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Pictorial essay

Laparoscopic ultrasonography for abdominal tumor staging: technical aspects and imaging findings

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Abstract

Since 1992 diagnostic laparoscopy combined with laparoscopic ultrasonography has been performed in our center in more than 300 patients for staging of tumors of the liver, bile ducts, pancreas, esophagus, and gastric cardia. In this article our experience with laparoscopic ultrasonography for abdominal tumor staging is described, with particular attention for the technical aspects, imaging findings, limitations, and pitfalls.

Key words: Laparoscopy—Laparoscopic ultrasonography—Neoplasm staging—Technique.

Diagnostic laparoscopy has become an established technique for staging of abdominal tumors because of its high accuracy in diagnosing peritoneal metastases and small liver surface metastases [1–4]. Despite the benefit of diagnostic laparoscopy and radiologic staging, small intrahepatic metastases, small lymph node metastases, and advanced local tumor extension will still be missed in a number of cases.

The development of dedicated laparoscopic ultrasonography (LUS) probes that can be inserted into the peritoneal cavity via laparoscopy trocars has provided additional possibilities for laparoscopic staging to reduce the abovementioned diagnostic failures. Several types of linear array and sector scan probes with a rigid or flexible tip and frequencies ranging from 5 to 10 MHz are currently available, some with (color-) Doppler facilities [5, 6]. These probes allow high-resolution imaging of the liver, bile ducts, pancreas, abdominal ves-

sels, and lymph nodes with the transducer very close to the organ of interest and without interference of bowel gas or the abdominal wall. With the rapid development of laparoscopic technique and the increasing number of diagnostic and therapeutic laparoscopic procedures performed, the availability and application of LUS are also becoming more widespread.

Since 1992 diagnostic laparoscopy combined with LUS has been performed in our center for staging of tumors of the liver, bile ducts, pancreas, esophagus, and gastric cardia in more than 300 patients. We have reported the initial benefit of this technique to avoid unnecessary laparotomies before [7–9]. In this article in particular, the technique is described to perform LUS, the typical imaging findings of LUS, and the technical limitations and pitfalls that we have experienced during LUS for abdominal tumor staging.

Technique and imaging findings

General

Routine diagnostic laparoscopy was performed under general anesthesia by a surgeon using 3 trocars (10/11 mm) at umbilical and left and right subcostal positions, and LUS was performed consecutively in the same session. In all patients, an Aloka SSD-650 CL ultrasonography (US) unit and a rigid 7.5 MHz linear array LUS probe (UST-5522-7.5, Aloka, Tokyo, Japan, probe length: 40 cm, probe caliber: 10 mm, field of view: 38 mm) were used. Depending on the organs to be investigated, LUS took 10–25 min. The LUS images were interpreted by a radiologist who was present during

Fig. 1. Left liver lobe (L), scanned from the inferior surface. The white line (arrows) represents the anterior surface of the liver. Liver parenchyma, seen below the white line is the mirror-image artifact (A), due to reflection of the ultrasonic beam by the pneumoperitoneum. HV = left hepatic vein.

Fig. 2. Sagittal scan of the right liver lobe. The most cranial part is scanned through the saline (S), which is installed in the right subphrenic space, enabling visualisation of a 1.3-cm isoechoic metastasis (M) of a colon carcinoma.

every examination. Initially, the LUS probe was sterilized with glutaraldehyde before insertion into the abdominal cavity. In the second part of the series—after the use of glutaraldehyde was prohibited by the hospital's hygiene committee—the LUS probe was wrapped in a sterile polyethylene cover sheet, which was partly filled with sterile ultrasonic gel, before insertion into the peritoneal cavity. Image quality was not adversely affected by using this method.

Liver

The liver was best studied by placing the LUS probe directly on the left and right lobe through the umbilical and left subcostal trocars and gently sliding and rotating the probe on the liver surface. Parts of the left and right liver lobe could be scanned from both the anterior and posterior surface, which was especially useful in patients in whom part of the liver was obscured by air artifacts, caused by aerobilia after endoscopic papillectomy or insertion of a bile duct endoprosthesis (Fig. 1). With the rigid LUS probe, imaging of the dome of the liver initially was a problem. This could be overcome by installing between 1 and 3 l of isotonic saline into the right subphrenic region and scanning the highest part of the liver through the fluid (Fig. 2). In many cases, contact between the LUS probe and the liver surface could be improved by lowering the inflation pressure and partly deflating the pneumoperitoneum. The possibility to compress focal lesions could be studied in many cases by exerting pressure on a lesion with the LUS probe or a biopsy forceps. This is a typical finding for hemangiomas as previously reported in intraoperative US, and, in our experience, this also applies to LUS [10] (Fig. 3A,B). Small hemangiomas were usually homogeneously hyperechoic and could in many cases be dif-

ferentiated from hyperechoic metastases using the compression technique. Suspected intrahepatic lesions were biopsied percutaneously by positioning the biopsy needle (Rotex® screw-tip needle or Tru-cut® needle) next to the LUS probe under laparoscopic observation and puncturing the lesion under ultrasonographic guidance.

Focal lesions as small as 3 mm were detected by LUS. The LUS appearance of focal liver lesions was similar to findings in transabdominal US. Small cysts could be distinguished from solid lesions by the usual US criteria. Small liver metastases were usually hypoechoic compared to normal liver parenchyma or isoechoic with a hypoechoic halo (Figs. 2, 4). Occasionally, metastases were hyperechoic. Primary liver tumors (benign or malignant) or large liver metastases were either hypoechoic, isoechoic, or hyperechoic compared to normal liver parenchyma.

Using the present technique and equipment, LUS of the liver showed certain limitations. It was difficult to take LUS-guided biopsies of small lesions, and, in some cases, it was impossible to obtain biopsies of very small deep-seated lesions. Because of the limited penetration depth of the 7.5 MHz transducer, imaging of the deeper parts of the right liver lobe in patients with extensive fatty changes was sometimes insufficient and the presence of small lesions in this area could not be excluded. Furthermore, in many cases LUS could not differentiate solid benign lesions from malignant lesions (e.g., adenoma or focal nodular hyperplasia from hepatocellular carcinoma or metastases of colorectal carcinoma).

Bile ducts and gallbladder

The intrahepatic bile ducts, the bifurcation, and proximal common bile duct were best imaged by placing the probe on the anterior surface of segment 4 of the liver.

Fig. 3. **A** Scan through segment 6 of the right liver lobe shows a hyperechoic hemangioma (*H*) measuring 2 cm. **B** Same hemangioma (*H*) as in **A**. During compression with the laparoscopic ultrasonography probe the hemangioma becomes flat. After release of the pressure, the hemangioma refills with blood and can be seen to expand during real-time ultrasonography.

Fig. 4. Scan of the right liver lobe shows a 4-mm isoechoic metastasis with a hypoechoic halo of a cholangiocarcinoma (arrows).

Fig. 5. Sagittal scan through segment 4 of the liver shows the proximal part of the hepatoduodenal ligament with the common bile duct (*C*), the portal vein (*P*), and the right hepatic artery (*R*), which crosses

between the common bile duct and the portal vein. Below the liver, the inferior vena cava (*I*) is seen.

Fig. 6. Longitudinal scan of the hepatoduodenal ligament with the laparoscopic ultrasonography probe placed directly on the ligament shows the common bile duct (*CBD*) and the cystic duct (*CD*). The wall of the common bile duct is thickened, due to cholangitis. A polyethylene bile duct endoprosthesis (arrows) is seen as a double hyper-echoic line and is malpositioned with the tip in the cystic duct.

Fig. 7. Transverse scan through the normal pancreatic head shows the distal common bile duct (*CBD*) and the pancreatic duct (*PD*). *S* = superior mesenteric vein; *D* = duodenum.

The umbilical and subcostal trocars were used alternately to obtain longitudinal and transverse scans (Fig. 5). The midpart and distal common bile duct were best visualized by positioning the probe on the hepatoduodenal ligament and on the stomach or duodenum in the pancreatic head region (Figs. 6, 7). The gallbladder could be imaged either through the liver or by placing the probe on the gallbladder itself. A polyethylene bile duct endoprosthesis, when present was easily recognized as a double hyperechoic line and could be used as a landmark to quickly localize the common bile duct (Fig. 6).

Bile duct dilatation, inflammatory bile duct thickening, and localized bile duct tumors as small as 1 cm were well seen (Figs. 6, 8, 9). Tumors of the bifurcation

or the proximal common bile duct were usually isoechoic or almost isoechoic to liver parenchyma. Small bile duct concretions were distinguished from tumors by the usual US criteria (hyperechoic concretion, acoustic shadowing).

We experienced a few limitations and pitfalls in LUS of the biliary tract. In some patients, tumor extension of a cholangiocarcinoma into the left hepatic duct was difficult to evaluate because the falciform ligament both prevented the LUS probe from being maneuvered into an optimal scanning angle and presented acoustic shadowing. This could be partly resolved by scanning not only from segment 4, but also from segments 2 and 3 to the left of the falciform ligament. In some other patients, LUS was not able to differentiate a small

Fig. 8. Sagittal scan through the liver shows a hilar cholangiocarcinoma (*T*) isoechoic to the liver parenchyma, measuring 1 cm. A hyperechoic interface (*arrows*) is visible between the tumor and the portal vein (*PV*); there is no tumor invasion of the portal vein. *R* = right hepatic duct; *RHA* = right hepatic artery.

Fig. 9. Transverse scan through the liver shows a 1.5-cm cholangiocarcinoma (*T*) of the common bile duct at the confluence with the cystic duct (*CD*). An endoprosthesis (*arrowheads*) runs through the tumor. *PV* = portal vein.

Fig. 10. Transverse scan through the normal pancreas with the laparoscopic ultrasonography probe placed on the stomach shows the pancreatic duct (*PD*) in the body of the pancreas, the splenic vein (*VL*), and the superior mesenteric artery (*AMS*). *H* = head of the pancreas.

Fig. 11. Transverse scan through pancreatic head (*P*) and duodenum shows a 1-cm gastrinoma (*G*) in the duodenal wall, adjacent to the pancreatic head. The duodenum is partly filled with saline (*S*) through

a nasogastric tube, improving visualization. Part of the duodenum contains air (*arrowheads*) and cannot be visualized because of acoustic shadowing (*A*).

Fig. 12. Transverse scan through the pancreatic head shows a 2-cm hypoechoic pancreatic ductal adenocarcinoma (*T*), adjacent to the superior mesenteric vein (*SMV*) (*arrowheads*). A thin rim of tissue is visible between the tumor and the vessel, and the tumor does not invade the superior mesenteric vein. The superior mesenteric artery (*SM*) is clearly free of tumor.

Fig. 13. Transverse scan through the uncinate process of the pancreas shows a 2-cm hypoechoic pancreatic ductal adenocarcinoma (*UP*), which invades the superior mesenteric vein. The hyperechoic interface between the tumor and the superior mesenteric vein (*VMS*) is obliterated (*arrowheads*). The superior mesenteric artery (*AMS*) is free of tumor. *A* = aorta.

cholangiocarcinoma from an intraluminal inflammatory mass with bile sludge, and a false-positive diagnosis of a tumor was made by LUS.

Pancreas

The pancreas, the pancreatic duct, and the intrapancreatic common bile duct were consistently well visualized by placing the LUS probe on the stomach and duodenum

(Figs. 7, 10). Tumors in the pancreatic head region were best imaged through the left and right subcostal trocars, producing transverse or oblique sections of the pancreas. In some cases, filling the stomach and duodenum with isotonic saline through a nasogastric tube was helpful in visualizing a small tumor (Fig. 11).

In patients with tumors of the bile ducts or pancreas, tumor ingrowth into the portal venous system could be closely studied by using different trocars to obtain trans-

Fig. 14. Transverse scan through the caudal part of the pancreatic head shows a 1.3-cm distal cholangiocarcinoma (*T*), growing into the pancreatic head. *D* = duodenum; *G* = gastrooduodenal artery.

Fig. 15. Transverse scan through the pancreatic head shows a 2.5-cm hypoechoic pancreatic ductal adenocarcinoma (*T*). A small side branch (arrowheads) of the superior mesenteric vein (*S*) is encased by the tumor. The superior mesenteric vein itself is clearly free of tumor.

Fig. 16. Longitudinal scan of the hepatoduodenal ligament through the liver shows a benign lymph node (*L*) adjacent to the hepatic artery (*H*). Note the longitudinal shape and echogenicity of the lymph node. *C* = common bile duct; *P* = portal vein.

Fig. 17. Transverse scan of the celiac axis (*CA*) in a patient with pancreatic carcinoma shows lymph nodes (*LN*) at the bifurcation of

hepatic artery (*HA*) and splenic artery (*SA*). Although the appearance of these nodes is not typical of malignancy, they should be biopsied because of their location to exclude lymph node metastases. *A* aorta.

Fig. 18. Transverse scan of the hepatoduodenal ligament through the liver shows an enlarged, benign lymph node, with a long axis diameter of 1.5 cm and a hyperechoic hilum (arrowheads). *P* = portal vein.

Fig. 19. Transverse scan through the compressed stomach of a patient with carcinoma of the gastric cardia. A metastatic lymph node (*L*), measuring 1 cm is seen adjacent to the left gastric artery (between arrowheads). Note the round shape, hypoechoic appearance, and absence of a hyperechoic hilum.

verse sections of the vessel studied. The sagittally oriented superior mesenteric vein was best evaluated from the left subcostal trocar, while the more obliquely oriented portal vein was best imaged from the right subcostal trocar.

Pancreatic ductal adenocarcinomas, distal cholangiocarcinomas and carcinomas of the papilla of Vater as small as 1 cm were imaged, in most cases as a hypoechoic mass, compared to normal pancreatic parenchyma (Figs. 12–14). Small neuroendocrine tumors were seen in the pancreas (mostly insulinomas) and du-

odenal wall (mostly gastrinomas) as sharply margined masses with higher echogenicity than adenocarcinomas (Fig. 11). Signs of tumor infiltration into the portal venous system were loss of the hyperechoic interface between the vessel lumen and the tumor with or without the tumor protruding into the vessel lumen, stenosis, and vascular occlusion (Fig. 13) [8].

In LUS of the pancreas, also some limitations and pitfalls were encountered. Like most pancreatic adenocarcinomas, inflamed pancreatic tissue was hypoechoic compared to normal pancreatic parenchyma at LUS,

and, in several cases, it was difficult to differentiate focal pancreatitis or obstructive pancreatitis from a malignant tumor. Determining the exact relationship between portal vessels and a tumor was impossible when—for instance, due to adhesions from previous surgery—the correct imaging planes could not be obtained. Side branches of the superior mesenteric vein that were encased by a pancreatic head tumor mimicked interruption of the hyperechoic plane around the superior mesenteric vein itself, suggesting a false-positive diagnosis of tumor ingrowth into this vessel (Fig. 15). The portal venous system was easily compressed by the LUS probe and, therefore, one should be careful in diagnosing stenosis of the portal vein or superior mesenteric vein with LUS.

Lymph nodes

Lymph nodes in the hepatoduodenal ligament and at the celiac axis were well imaged with LUS, either through the left liver lobe or with the LUS probe placed directly on the hepatoduodenal ligament or celiac axis (Figs. 16, 17). Lymph nodes at the celiac axis could be biopsied laparoscopically after localization with LUS. In some patients with carcinoma of the gastric cardia, LUS was helpful in differentiating enlarged lymph nodes at the celiac axis in the retroperitoneum from nodes at the lesser curvature of the stomach, which can have important therapeutic consequences.

LUS findings of lymph nodes were similar to percutaneous US features. A longitudinal shape and presence of a hyperechoic center, representing hilar fat were often seen in benign nodes, while a more rounded shape, a hypoechoic appearance, and loss of the hyperechoic center were more often seen in metastatic lymph nodes (Figs. 16, 18, 19). In most patients with bile duct obstruction or with a bile duct endoprosthesis, enlarged lymph nodes were seen in the hepatoduodenal ligament, especially adjacent to the hepatic artery. In most patients, these were not biopsied because of their location (within resection margins) or because of a benign appearance; However, as reported in the literature, there is some overlap between benign and malignant US features of lymph nodes, and in many patients no certain characterization of enlarged lymph nodes was possible by LUS [11].

Esophagus and gastric cardia

Most tumors of the gastric cardia were visualized as an inhomogeneous mass and were more or less isoechoic to the stomach. The relation of the tumor to the abdominal aorta was well visualized in most cases. Tumor infiltration of the diaphragm could not be well evaluated

by LUS. Esophageal tumors were in most cases not visualized with LUS.

Except for the already mentioned possibility to detect and differentiate lymph node metastases at the lesser curvature of the stomach from those at the celiac axis, no other relevant local staging information was obtained by LUS in this group of patients.

Conclusion

The potential value of LUS in liver tumor imaging consists mainly of increased small lesion detection. It can also prove small cysts and can, in many cases, distinguish small hemangiomas from metastases by means of the compression technique. However, its value in characterizing large, solid, liver tumors is limited, and currently LUS cannot add information to noninvasive staging by transabdominal US, computed tomography (CT), or magnetic resonance imaging (MRI) of these lesions. In the future, the use of color-Doppler probes may play a role in improving lesion characterization. A limitation of the 7.5 MHz LUS probe, currently used by us is the limited penetration depth in patients with fatty livers. This problem might be overcome by using a transducer which is also equipped with a 5-MHz facility to increase the penetration depth of the ultrasonic beam. The problem of the impossibility to take biopsies of very small, deep-seated lesions should in the future be solved by the development of specially designed puncture devices. LUS probes with a flexible tip will probably obviate the need to install fluid in the peritoneal cavity because the transducer can be curved over the dome of the liver [12].

The additional value of LUS in local tumor staging may consist of improved assessment of tumor ingrowth into the portal venous system and diagnosing suspected, but occult, carcinomas of bile ducts and pancreas or small neuroendocrine tumors. Color-Doppler probes will probably not produce additional information by detecting vascular occlusion or stenosis since this can also be detected by transabdominal duplex-Doppler US, contrast-enhanced dynamic/spiral CT or MRI. Contrary to some reports, color-Doppler probes are, in our experience, not needed to differentiate vessels from bile ducts or lymph nodes [5]. LUS can visualize abdominal lymph nodes in detail and may in some cases help to exactly define the localization of these nodes. The appearance of lymph nodes may in many cases suggest their nature, but in case of doubt, cytologic puncture currently remains indicated. The use of color-Doppler probes and pulsed wave Doppler may in the future help to characterize lymph nodes.

In conclusion, LUS can consistently produce high-quality images of the liver, bile ducts, pancreas, the portal venous system, and abdominal lymph nodes. The technique is not difficult to perform, but image inter-

pretation has a learning curve, and certain limitations and pitfalls have to be taken into account. We found the presence of a radiologist during every investigation essential to obtain optimal results.

Currently, an increasing number of reports are emerging, evaluating the benefit of LUS in abdominal tumor staging [7–9, 13–16]. These studies show an additional benefit of LUS in 5–25% of patients.

Technical improvements of US equipment and LUS probes, especially the development of dedicated puncture probes and the results of prospective comparative studies with state-of-the-art noninvasive imaging techniques will in the near future define the precise place of LUS in the staging of abdominal tumors.

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