrences or in previously resected livers [22,23,29]. A review of 154 hepatic lesions at Deaconess Hospital revealed that 51 of these lesions were identified intraoperatively [1]. Of these 51 lesions, 65% were detected by ultrasound alone. More specific reviews have demonstrated that nearly 30% of HCC lesions are nonpalpable and that 10% to 40% of colorectal carcinoma metastases will not be palpable [26]. In 51% of these cases, the planned procedure may be changed due to IOUS findings [30]. An additional review by Brower and colleagues [31] reveals that the sensitivity, specificity, and accuracy of IOUS (78%, 100%, and 84%, respectively) are superior to those of arteriography, CT, preoperative ultrasound, and palpation. In this review, 15% to 25% of surgical plans were modified based on IOUS findings in both HCC and colorectal metastases cases [31].

Clarke and colleagues [8] have demonstrated that IOUS has detected an additional 25% to 35% of hepatic lesions while performing resection and staging of colorectal carcinomas. In a series of 250 patients, Machi and colleagues [12] demonstrated that the overall accuracy of IOUS was 94.2% compared with 73%, 75%, and 80% of preoperative ultrasound, preoperative CT scan, and surgical exploration, respectively. Similar superior results were seen for IOUS when considering sensitivity, specificity, and positive and negative predictive values. In a review of 12 studies by Kolecki and colleagues [32], the detection rate of occult metastases by IOUS alone ranged from 3.5% to 14%. These findings have led some investigators to include IOUS of the liver as a standard procedure during the primary resection of colorectal carcinomas [33–36]. In a series of 58 patients by Stone and colleagues [37], occult metastases were found in 5% of all patients undergoing primary colorectal resections. This yield was increased to 10% if limited to T3 and T4 lesions. The false-negative findings were 13% overall, 0% in T1 and T2 lesions, and 7% in T3 N0 lesions. While some groups [38] have demonstrated conflicting results, a reduction in hepatic recurrence to 7% from the expected 20% has been noted using IOUS at the time of primary resection [2,36]. These data suggest that the routine use of IOUS may improve the therapeutic impact of hepatic resection in these patients, and that proper patient selection may improve overall yield.

Evaluation of intrahepatic vasculature

Following the identification of occult lesions, IOUS can evaluate intrahepatic vessel patency, the presence of tumor thrombus, and tumor invasion. The proximity and extension of tumor into the hepatic veins, inferior vena cava, and the portal venous system influence the type and extent of resection performed. These considerations are crucial in patients with HCC because it spreads principally by way of the portal venous branches supplying the tumor. Therefore, tumor thrombi may propagate and give rise to "daughter lesions." Radical resection in these cases must include the entire portal region supplying the tumor. This is often difficult to ascertain clinically in the cirrhotic liver because of changes in topography, and is facilitated by the use of IOUS [31]. Intravascular tumor thrombus has been found in as many as 20% of cases of HCC [39]. These findings are often missed by preoperative studies [3,40].

Guidance of intraoperative and percutaneous radiofrequency ablation and other ablative techniques

Local tumor ablative techniques were developed as an alternative treatment for unresectable lesions. These techniques include ethanol injection, cryoablation, interstitial photocoagulation, and microwave tumor coagulation. The most recent technique, radiofrequency ablation, destroys tumors by generating heat within the lesion. The application of this technology was first described in 1911 [41]. Radiofrequency ablation has now become the method of choice for ablative therapy at most centers, and would not be possible for nonpalpable lesions without the use of IOUS. IOUS also provides a reliable means of obtaining pretreatment size of lesions to determine if they can be ablated and gives a sense of the extent of ablation performed posttreatment. Lesions are routinely identified using IOUS, the ablation probe is positioned under direct visualization of the ultrasound probe, and ablation is performed under direct visualization of the ultrasound probe. Once a cycle of ablation is completed, the lesion is then reaccessed to determine adequate kill and the absence of grossly viable tumor.

Laparoscopic techniques

As the use of laparoscopic and minimally invasive surgery continues to increase, the role of IOUS during laparoscopy has become even more important. Laparoscopy has obvious shortcomings in evaluating the liver because it eliminates the surgeon's ability to palpate structures and lesions. IOUS attempts to restore some of this tactile feedback while providing important information as seen in open procedures. The technique of laparoscopic ultrasound is well described [42,43] and it has a better sensitivity than most preoperative studies [44–47]. When compared with open IOUS, laparoscopic IOUS has a similar sensitivity and specificity [48]. Some authors have suggested the routine use of laparoscopic IOUS in laparoscopic colorectal cancer surgery [49] and before laparotomy for planned hepatic resection [50]. In such cases with known hepatic disease, nearly 64% of patients could be spared a laparotomy incision based on laparoscopic findings [50,51].

Several series have also suggested the role of laparoscopic ultrasound in the ablation of hepatic lesions [52–54]. The advantages of this technique over percutaneous ablation include direct visualization of the peritoneal cavity, detection of occult lesions, and decreased risk of injury to adjacent organs. In comparison to open ablation, laparoscopic techniques may require more advanced technical skills and localizing lesions in segments

7 and 8 may be more difficult. To overcome this difficulty, a hand-assisted technique has been suggested [52]. When technically feasible, however, the laparoscopic approach has the benefit of a shorter recovery and greater patient satisfaction.

Summary

Intraoperative ultrasound has become an essential tool for the surgeon in the field of hepatobiliary surgery. No preoperative study has been able to duplicate the sensitivity and specificity of IOUS in the identification of occult lesions. With recent improvements in technology, IOUS has now become an indispensable means of defining the extent of disease and respectability, and providing a guide to anatomic and nonanatomic hepatic resections and minimally invasive and percutaneous ablative techniques.

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