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Intraoperative ultrasonography of robot-assisted laparoscopic hepatectomy: initial experiences from 110 consecutive cases

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Abstract

Background To evaluate the safety and efficacy of IOUS in robotic liver surgery and propose a standard protocol of IOUS for safe robot-assisted hepatectomy.

Methods Between February 2015 and December 2016, liver resection was performed in 110 patients with robotic approach in Tongji Hospital. In these patients, IOUS was routinely performed. All data about demographic, surgical procedure, postoperative course were collected prospectively and analyzed.

Results A four steps IOUS protocol in robotic liver surgery was proposed, including exploration, verification, guidance, and confirmation. A total of 11 additional lesions in 11 patients were detected and 7 patients accepted strategic surgical modification. No patient suffered from any single or multiple organ dysfunctions, and there were no mortalities observed.

Conclusion IOUS is indispensable to understand lesions and vessels in robotic liver surgery. A four-step standard protocol of IOUS is essential for safe robot-assisted hepatectomy.

Keywords Robot · Ultrasonography · Hepatectomy · Laparoscopic

Over the last two decades, minimally invasive surgery has developed into a mainstream surgical modality and has had an enormous impact on surgical practice [1–5]. Laparoscopic hepatectomy has been performed for resections of both benign and malignant tumors because of its advantages compared to the open approach [3–6]. These advantages include, but are not limited to the following: a decrease in blood loss, postoperative pain and morbidity, length of stay, hospital costs, not to mention improved tolerance to oral intake after surgery and cosmesis [7, 8]. Since the Louisville statement was published in 2008 [9], the number of laparoscopic liver resections performed has increased exponentially, which has been shown to be safe and feasible in experienced hands [10]. In recent years, laparoscopic liver surgery has gained widespread acceptance for different types of liver resections of varying pathologies [4]. However, the drawbacks of laparoscopic instruments, such as intrinsic human tremor, restrictive movement with only 4 degrees of freedom and a 2-dimensional view, limits its utility in complex liver resections [11]. In actuality, according to published literatures from 1991 to 2014 [10], minor liver resections still comprise the vast majority of procedures in clinical practice. Thus, the robotic approach was developed and aimed at alleviating the inherent limitations of conventional laparoscopy.

Intraoperative ultrasonography (IOUS) was initially introduced as a useful tool for open liver surgery [12, 13], however, it is becoming more valuable for intraoperative evaluation of hepatic tumors and determination of parenchymal transection planes in both the open and laparoscopic approaches [14]. The systematic use of IOUS becomes indispensable during robotic surgery due to the lack of tactile sensation [15]. In our experience, IOUS represents a fundamental step forward in robotic

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laparoscopic surgery. Nevertheless, to our knowledge, although several studies have mentioned the importance of IOUS during laparoscopic surgery [14–16], there is no published data that focused on the standard procedures of IOUS during robotic hepatectomy. In this study, we summarize our experience using IOUS from 110 consecutive cases, and propose a standard protocol of IOUS aimed at increasing the safety and efficacy in robotic liver surgery.

Methods

Between February 2015 and December 2016, liver resection was performed in 110 patients with robotic approach in Tongji Hospital. Treatment recommendations were made through a multidisciplinary liver tumor conference, and the type of surgical resection was based on lesion location and assessment of overall clinical status.

Preoperative assessment

All patients underwent chest radiography, ultrasonography of the abdomen, contrast computed tomography (CT) or magnetic resonance imaging (MRI). Laboratory blood tests, including determination of hepatitis B surface antigen, antibodies to hepatitis C, serum alpha-fetoprotein (AFP), carcinoembryonic antigen (CEA), carbohydrate antigen 199 (CA199), serum albumin, serum total bilirubin, aspartate aminotransferase, alanine aminotransferase, and prothrombin time were obtained, and the Child–Pugh score and indocyanine green retention rate at 15 min (ICG-R15) were also calculated. Further investigations were considered to exclude extrahepatic metastasis, if necessary. The selection criteria for robotic approach were as follows: no major vascular invasion, Child–pugh class A, American Society of Anesthesiologists score of 2 or less, and ICG-R15 less than 15%. All procedures were performed by experienced surgeons in hepatobiliary and laparoscopic surgery after obtaining informed consent issued by patients.

Operative procedure

The patient was placed in a supine position for left lateral segmentectomy, left hepatectomy, right hepatectomy, and segment 1, 2, 3, 4, 5, 8 resections, while in left decubitus position for right posterior sectionectomy or segment 6, 7 resections. A 12-mm camera port, 12-mm operative port, and two or three working 8-mm robotic ports were utilized. They were positioned along a semicircular arc facing the tumor or designed transection plane. The da Vinci® S Surgical system (Intuitive Surgical Inc., Sunnyvale, CA) was used for all robot-assisted procedures. The robotic surgical system's patient cart was docked at the patient's head. The surgical team comprised of at least 2 surgeons. The first surgeon was seated at the robotic console, while the second surgeon was positioned on the left or right side of the patient and was responsible for exchanging robotic instruments and managing classical laparoscopic tasks including using IOUS.

We used the Esaote MyLab™ClassC Ultrasound Scanner system with laparoscopic transducer probe, which can be adjusted through an angle of up to 90° in four directions (up, down, left, and right) by two levers. We recommend the TilePro mode on the robotic monitor, which allowed the surgeons to see both robotic and ultrasound images on one monitor. The assistant surgeon manipulated IOUS handling on the hepatic surface for tasks such as tumor detection, vascular structures, or Dopplerable blood flow. After surgery, the patient was not routinely sent into intensive care unit.

Definition

A new lesion was defined as any nodule undetected by preoperative imaging and discovered by IOUS [14]. Each nodule was assigned to a liver segment on the basis of its feeding portal branch. Large lesions occupying the right liver were classified as right liver lesions. A strategy modification was defined by the need to schedule a different liver resection or other surgical treatments from that planned before surgery because of newly acquired intraoperative data. Conversion was defined as the completion of the procedure via a laparotomy. Operative mortality was defined as death within 30 days after surgery. Postoperative morbidity and mortality were assessed according to the Clavien–Dindo classification [17]. Liver dysfunction was defined as both a prothrombin rate $<50\%$ and a serum bilirubin level >50 μmol/L at postoperative day 5 as reported by Belghiti [18].

Statistical method

All data about demographic, preoperative course, surgical procedure, and postoperative course were collected prospectively. Continuous variables are expressed as mean $\pm$ SEM if gauss distribution, otherwise median value if skewed distribution.

Results

Characteristics of the 110 patients with liver resection

Between February 2015 and December 2016, liver resection was performed in 110 patients with robotic approach in Tongji Hospital. The background demographic patient characteristics are summarized in Table 1.

Perioperative and postoperative parameters

The indications for liver surgery are shown in Table 2. In six patients with metastatic liver cancer, there was 1 pancreatic cancer, 1 yolk sac tumor, 1 colonic carcinoma, and 3 carcinoma of the rectum. In addition, there were 3 angiomyolipomas, 1 serous cystadenoma, 1 focal fatty change, 1 mesenchymal hamartoma, 1 neuroendocrine tumor, 1 inflammatory pseudotumor, and 1 hepatolithiasis. In this series of patients, we chose two different hepatectomy strategies: (1) parenchymal-sparing resection and (2) anatomical liver resection. The former strategy was employed for benign tumors or hepatic metastasis, the latter one was for hepatocellular carcinoma, which was also in accordance with the latest consensus regarding laparoscopic liver resection [10].

The type of hepatectomy employed is summarized as shown in Table 2. A tape was routinely placed around the hepatic pedicle, and intermittent Pringle maneuver was performed if necessary. The infrahepatic inferior vena cava clamping was utilized to decrease central venous pressure and control hepatic venous bleeding during parenchymal transection, if necessary. In total, there were 17 patients with more than 1000 mL blood loss, no patient suffered from any single or multiple organ dysfunctions, and there were no mortalities observed.

The standard procedures of IOUS

During the operation, we followed a four-step IOUS protocol:

a. *exploration phase*, after mobilization, IOUS was used to detect tumor number, size and location, and ruled out any lesions undiscovered in preoperative image evaluation. Figure 1 showed tumor location, size, and the relationship with important vessels.
b. *verification phase*, we collected information about hepatic vascular structures in the liver and determined longitudinal and latitudinal parenchymal transection plane, sometimes combined with external landmarks if necessary. Figures 2, 3, 4 showed left hepatic vein (LHV), middle hepatic vein (MHV), right hepatic vein (RHV), inferior vena cava (IVC), and portal branches.
c. *guidance phase*, we performed parenchymal transection using harmonic dissector or Maryland forceps under the real-time guidance of IOUS, which helped avoid the accidental injury of vessels and to ensure the correct transection plane.
d. *confirmation phase*, after transection, IOUS was applied for ensuring intact vascularization and no residual tumor in the remnant parenchyma. In these patients, no outflow damage and no tumor residual was found.

Table 1 Patient characteristics

Sex ratio (M/F)	71/39
Age[mean ± SD]	48.8 ± 12.1
BMI (kg/m^2)	23.1 ± 2.9
ASA score(1/2/3/4)	80/30/0/0
HBsAg serology (±)	70/40
HCV antibody serology (±)	1/109
ICG retention rate at 15 min (%)	4.85 ± 5.33
Diameter of tumor (cm)	5.4 ± 3.0
Tumor (malignant/benign)	77/33
Cirrhosis (yes/no)	56/54

BMI body mass index, *ASA* American Society of Anesthesiologists, *HCV* hepatitis C virus, *ICG* Indocyanine green

Table 2 Perioperative and postoperative parameters

Pathological diagnoses	
Hepatocellular carcinoma	63
Cholangiocarcinoma	6
Metastatic carcinoma	6
Hemangioma	20
Focal nodular hyperplasia	6
Others	9
Types of hepatectomy performed	
Segment 1/2/3/4/5/6/7/8/	1/1/1/6/9/8/1/6
Segment 2,3/2,3,4/5,6,7,8 resection	30/8/3
Segment 5,8/6,7/4b, 5/5,6 resection	6/23/4/5
Operation time (min)	216.7 ± 91.7
Total blood loss (mL)	50–2000 (375)
Numbers of transfused patients	23
Units of blood transfused#(units)	2.35 ± 1.17
Overall complications	
Grade 1/2	1/25
Grade 3/4/5	9/0/0

Types of hepatectomy were classified according to Brisbane 2000 terminology [25]. Postoperative morbidity was assessed according to the Clavien–Dindo classification [17]

Detection of new nodules and strategic surgical modification

A total of 11 additional lesions in 11 patients (10%) were detected, which are listed in Table 3. The diameters of new lesions were all less than 1 cm. Of these patients, seven

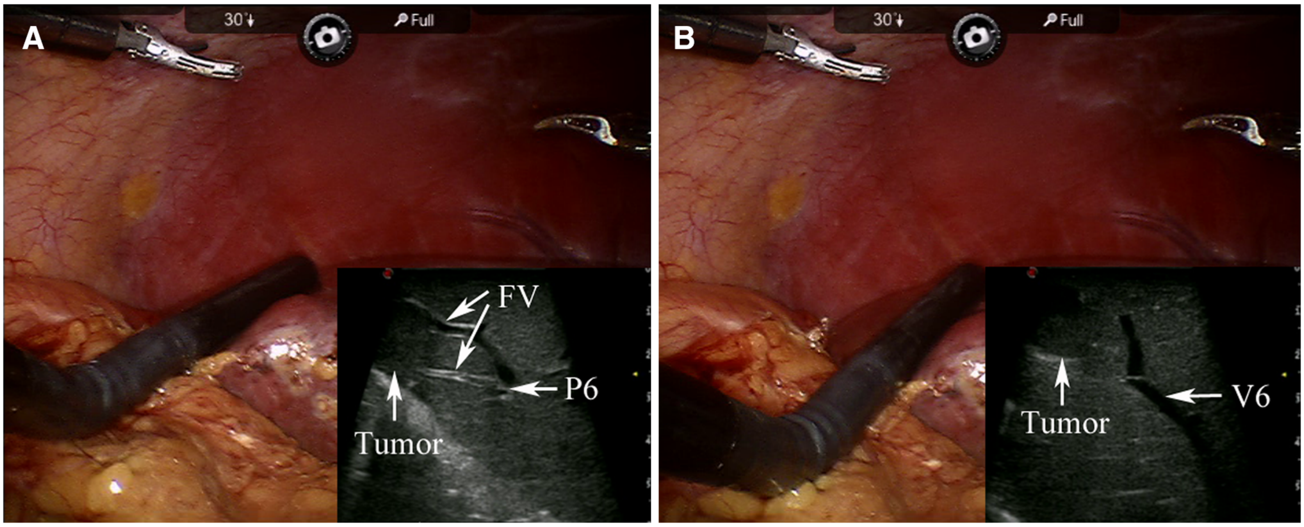

Fig. 1 **A** Tumor located in Segment 6 and its feeding vessels (FV); **B** Tumor and its relationship with segment 6 hepatic vein (V6)

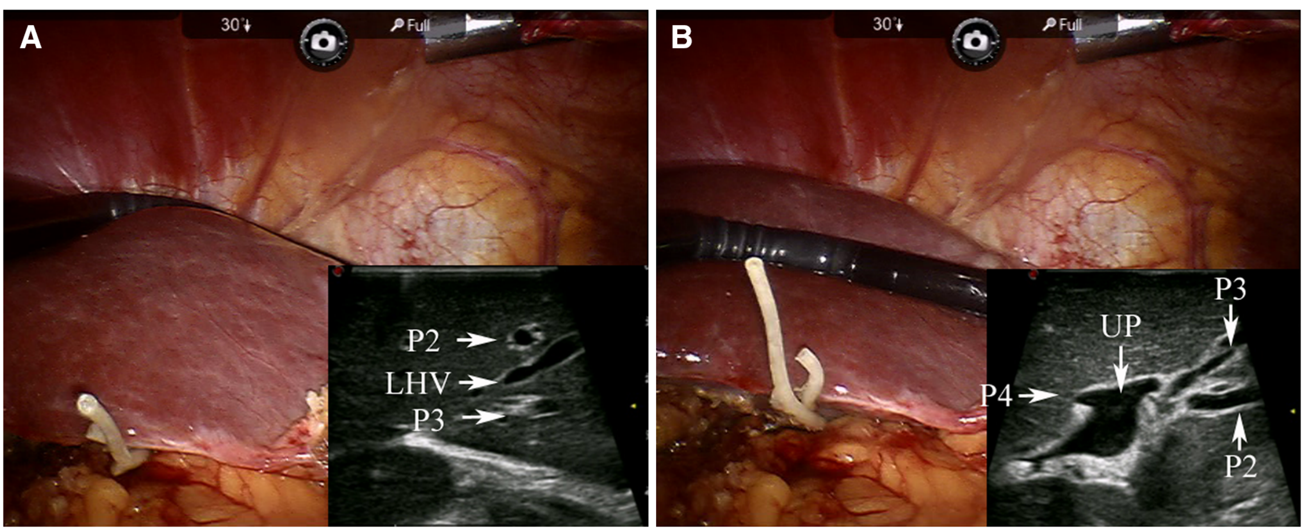

Fig. 2 **A** Left hepatic vein (LHV) and branches of portal pedicles of left lateral section (P2, P3); **B** The branches of left portal pedicles. UP means umbilical portion of portal vein

patients (6.36%) accepted modified surgical strategy including additional liver resection or microwave ablation therapy, and those resected nodules were all confirmed by pathology. Only 4 patients did not need an additional surgical plan because of the location of the new lesion in the planned resection landscape.

Discussion

IOUS is essential for completing tumor staging and for planning surgical strategy of liver resections, either in the open approach, laparoscopic approach, or robot-assisted approach [10, 12–15]. Several studies have highlighted that IOUS increases the safety of laparoscopic hepatectomy allowing for its broad acceptance [10, 14, 16]. Since the introduction of the robotic technique in the late 1990s, robotic-assisted hepatectomy has been reported frequently during the past few years because of the many advantages of the approach [7], such as improved dexterity, precise movements, visual magnification, better ergonomics, decreased tremor, to name a few. But palpation is also precluded during the robotic approach, similar to laparoscopic liver resections. The limitation of lack of tactile sensation may be an obstacle to extending the robot's application, which could be alleviated by IOUS [15]. Nevertheless, no standard technical protocol of IOUS exists to date. Here, we summarized our IOUS experiences from 110 consecutive cases with robotic liver resection, and proposed a standard protocol of IOUS.

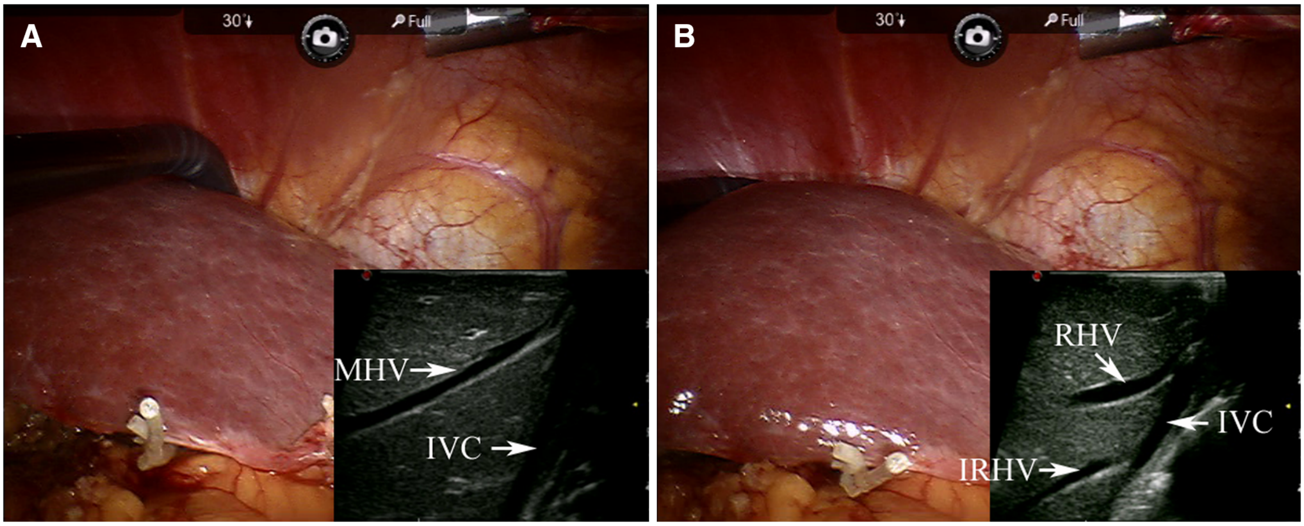

Fig. 3 **A**. Middle hepatic vein (MHV) and inferior vena cava (IVC); **B**. Right hepatic vein (RHV) and IVC. IRHV means inferior right hepatic vein

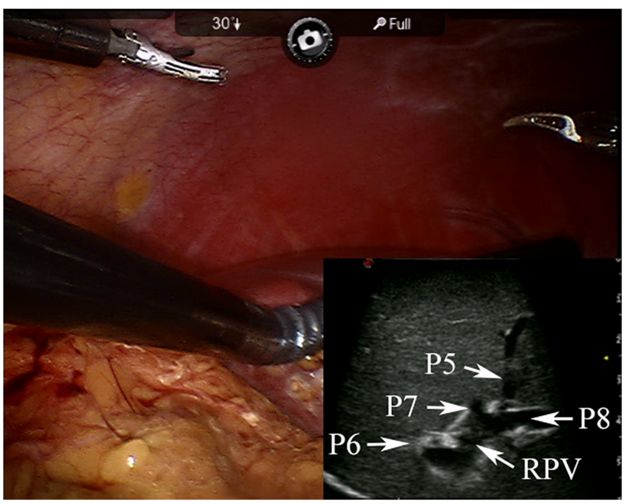

Fig. 4 The branches of right portal pedicles (P5, P6, P7, P8). RPV means right portal vein

Although there was better performance of robotic IOUS reported in liver surface exploration and tool manipulation because of more degrees of freedom design compared with laparoscopic counterpart [15], there were no differences in lesion identification in pig experiments. In fact, the robotic instruments described are not available at most centers until recently and remain extremely expensive. Therefore, in this study, we chose to utilize laparoscopic IOUS, which connected with robot console through a s-video line. For IOUS manipulation, there were some differences in robotic hepatectomy compared with laparoscopic approach. One was only 1 or 2 assistant trocars placed, whereas 4 or 5 trocars in laparoscopic approach, the other were the second surgeon handling the probe in robotic approach. These limitations sometimes resulted in unanticipated probe alignment and increased difficulties of interpretation regarding the resulting image. In these cases, we

Table 3 Detection of new nodules and surgical strategy modification

	Previous lesion		New lesion		Surgical strategy	
	Location	Number	Location	Number	Previous plan	Additional plan
MLC(rectal)	S6	1	S4	1	S6 resection	S4 resection
Hemangioma	S6, 7	4	S5	1	S6, 7 resection	S5 ablation
HCC	S6, 7	2	S8	1	S6, 7 resection	S8 resection
HCC	S2, 3	1	S4	1	S2, 3 resection	S4 resection
HCC	S2	1	S8	1	S2, 3 resection	S8 resection
MLC(Yolk sac tumor)	S6, 7	1	S7	1	S6, 7 resection	No change
HCC	S6	1	S6	1	S6 resection	No change
Hemangioma	S5, 8	1	S8	1	S5, 8 resection	No change
HCC	S4, 5	1	S6	1	S4, 5 resection	S6 resection
HCC	S5, 8	2	S6	1	S5, 8 resection	S6 resection
FNH	S2, 3	1	S2	1	S2, 3 resection	No change

recommended the Tilepro function to allow for laparoscopic and ultrasonic pictures on one monitor simultaneously, and the second surgeon should always keep in close communication and cooperation with the first surgeon and utilize an ultrasonographer or consultant radiologist if necessary. These recommendations are intended to overcome the aforementioned limitations and make robotic-assisted laparoscopic hepatectomy easier.

As for learning curve of laparoscopic IOUS in robotic approach, it still remains to be clarified. In our experiences, it is undoubted that the surgeon can shorten the learning process if he/she follows the standard protocol of IOUS during robotic surgery. We also recommend the surgeons to seek consultancy of an ultrasonographer or radiologist if there are difficulties in explaining ultrasonic pictures because of unanticipated probe alignment.

Although it may make the operating time longer, the importance of IOUS in exploration during liver surgery has been demonstrated by several studies [14, 15, 19]. Studies have also demonstrated the importance of IOUS in the identification of occult lesions, which can change the operative plan in up to 50% of patients [20, 21]. Along with the development of newer imaging technology, the rate of surgical modification due to IOUS detection has decreased to 22% [14], which is also in line with our study. In these patients, only 10% patients had new lesions detected by IOUS and 6.36% patients needed modification of surgical strategy which could be explained by particular imaging evaluation including enhanced CT pictures and MRI with perfusion weighed imaging (PWI) and diffusion weighed imaging (DWI).

Another documented important purpose of IOUS is documented to guide anatomic liver resection [16, 19]. In left lateral sectionectomy (segment 2 + 3), IOUS could recognize portal pedicle (P2 + P3) and LHV. The transection plane could be easily determined along the left side of falciform ligament as external landmark. MHV required recognition due to its proximity to the transection plane. In right anterior sectionectomy (segment 5 + 8), MHV should be identified initially as a landmark of the left parenchymal transection plane. RHV was also visualized as a vertical landmark, which was located in the right transection plane. Portal branches of segment 5/8 (P5 + P8) could be recognized. The visualization of RHV was also necessary in right posterior sectionectomy (segment 6 + 7) as a landmark of vertical line. Rouviere's Sulcus sometimes could be used as a boundary between S6/7 and S5/8 on the visceral surface of the liver. For segmentectomy 4, MHV recognition and falciform ligament could help determine the line of demarcation. To determine the latitudinal transection line of the segment or subsegment, such as boundaries between S6 and S7, S5 and S8, S4a and S4b, the visualization of the portal vein bifurcation could be allowed for as a horizontal landmark by IOUS. In left or right hepatectomy, the line of ischemia due to preliminary ligation of inflow vessels could help contribute to the determination of the transection plane. In some situations, the segment-dyeing technique, in which ICG [22] or methylene blue [12] solution was injected into the corresponding portal branch under IOUS guidance, could easily identify the boundaries of hepatic segments. In our studies, we didn't apply it because of injection technical difficulties or requirement of specific fluorescence imaging system.

In margin-negative parenchymal-sparing resection for liver metastasis and benign tumors, care must be taken to secure an adequate resection margin due to the lack of tactile sensation. We performed parenchymal transection using harmonic dissector or Maryland forceps under the real-time guidance of IOUS, which helped accuracy of clear margin and avoiding injuries of major vessels. Because IOUS could show any vessels crossing the transection plane and any vessels more than 3 mm should be safely clipped, ligated or sutured, we did not experience any accidental vascular injuries during transection with IOUS guidance.

Another advantageous alternative to classical IOUS is contrast-enhanced IOUS (CE-IOUS), which has been reported to increase the detection rate of new nodules, especially for colorectal liver metastases [23, 24]. In our opinion, the aim of IOUS was not to distinguish the characteristics but to detect new nodules. For those suspicious lesions, we could collect enough diagnostic information through preoperative MRI and CT imaging, especially MRI-DWI. Thus CE-IOUS was rarely used in the present study.

For surgeons who perform robotic-assisted laparoscopic liver resection, IOUS is indispensable to understand lesions and vessels in the liver, prevent accidental bleeding during transection, ensure no vascular damage, and residual tumor in the remnant liver. In conclusion, a four-step standard protocol of IOUS is essential for safe robot-assisted hepatectomy.

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Author contributions P.Z. perform the operation, analysis and interpretation of data, draft and revise the article. W.L., Z.-Y.D., B.-H.Z., W.-G.Z. acquisition and analysis of data. H.-C.L.: explanation of ultrasonic data. B.-X.Z., X.-P.C.: conception and design, perform the operation.

Compliance with ethical standards

Disclosures Peng Zhu, Wei Liao, Ze-yang Ding, Hong-chang Luo, Bin-hao Zhang, Wan-guang Zhang, Wei Zhang, Zhan-guo Zhang, Bi-xiang Zhang, Xiao-ping Chen have no conflicts of interest or financial ties to disclose.

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