Chapter 1

Intraoperative Ultrasound: Applications in Digestive Surgery

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Introduction: Brief History

Ultrasound has its well-established role in the diagnosis guidelines of abdominal pathology, being widely used in the internal medicine, gastroenterology and emergency services. Its use in surgery is best known through FAST protocols (focused abdominal sonogram for trauma) [1-3], very important in the management of patients presenting with abdominal trauma or suspected acute abdomen. Under elective conditions, conventional transabdominal ultrasonography has a high sensitivity and specificity in the detection of benign formations located mainly in the parenchymal organs: liver or splenic cysts, hemangioma, etc. [4-6]. In case of neoplasia, the ultrasound provides diagnostic guidance informations about intra-abdominal organs, the preoperative staging being mostly done by computed tomography (CT) or magnetic resonance imaging (MRI) examinations [7,8].

Technological breakthroughs have allowed the development of this domain. By introducing contrast agents, diagnosis by ultrasound became more sensitive and its applicability in the surgery field become more certain once high-fidelity transducers valid for intraoperative use were developed. Thus, intraoperative ultrasonography (IOUS) has become an important examination for the surgeon, often having a major role in the intraoperative decision making.
Ultrasound was first used intraoperatively in 1961 to detect kidney stones in order to perform nephrolithotomy [9]. At that time, the method has not been widely accepted because of the A-mode imaging mode, difficult in terms of interpretation [10]. The introduction of the B-mode in the 70’s, with real-time and two-dimensional visualization advantages, led to an increased use of intraoperative ultrasound in abdominal, thoracic, cardiovascular, neurological and endocrine surgery [10-12]. In the 90’s, due to scientific papers that highlighted the importance of intraoperative ultrasound, the technique became a routine one in concern of hepato-bilio-pancreatic and vascular surgeries [10].

**Equipment: Learning Curve**

High-end equipment and experienced ultrasonographer are mandatory for good application of intraoperative ultrasound techniques. Transducers used in IOUS must work at high-frequency (7.5-10 MHz), thereby allowing a higher spatial resolution than obtained with conventional transducers (3.5-5 MHz). The last ones can be used at the beginning of the examination of the liver, to get a panoramic overview of the organ’s anatomy [13,14]. Technological developments have allowed the production of transducers that can work on multiple frequencies, which can be adapted to each individual case, depending on the type and location of the lesion. The ideal transducer for intraoperative use should be small, in order to be able to be easily manipulated in narrow spaces, but at the same time has to ensure a wide scan area [13] (Figure 1a, 1b). When needs, the IOUS can be applied in laparoscopic or robotic surgery, but with the use of special probes suited for these types of approaches (Figure 2a-b). The option of doing an IOUS with contrast agent (CEIOUS) is an important factor in the choice of equipment. Currently, the most commonly used contrast agents are SonoVue (gaseous sulfur hexafluoride; Bracco, Milan Italy) and Sonazoid (gaseous perfluorane; GE Healthcare, Norway/Daiichi Sankyo, Japan), both with applications in the characterization of liver and pancreatic lesions, with role in the differentiation of benign from malignant tumors [13,15-18]. Elastography, the fusion imaging modules of real-time US with CT or MRI and the software that enable 3D ultrasound reconstruction, usefully in guided surgical resections, have been shown to be feasible, being a real asset when listed on the specifications of the ultrasound machine used intraoperative [19-21].

Ultrasound has been and remains an imaging method operator dependent. According to the literature, the learning curve of intraoperative ultrasound depends on the using purpose of this technique, on the complexity of the desired maneuvers and the targeted organ [22]. Thus, it is considered that the learning curve for screening liver metastases is overcome after a minimal 25 intraoperative examinations [10]. The same value is indicated for intraoperative diagnosis of gallstones. In case of interventional procedures on parenchymal organs (punctures, radiofre-
quency ablation, etc.), the learning curve assume at least 25-40 and 50 ultrasound maneuvers on pancreas respectively on liver [10]. Of course, all this after completing the training in general ultrasound, considered by some authors as being easier for surgeons, which have the advantage of knowledge and understanding in detail the three-dimensional anatomy [10].

![Figure 1a: Intraoperative L46K probe (linear), 13-3 Mhz, 60 mm, Hitachi Aloka Medical Ltd / Japan.](image1)

![Figure 1b: Intraoperative C42T probe (miniconvex), 1-13 MHz, 65°, Hitachi Aloka Medical Ltd / Japan.](image2)
Intraoperative Ultrasound of the Liver: Diagnostic and Therapeutic Role

Because of high relapse rate after percutaneous punctures, simple symptomatic liver cysts benefit from surgical indication. Fenestration or cyst resection is possible through laparoscopic or conventional surgery, the proce-
procedure being facile for superficial topography in the II, III, IVb, V, VI segments (after Couinaud) [23]. In case of lesions located deep in the liver, when surgery is required because of the symptoms given by cyst compression, intraoperative ultrasound is indispensable for locating the cyst and for establishing its vascular and biliary relations [6].

Intraoperative ultrasound has the same indication for hydatid hepatic cysts and abscesses, being of real help for the surgical team in establishing surgical tactics and to verify treatment radicalism (the remaining cavity containing residual content, multilocular abscess, etc.).

Benign liver tumors can be diagnosed and characterized easily by transabdominal ultrasound, especially through the association of contrast agents, which have a role in the differential diagnosis of malignant lesions. IOUS can be useful in tumors with surgical indication (large hemangiomas) to determine the vascular and biliary relationship. The same principle is used for malignant tumors where IOUS is generally useful for local tumor staging and confirmation of resectability criteria.

In terms of primary malignant tumors (hepatocellular carcinoma), IOUS is superior in detecting lesions measuring less than 1 cm, for which MRI has a lower specificity and sensitivity [13, 24]. Furthermore, it is proven that in 19-29% of the cases, the results given by contrast IOUS changed the therapeutic plan [25-27]. The CEIOUS utility is obvious in cirrhotic patients for the differential diagnosis of suspicious hepatic nodules that can be malignant lesions or regeneration nodules [28, 29]. Contrast agents used for this purpose (SonoVue) help to analyze the vascularization of concerned lesions with the potential of highlighting the pathognomonic phenomenon of wash-in and wash-out [13, 16] (Figure 3).

Figure 3: CEUS of the liver showing a tumor with typically washout effect. (ARIETTA V70. Hitachi Aloka Medical Ltd / Japan. Contrast Harmonic Imaging Software) (From the personal archive of the authors).

In colorectal liver metastases, CEIOUS can reach an accuracy of 96% versus 74% and 79% for preoperative MRI/CT respectively intraoperative conventional ultrasound [27, 30]. The fact that undetectable colorectal liver...
metastases (by preoperative imaging) are the primary cause of recurrent neoplastic disease [31], emphasizes the role that IOUS can play in the management of patients diagnosed with colorectal cancer. That is why international guidelines recommend routine use of IOUS in patients with this pathology [32].

Chemotherapy is part of adjuvant and neoadjuvant treatment arsenal of colorectal cancer [7,8], with the potential to obtain good results in cases with liver metastases, translated by stagnation or regression of lesions [33,34]. A particular case is when liver metastases are no longer visible by imaging (CT, MRI) after chemotherapy. Complete response to cancer treatment can be found in 66% of cases [33,35]. For the remaining cases, the chemotherapy can affect the echogenicity of liver lesions, making them difficult to diagnose by preoperatively CT/MRI or even through IOUS [13,33]. In these particular situations, CEIOUS can underline the diagnosis, making possible to check areas where liver lesions described before chemotherapy are no longer visible by conventional investigations [13]. The role of this technique is highlighted by the results of multiple studies that show that only the IOUS confirmation of disappearance of liver metastases was associated with a pathologic complete response [33,36].

Navigation technology is coming to help for liver lesions detection after chemotherapy. This procedure consists in the combination and synchronization of CT or MRI images obtained prior to chemotherapy with real time ultrasound, with the purpose of ultrasound guided procedure. The diagnosis is facilitated by the use of contrast agents [13,19,37].

Liver tumors elastography evaluates the tissue elastic properties and can be useful in characterizing focal liver lesions [33,38,39]. Combining this technique with IOUS can increase the ability of liver lesions detection by 8% [40], elastography being proved to be useful in the differentiation of benign and malignant tumors and of liver metastasis and primary tumor [20,33,40,41]. Utility of the procedure has been proven in the assessment of the efficacy of liver tumors ablation, elastography applied through IOUS being able to better estimate the necrosis areas than gray-scale US [33,42].

In all the situations described above, liver biopsy for suspicious lesions, performed intraoperatively under ultrasound guidance, can essentially contribute to the proper management of patients. Puncture procedure, guided by IOUS, is considered a safe procedure with high diagnostic accuracy, that can provide sufficient material for extemporaneous histopathological examination, which may have impact on intraoperative decision [33,43]. For example, liver metastases detected intraoperatively and histologically confirmed as having pancreatic origin are contraindications for radical pancreatic surgery [8].
It is known that surgical resection is the standard treatment for malignant liver tumors, being the only procedure that can provide oncological radicalism [8].

Liver parenchyma preservation should be an important goal for the surgical team, especially in patients with liver cirrhosis on which the liver function and the prognosis may be influenced by the extension of the resection. In this regard, the advantages brought by IOUS are indisputable, thus enabling local assessment of intrahepatic tumor relations, thereby facilitating the limited resection, while maintaining oncological margins.

In addition to the important role that IOUS plays in staging liver lesions, it can guide surgical resection, allowing to perform the so-called “radical but conservative surgery” [13,44]. This concept is vital for the radical treatment of patients with multiple liver metastases, for which, several years ago, the only therapeutic option was palliative treatment [44,45]. Obtaining continuous intraoperative ultrasound information about the relationship that the lesions have with intrahepatic structures, the surgeon can guide the resection line, with respect to the glissonean pedicles and suprahepatic veins in order to preserve as much as possible from the functional hepatic parenchyma [13,37,46]. Moreover, anatomic resections are possible by the use of IOUS. This technique involves compression of the segmental portal branch between the surgeon finger and the transducer, resulting a transient ischemia. The resection is being carried out along the emerging demarcation line [45,47-51]. Same authors (Torzilli et al) have introduced new operations (eg: mini-mesohepatectomy) for tumors located at the confluence of the vena cava and suprahepatic veins [13,37,52]. These hepatic resections are based on IOUS studying of the relationships that tumor has with the suprahepatic veins and blood flow analysis at this level after clamping of the vein proposed for resection. Highlighting the reverse flow direction in the peripheral portion of the compressed vein or shunting collaterals between the clamped vein and another suprahepatic or cava vein will allow limited resections while maintaining the oncological principles and minimalizing the risk of postoperative complications [13,37].

Conservative, local treatment for liver tumors can also be achieved by ablative methods: ethanol injection or induced coagulation necrosis by the use of radiofrequency or microwave [53,54]. These procedures are often used to complete surgical resections. Performed even by laparoscopic approach, these procedures may be indicated for patients who are on the waiting list for liver transplantation or those who cannot benefit from surgical resection due to comorbidities, liver cirrhosis or impaired liver function due to chemotherapy [55-58]. Of course, percutaneous approach of these lesions is superior in terms of less postoperative pain and shorter length of hospital stay, but does not provide the accessibility that IOUS has on “hard to approach” liver areas, such as the caudate lobe [33,59,60].
Surgical indication may be influenced by CEIOUS. An example is the classification introduced by Torzilli et al. which establishes criteria for surgical resection of the detected lesions, criteria made by the ultrasound appearance after intravenous administration of contrast agent (SonoVue) [37]. The authors indicate a sensitivity of 100% and a specificity of 69%, CEIOUS changing surgical strategy in 79% of cases [61].

**Intraoperative Ultrasound of the Pancreas: Diagnosis and Treatment Role**

IOUS has applicability in pancreatic surgery also. For small benign lesions (e.g. insulinoma) done by laparoscopic approach, IOUS is indispensable in identifying lesions and thus guide surgical resection (enucleation, limited pancreatic resection). Cephalopancreatic cystic lesions, confirmed as having a benign origin (e.g. multiple pancreatic cysts within Von Hippel Lindau disease) have surgical indication when producing compressive effect on neighboring structures (e.g. jaundice, portal vein thrombosis). The dome resection of these cysts, especially for intrapancreatic lesions is facilitated by IOUS which can show the relationships with major vascular structures, all these being done with the intent of a safe surgery (Figure 4a-b).

IOUS utility is also demonstrated in the case of pancreatic pseudocysts, minimally invasive techniques of laparoscopic transgastric drainage being facilitated by ultrasound examination, which highlights the vital relationships and content of the cyst (e.g. necrosis) [62,63].

In cases of pancreatic neoplasia, IOUS allows safe puncture biopsy, by guiding the procedure.

The use of contrast agents (SonoVue) improves the diagnostic accuracy of IOUS, being recommended to characterize lesions detected previously by other methods (conventional ultrasound, CT, MRI) [64]. CEIOUS is superior to pancreatic Doppler ultrasound in visualizing the intra and retropancreatic vascularization, having the ability to highlight any vascular tumor invasion, sparing the surgeon to do an exploratory dissection of that area [65,66]. Also, CEIOUS may be useful in pseudotumoral chronic pancreatitis when, one cannot rule out a malignant pancreatic tumor (Figure 5).

By this method, characterization of pancreatic parenchyma and typical appearance of inflammatory and/or malignant lesions diagnosis can be put easily. Suspected malignant lesions can be biopsied under ultrasound guidance during surgery with minimal risk.

Patients with chronic pancreatitis with pancreatic duct litiasis and consecutive obstruction of it, who are candidates for pancreatoco-jejunostomy, can benefit of IOUS, useful for quick identification of Wirsung duct and the level of obstruction (Figure 6).
4 (a) Intraoperative aspect.

4 (b) Ultrasonographic aspect of a cystic lesion located in the pancreatic head.

**Figure 4:** Intraoperative ultrasound of the pancreas. L44LA intraoperative probe, 13-2 MHz, 36 mm, Hitachi Aloka Medical Ltd / Japan. (From the personal archive of the authors).

**Figure 5:** CEIOUS of the pancreas with chronic pancreatitis. L44LA intraoperative probe, 13-2 MHz, 36 mm, Hitachi Aloka Medical Ltd / Japan, Contrast Harmonic Imaging Software. (From the personal archive of the authors).
Future Perspectives

Technical progress and research findings will definitely be followed by improvement of contrast agents, as happened with first generation contrast agents that were abandoned in favor of the second generation: SonoVue and Sonazoid. The second, recently introduced in clinical use, mainly used in Japan, has a high diagnostic accuracy, holding the advantage of Kupffer cell imaging in addition to vascular imaging [13,68]. Certainly, nanotechnology will have a decisive role in the progress of the field, this topic being a main activity for research teams worldwide [69].

Results so far indicate that elastography and its applications will play an important role in the management of abdominal parenchymal organ's lesions. Standardization of this technique for the evaluation of liver and pancreatic tumors, with intraoperative application, could increase the minimally invasive nature and accuracy of diagnoses.

Hardware and software developments have resulted in the partition of navigation technology, technique applied in IOUS and compatible with CEIOUS, all contributing to improved methods of liver lesions detection [13,37]. The association of 3-dimensional ultrasound can add more accuracy to these procedures, with potential guidance for liver resection [19].

It is clear that this area is continuously evolving, future progresses and routine application of imaging techniques in the operating room being able to improve the surgical act, with positive impact on patient prognosis.
References


15. von Herbay A, Westendorff J, Gregor M. Contrast-enhanced ultrasound with SonoVue: differentia-


26. Shah AJ, Callaway M, Thomas MG, Finch-Jones MD. Contrast-enhanced intraoperative ultra-


