A European expert consensus surgical technique description for robotic hepatectomy

Gabriela Pilz da Cunha[1]^, Daan J. Lips[2]^, Jawad Ahmad[3], Niclas Kvarnström[4], Luca Aldrighetti[5]^, Mathieu D'Hondt[6*]^, Jeroen Hagendoorn[7*]^, Rutger-Jan Swijnenburg[1*]^

[1]Department of Surgery, Cancer Center Amsterdam, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands; [2]Department of Surgery, Medisch Spectrum Twente, Enschede, The Netherlands; [3]Department of Hepatobiliary and Pancreatic Surgery, University Hospitals of Coventry and Warwickshire NHS Trust, Coventry, UK; [4]Department of Surgery, Sahlgrenska University Hospital, Goteborg, Sweden; [5]Faculty of Medicine and Surgery, Vita-Salute San Raffaele University, Milan, Italy; [6]Department of Digestive and Hepatobiliary/Pancreatic Surgery, Groeninge Hospital, Kortrijk, Belgium; [7]Department of Surgery, University Medical Center Utrecht, Utrecht, The Netherlands

Contributions: (I) Conception and design: All authors; (II) Administrative support: G Pilz da Cunha, RJ Swijnenburg; (III) Provision of study materials or patients: RJ Swijnenburg, J Hagendoorn; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: None; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

*These authors contributed equally to this work as co-senior authors.

Correspondence to: Rutger-Jan Swijnenburg, MD, PhD. Department of Surgery, Cancer Center Amsterdam, Amsterdam UMC, University of Amsterdam, De Boelelaan 1117, 1081 HV Amsterdam, The Netherlands. Email: r.j.swijnenburg@amsterdamUMC.nl.

Abstract: The robotic platform enables surgeons to operate with a similar level of freedom and control as in open surgery, while still providing the patient with the benefits of a minimally invasive approach. More centres continue to adopt robotic liver surgery however standardized training materials and consensus on the surgical technique are currently lacking. The availability of a standardized surgical protocol could benefit the further dissemination of the robotic approach while promoting safe and effective operating techniques. We present a comprehensive surgical technique description for robotic hepatectomy agreed upon by seven expert robotic liver surgeons in Europe. They contributed insights from their extensive experience with the robot to develop this report, highlighting the key steps and important considerations for performing robotic hepatectomy. We describe the surgical technique for four most common hepatectomy types with varying complexity: partial anterolateral resections, partial posterosuperior resections, left hepatectomy and right hepatectomy. This report encompasses recommendations from the experts, covering the preparatory steps such as patient selection and pre-operative imaging, and extending through to care in the postoperative phase. The step-by-step surgical technique description serves as a compendium of best practice methods presently utilized in robotic liver surgery. Although some variations in technique cannot be eliminated from practice, general recommendations in a structured form will help to homogenize the technique, safeguarding surgical quality. This paper aims to inform and advise surgeons in the process of adopting robotic liver surgery and can act as a starting point for further optimization and refinement of the technique.

Keywords: Hepatectomy; robotic surgery; minimally invasive liver surgery; technique description

Submitted Oct 02, 2023. Accepted for publication Mar 13, 2024. Published online Jul 11, 2024.
doi: 10.21037/hbsn-23-510
View this article at: https://dx.doi.org/10.21037/hbsn-23-510

^ ORCID: Gabriela Pilz da Cunha, 0000-0001-9055-1049; Daan J. Lips, 0000-0001-7515-9276; Luca Aldrighetti, 0000-0001-7729-2468; Mathieu D'Hondt, 0000-0001-5542-3017; Jeroen Hagendoorn, 0000-0001-8737-3923; Rutger-Jan Swijnenburg, 0000-0002-3980-4634.

Introduction

Over the years, minimally invasive techniques have played an increasingly frequent role in the treatment of patients with resectable liver and biliary tract disease (1). When compared to open surgery, minimally invasive surgery has superior postoperative outcomes such as less blood loss, decreased length of hospital stay and lower complication rates (2). Despite these advantages, laparoscopy has so far only been recommended as the 'gold standard' approach for minor liver resection in the anterolateral segments (3). Concerns about the inherent limitations of laparoscopic instruments, restrict laparoscopic anatomically and technically major liver resections to high-volume expert centres (3,4). Surgeons perceive that the increased dexterity, better ergonomics and three-dimensional stable vision of the robotic platform enhance their surgical abilities (5). Hereby helping them to overcome many of the challenges encountered in laparoscopy. Some reports state that the robot may prove especially helpful in technically and anatomically major resections (6-9). The robotic platform could therefore help to push the boundaries of minimally invasive liver surgery and enable surgeons to provide the benefits of minimal invasive surgery to more patients.

So far, adoption of the robotic technique for hepatectomy has been slow, partly due to high procedural costs, limited accessibility to the robot, gradual development of appropriate robotic instruments and lack of surgical training (1). It is expected that the number of hepato-biliary surgeons with access to a surgical robot will continue to grow in the coming years. There is clear enthusiasm within the surgical community to incorporate the robot into everyday practice (10). Availability of standardized training material will benefit the dissemination of the robotic technique.

A detailed step-by-step description of the robotic hepatectomy technique, agreed upon by expert liver surgeons, is not currently found in literature. Such a protocol could facilitate safe implementation and teaching of robotic hepatectomy worldwide. Below, we present a procedure description for robotic hepatectomy, developed as a collaboration between expert robotic liver surgeons (more than 150 procedures each) in Europe as an effort to standardize the robotic hepatectomy technique. All contributing surgeons have extensive experience in implementing robotic liver surgery programs at their respective centres in the Netherlands, Belgium, United Kingdom, Sweden, and Italy. Consensus on the surgical technique was reached during online expert meetings between the authors. We present this article in accordance with the SUPER reporting checklist (available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-23-510/rc).

Highlight box

Key findings

- The robotic platform enables surgeons to approach complex liver resections minimally invasively.

What is conventional and what is novel/modified?

- With the introduction of laparoscopy, liver resections could be performed with profoundly less surgical trauma compared with open surgery. However, the applications of laparoscopy remain limited by the straight laparoscopic instruments.
- The robotic platform offers increased dexterity, better ergonomics and three-dimensional stable vision enhancing the operative abilities of the surgeon.

What is the implication, and what should change now?

- Implementation of the robotic platform in liver surgery could help expand the indications for minimally invasive liver surgery.
- It is essential that the safety of the patient is safeguarded during the introduction of novel surgical techniques, such as robotic hepatectomy. The use of standardized protocols developed by expert surgeons can help preserve surgical quality.

Surgical technique

A large array of procedures with ranging difficulty levels are grouped under the broad notion of 'hepatectomy'. Depending on tumour size and location, varying liver segments and volumes may need to be resected. We describe the surgical technique for robotic hepatectomy subdivided into four commonly performed hepatectomy subtypes: partial anterolateral (AL) and posterosuperior (PS) resection, left hemihepatectomy (LH) and right hemihepatectomy (RH). Partial resections refer to both anatomical and atypical (wedge) resections. Anatomical segmentectomy follows the segment boundaries as defined by Couinaud (11). A partial resection refers to a resection of 1 or 2 segments. The AL are segments II, III, IVb, V and VI; the PS segments are I, IVa, VII, VIII. In LH and RH segments II to VIb and V to VIII are resected, respectively, with or without removal of the caudate lobe (segment I). This technique description generally assumes a classical patient anatomy and some commonly occurring anatomical variations are addressed. Moreover, procedures requiring construction of a hepaticojejunostomy or vascular resections due to vascular invasion do not fall within the scope of this paper.

All procedures performed in this article were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patients for publication of this article and accompanying video and images. A copy of the written consent is available for review by the editorial office of this journal.

Preoperative preparations and requirements

Robotic system

This protocol applies directly to the Intuitive (Sunnyvale, CA, USA) da Vinci Xi surgical system. At time of writing this protocol, robotic surgical systems from other manufacturers were not yet approved for use in hepato-biliary procedures in Europe.

Surgical team

A surgical team consists of two surgeons (one console and one bedside surgeon). Although the bedside surgeon does not need to be an accredited surgeon, it is recommended that they have prior experience with minimally invasive liver resections. The bedside surgeon should possess some basic skills to provide safe assistance to the console surgeon. Experience with handling basic laparoscopic instruments such as grasper, scissors, suction and vascular stapler are a prerequisite. Additionally, proficiency in instrument exchanges as well knowledge of what to do in the case of a conversion play an important role in supporting the console surgeon.

When available, the introduction of a second console may be considered. A two-console approach involves two surgeons alternatingly controlling the robot from individual consoles, promoting collaboration with smooth transitions between surgeons. This can be particularly beneficial for novice robotic surgeons during their learning curve, as it allows a more experienced proctor to seamlessly intervene during critical moments.

Patient selection

Cases must be selected carefully to match the proficiency of the operating surgeon. Disease characteristics such as larger tumor size, tumor location in the PS segments, extensive parenchymal transection, proximity to major vasculature/ bile ducts, diaphragm involvement, presence of cirrhosis, and use of neoadjuvant chemotherapy may complicate the resection. Patient characteristics to be considered which may complicate the resection are a history of abdominal or hepatic operations, elderly age and high body mass index (3). Various scoring systems have been developed to help predict the difficulty of liver resections (12-15). The authors recommend using the IWATE-score, which has been shown to correlate well with postoperative outcomes in laparoscopic liver surgery (12,16,17). Its applicability to robotic liver surgery has also been studied (18).

Preoperative imaging

Triple phase abdominal computed tomography (CT) scan or magnetic resonance imaging should be studied preoperatively to construct a surgical plan and identify aberrant vasculature and/or bile duct anatomy. Thereby allowing an appropriate surgical plan to be devised. It is preferred that the most recent imaging is completed maximally 6 weeks prior to the date of operation owing to possible tumor progression which may require adaptation of the surgical plan. For perioperative tumor demarcation, indocyanine green (ICG) can be administered to the patient 24 hours prior to surgery, and longer in cirrhotic patients. A standard dose of 10 mg, irrespective of weight, can be given. For biliary fluorescence imaging, the ICG can be administered during anesthesia induction (19,20). Negative and positive ICG staining techniques have been described in literature for demarcating resection margins in anatomical resections (21). Negative staining involves intraoperative administration of ICG after selective pedicle clamping, creating a fluoroscopic contrast between the obstructed segment and the remaining parenchyma. Positive staining involves intraoperative injection of ICG into a vascular pedicle to highlight a specific segment. The authors find the positive staining technique to be technically demanding and suggest its use only be considered once advanced robotic expertise has been acquired.

Perioperative care

Perioperative care should be conducted in accordance with the Enhanced Recovery After Surgery (ERAS) Society Guidelines and local hospital protocol (22).

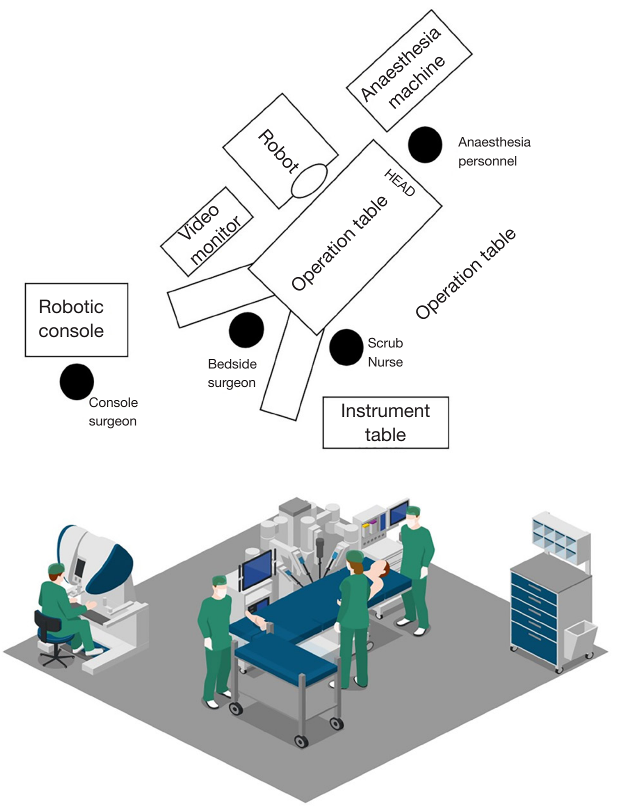


Figure 1 Operation room setup for the a da Vinci Xi surgical system. Image created in Icograms Designer (https://icograms.com).

Operating room

Robotic hepatectomy should be performed in an appropriate operating theatre. An overview of the operating room setup is provided in *Figure 1*. This setup may need to be modified depending on operation room layout; however, the following should always apply:

- ❖ Communication and eye-contact between console surgeon and bedside team is unobstructed;
- ❖ The bedside surgeon is on the patient's left side or in between the patients' legs;
- ❖ A video monitor (three-dimensional view is recommended) is placed across from the bedside surgeon and the scrub nurse is at the patient's feet.

Patient positioning

Following the induction of general anesthesia, the patient is positioned on a vacuum mattress with arms and legs fixated with straps and pressure points are padded.

Partial AL

The patient is positioned in a supine position, with legs together or in French position, with the right arm alongside the body on an arm support and the left arm extended. Alternatively, both arms can be extended. Lowering the patient's arms in relation to their body can help to expand the extracorporeal freedom of movement of the robotic arms. The operating table is tilted in 15°–30° in reverse Trendelenburg and, depending on position of the lesion, 10°–15° to the right. In French position the bedside surgeon takes place in between the patient's legs. If the patient's legs are closed, the bedside surgeon takes place at the left side of the patient.

Partial PS

Patient lies in left lateral decubitus position, with their right arm over their head on an extra arm support. The patients' legs are positioned together or in French position depending on the preferred positioning of the bedside surgeon either at the patients' left side or in between the legs, respectively. The operating table is tilted 15°–30° in reverse Trendelenburg.

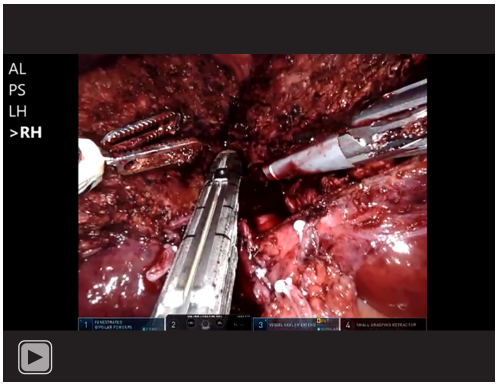
Hemihepatectomy

The patient is positioned in supine position with the right arm alongside the body on an arm support and the left arm extended. Alternatively, both arms can be extended. Lowering the patient's arms in relation to their body can help to expand the extracorporeal freedom of movement of the robotic arms. The patient's legs are positioned together or in French position depending on the preferred positioning of the bedside surgeon either at the patients' left side or in between the legs, respectively. The operating table is tilted in 10°–20° in reverse Trendelenburg with no or 5° tilt to the right depending on the position of the liver in LH and 10°–15° to the left in RH.

The above recommendations concerning the degree of table tilt serve as general guidelines and need not be adhered to strictly. Deviations may be necessary depending on specific intrabdominal anatomy. Depending on the procedure, adjustments to the tilt during the operation can be helpful.

Step-by-step description

An intraoperative video containing the highlights of four common robotic hepatectomy procedures accompanies this report (multimedia file) (*Video 1*).



Video 1 Surgical technique for robotic hepatectomy. AL, partial anterolateral; PS, posterosuperior; LH, left hemihepatectomy; RH, right hemihepatectomy.

Step 1: trocar placement, pneumoperitoneum and diagnostic laparoscopy

Trocar insertion can be performed in one of the following ways:

(I) Pneumoperitoneum creation with a Veress needle at Palmer's point (left subcostal, midclavicular line) is followed by insertion of a 12-mm assistant port using an optical trocar at assistant port 1 location (*Figure 2*). The remaining trocars are then placed under direct endoscopic visualization.

(II) Pneumoperitoneum creation with a Veress needle at Palmer's point is followed by blind insertion of the robotic endoscope port with a blunt obturator at robotic port 2 location (*Figure 2*). The remaining robotic trocars are then placed under direct endoscopic visualization; assistant ports are placed after docking of the robot. This method allows for optimal placement of the assistant ports with regards to the target lesion and robotic arms.

(III) A 12-mm assistant port is placed using an open introduction method (mini-laparotomy) at assistant port 1 location (*Figure 2*). After achieving pneumoperitoneum, the remaining trocars are placed under direct endoscopic visualization.

Pneumoperitoneum is set at 8–15 mmHg. The trade-off between higher risk of bleeding at lower pressures, and higher risk of air embolism at higher pressures should be carefully considered when determining the pneumoperitoneum pressure level.

Port placement is outlined in *Figure 2*. Trocars for the robotic arms are placed along a straight plane. In LH, the operation is performed with the robotic ports in a transverse plane (perpendicular to the longitudinal axis of the patient). In RH, the axis of this plane is rotated by 15°–20° anti-clockwise (*Figure 2D*).

The use of a second assistant port is optional. During larger resections the bedside surgeon may introduce additional instruments through this port facilitating tissue exposure. Furthermore, it can be helpful to have additional support from the bedside surgeon with additional instrumentation when the first port is being occupied by the Cavitron Ultrasonic Surgical Aspirator (CUSA).

After insertion of the endoscope through the first trocar, a diagnostic laparoscopy is performed to identify possible extrahepatic metastases, optimal port placement and intra-abdominal adhesions. It may be necessary to perform laparoscopic adhesiolysis to create space for the remaining trocars.

Trocar placement for partial AL and partial PS may vary depending on the specific location of the tumor. The general rule to be followed when determining trocar placement are keeping approximately 12–15 cm distance from the target area (i.e., the tumor) and always maintaining at least 8 cm between all robotic trocars. It may be helpful to draw a direct marking line on the patient from the robotic arm 2 position to the intended operating field. It can also be helpful in early stages of the learning curve to measure out the distance between target area and abdominal wall on sagittal CT images.

Depending on the patient, trocar placement may need to be adjusted accordingly to avoid instrument collisions. Throughout the procedure the assistant bedside surgeon should remain on the lookout for collisions between the robot arms and with the patient.

Step 2: robot docking

Due to the positioning of the robot, attention to patient positioning with regards to the anesthesia equipment prior to start of the operation is important. The da Vinci Xi system is docked from the right side of the patient (*Figure 1*). After docking, the operating surgeon takes place at the console and the assisting surgeon at the patient's left side or in between the legs. It is important to maintain symmetry in the placement of the robotic arms and to keep approximately a fists' distance between the robotic arm joints. After docking check for possible collisions with the patient, if no collisions are observed at this stage, it is highly unlikely that they will happen during the procedure itself.

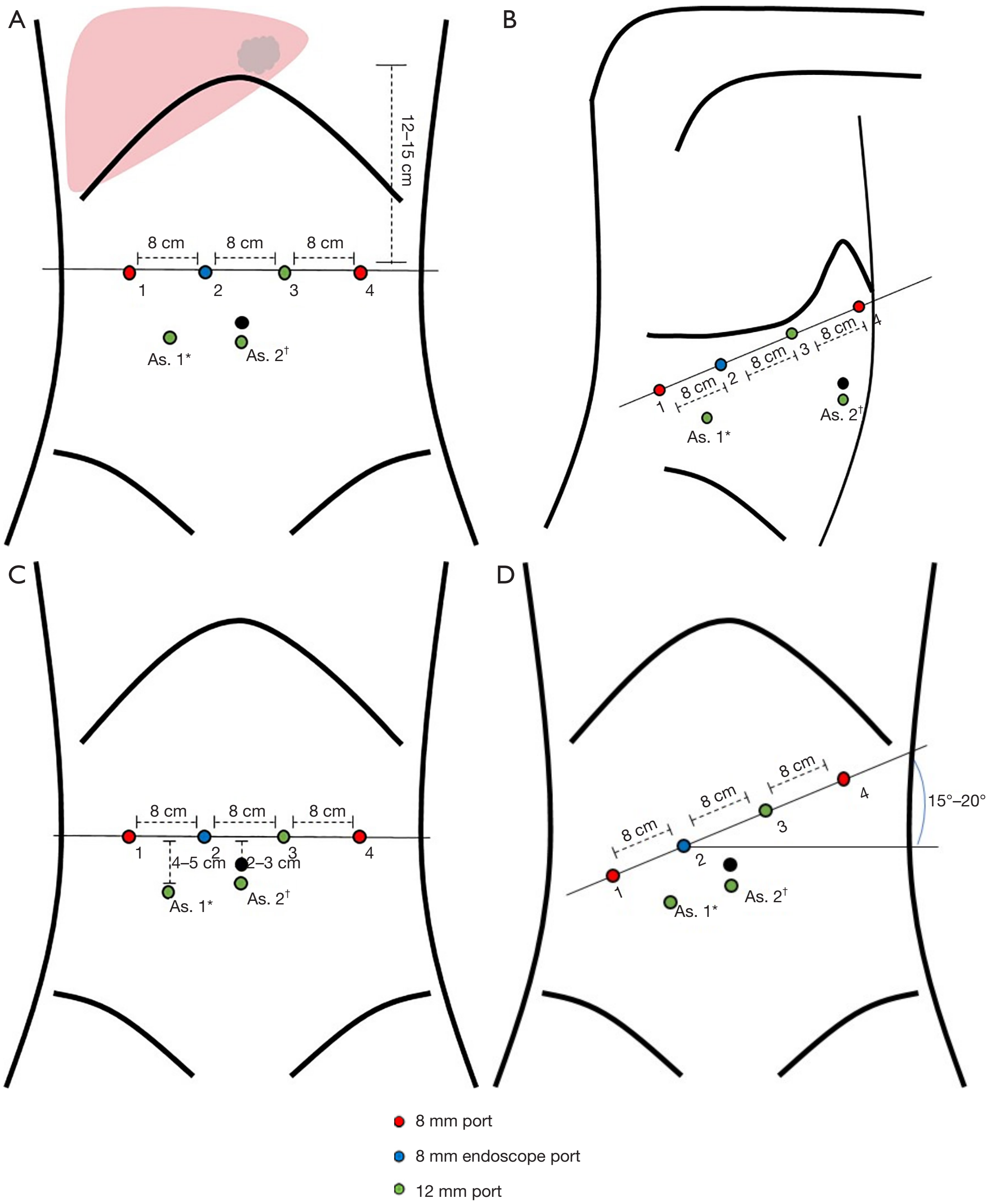


Figure 2 Port placement per hepatectomy type. (A) Partial anterolateral resection; (B) partial posterosuperior resection; (C) left hemihepatectomy; (D) right hemihepatectomy. *, when using the CUSA for parenchymal transection, assistant port 1 (As. 1) may also be placed in line with the other surgical trocars in between robot ports 1 and 2. Additionally, the distance between the first and second robot ports may be increased to 12 cm when using the CUSA; †, planned site of specimen extraction, location may differ depending on method of extraction. The second assistant port (As. 2) is optional and is primarily used in larger resections. CUSA, cavitron ultrasonic surgical aspirator.

Table 1 Instrumentation per operative step

Operation step	Robotic arm 1	Robotic arm 2	Robotic arm 3	Robotic arm 4	Bedside surgeon
Step 1: liver mobilization	Fenestrated bipolar forceps	Endoscope	Monopolar cautery hook, intermittently alternated by monopolar curved scissors	Tip-up fenestrated grasper	Suction-irrigation intermittently alternated by laparoscopic fenestrated grasper
Step 2: pringle maneuver	Fenestrated bipolar forceps		Maryland bipolar forceps	Tip-up fenestrated grasper	Laparoscopic clip applier
Step 3: hilar dissection and cholecystectomy	Fenestrated bipolar forceps		Monopolar cautery hook or Maryland bipolar forceps alternated by monopolar curved scissors	Tip-up fenestrated grasper	Suction-irrigation intermittently alternated by laparoscopic fenestrated grasper
Step 4: resection demarcation	Fenestrated bipolar forceps		Monopolar cautery hook	Tip-up fenestrated grasper	Suction-irrigation intermittently alternated by laparoscopic fenestrated grasper
Step 5: resection/ parenchymal transection†	(I–III, V) Fenestrated bipolar forceps		(I) Vessel sealer	Tip-up fenestrated grasper	(I–IV) Suction-irrigation intermittently alternated by laparoscopic stapler if necessary
	(IV) Bipolar instrument		(II) SynchroSeal		(V) Suction-irrigation and CUSA
			(III) Harmonic ACE		
			(IV) Scissors		
			Robotic stapler‡		
Step 6: hemostasis and biliostasis	Fenestrated bipolar forceps		Monopolar cautery hook or Maryland bipolar forceps	Tip-up fenestrated grasper	Suction-irrigation intermittently alternated by laparoscopic fenestrated grasper
Step 7: drain placement	Fenestrated bipolar forceps		Monopolar cautery hook or Maryland bipolar forceps	Tip-up fenestrated grasper	Laparoscopic fenestrated grasper
Step 8: specimen extraction	Fenestrated bipolar forceps		Monopolar cautery hook or Maryland bipolar forceps	Tip-up fenestrated grasper	Laparoscopic retrieval pouch

Not all variations of the robotic instruments are listed. This overview serves as a general guideline and surgeons may choose to deviate from this based on personal instrument preference. For example, the Cadiere Forceps and Small Graptor can be used as alternatives to the tip-up fenestrated grasper in arm 4. Note that some instruments are not compatible with the drop-in ultrasound probe and robotic bulldog clamps. †, instruments dependent on parenchymal transection technique (I)–(V); ‡, intermittently used through this port, if necessary.

The suggested instrumentation per robotic arm for each step of the procedure is outlined in *Table 1*. The bedside surgeon can be provided with longer surgical instruments (>40 cm) to facilitate reach.

Step 3: mobilizing the liver

In the case of abdominal adhesions perform adhesiolysis as necessary. The falciform ligament is divided from the ventral abdominal wall. A few centimeters of falciform ligament are left attached to the liver to facilitate manipulation.

In LH the left coronary and triangular ligaments are sectioned at this step. In partial PS resection and RH these structures may be left intact.

In partial PS resection and RH the authors recommend

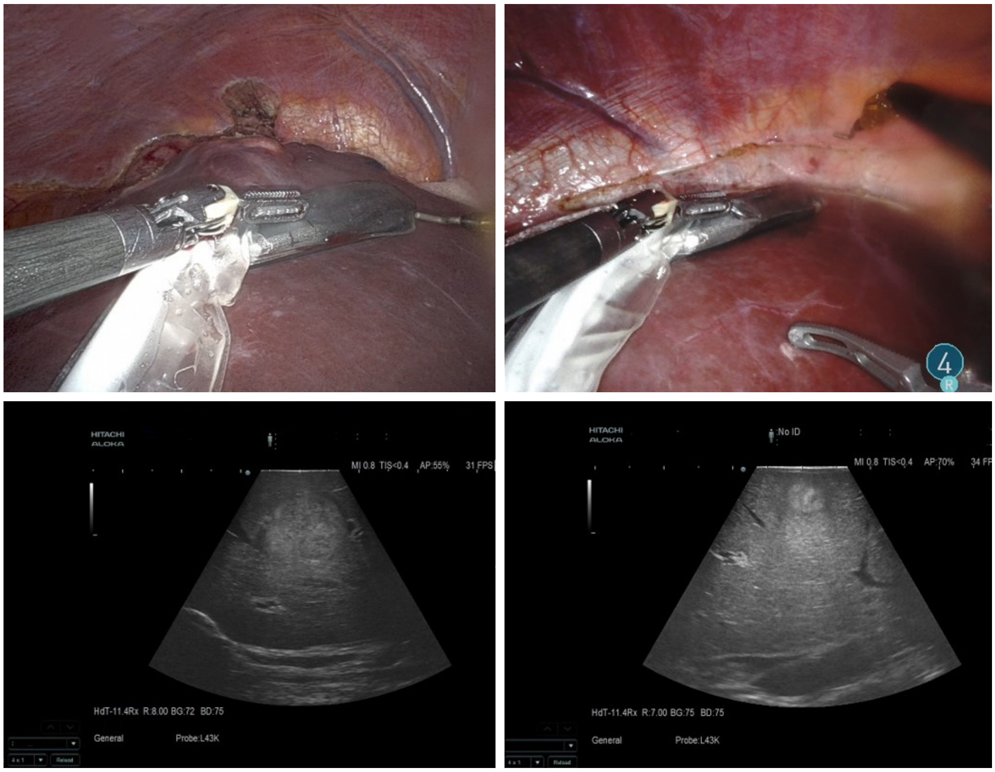


Figure 3 Intraoperative ultrasound with drop-in probe.

a top-down mobilization whereby firstly the upper part of the right coronary ligament is sectioned after which a counterclockwise mobilization is enabled by further sectioning of the remnant part of the right coronary and triangular ligaments.

In partial resections, extent of mobilization is dependent on patient anatomy, extent of resection and surgeon preference.

Step 4: intraoperative ultrasound

Intraoperative ultrasound is performed to assess the extent of the tumor and its relationship with adjacent vasculature. Use ultrasound to assess all lesions detected by preoperative imaging. The authors strongly prefer the use of a drop-in ultrasound probe that can be manipulated by the console surgeon over a laparoscopic probe. The robotic 'endowrist' capability enables the console surgeon to freely manipulate the ultrasound probe with similar degrees of freedom as in open surgery in contrast to the limited movement of laparoscopic probes. During parenchymal transection the ultrasound is utilized to identify intrahepatic anatomy. Visualization of the left and middle hepatic vein (LHV and MHV) are of importance in LH and the right hepatic vein (RHV) and MHV when performing RH. A great advantage of the robotic platform is the possible integration of ultrasound images into the console screen allowing the surgeon to visualize the operative and ultrasound images simultaneously (*Figure 3*).

Step 5: pringle maneuver

Exposure of the hilar structures can be facilitated by using robotic arm 4 to lift the liver with a tip-up instrument. The Pringle maneuver is performed at the discretion of the surgeon. Regardless of whether the Pringle is used, it is recommended to prepare it so that it can be used to control bleeding. The Pringle maneuver can be performed both intra- and extracorporeally. The extracorporeal Pringle is prepared using an umbilical tape and chest tube. Intracorporeally, the Pringle can be performed using a tourniquet (*Figure 4A*) or a modified urinary Foley catheter (Huang's Loop technique) (*Figure 4B*) (23). The advantage of an intracorporeal method is that the Pringle can be

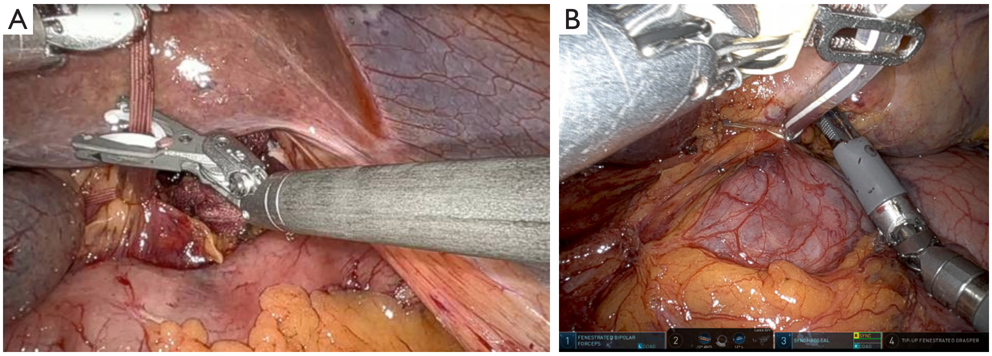


Figure 4 Pringle manoeuvre techniques. (A) Intracorporeal technique with tourniquet; (B) intracorporeal technique with Huang's loop.

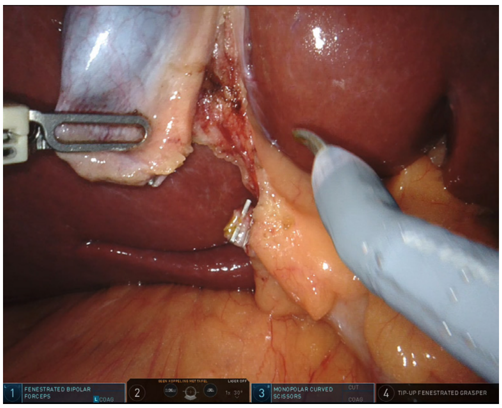


Figure 5 Transection of the cystic duct using robotic monopolar curved scissors following ligation with three titanium clips (two proximally, one distally).

loosened and tightened by the robotic console surgeon. Laparoscopic or robotic bulldog clips can also be used to clamp the portal vein, hepatic artery or both. In cases where hepatic hilum dissection is not required the Pringle can be placed around the whole of the hepatoduodenal ligament, through a small incision in the pars flaccida of the lesser omentum. Alternatively, bulldog clips can be used for selective (segmental) inflow occlusion. Pringle duration is determined by local protocols and surgeon preference.

Step 6: hilar dissection and cholecystectomy

If required, a lymphadenectomy can be performed at this stage. This improves exposure to the hilar structures.

In RH and LH, it is standard to perform a cholecystectomy. In partial AL and PS resections, the choice is left up to surgeon preference. Cholecystectomy is particularly indicated for tumors adjacent to the gallbladder. The cystic duct and artery are identified, dissected, and divided (*Figure 5*). Complete removal of the gallbladder from the liver bed can be left until after liver transection.

Partial AL and PS

In partial liver resections it is usually not necessary to dissect the liver hilum further.

LH (*Figure 6*)

The left hepatic artery (LHA) and left portal vein (LPV) are identified and dissected at the base of the umbilical fissure beyond the caudate branch (LH without segment 1). Vessel loops or sutures are used to mark the LHA and LPV. Aberrant anatomy containing a middle hepatic artery (MHA) may be present. If so, identify and dissect the MHA. Confirm that the correct vessels have been identified by test-clamping the LHA and LPV (and MHA, if present) using a Bulldog clamp. Additionally, Doppler ultrasound is also a helpful tool for identifying the correct vasculature. The vessels are then ligated using (robotic) Hem-o-Lok clips (Teleflex Inc., Morrisville, NC, USA) and divided. Optionally, a ligating suture can be placed around the portal vein to lessen its diameter before applying Hem-o-Lok clips. In cases with wide portal vein anatomy a vascular stapler can be used for its ligation and division. Make note to spare the caudate branch when dividing the LPV.

RH (*Figure 7*)

Dissect the hilar structures cranially from the stumps of the cystic artery and duct. The right hepatic artery (RHA) is identified and dissected. Next, the right portal vein (RPV) is identified and dissected. A vessel loop can be used for marking the vessels. Test-clamping is performed using a Bulldog clamp. After confirmation by visual inspection of liver perfusion and/or ultrasound doppler that the correct

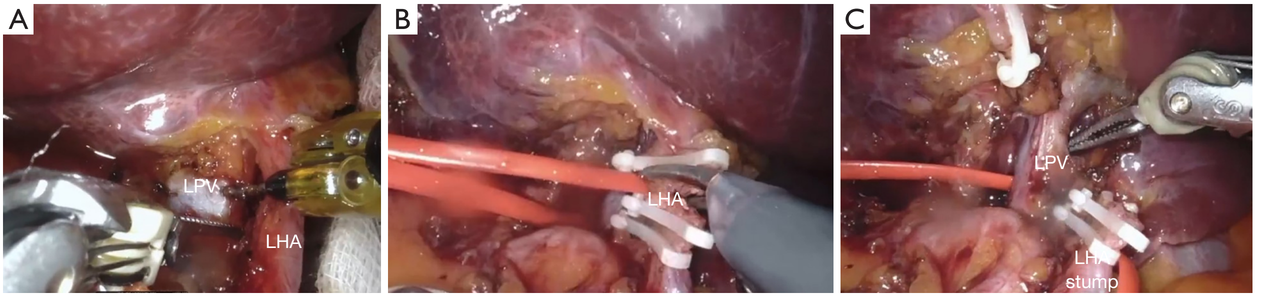


Figure 6 Dissection of the hepatic hilum in left hemihepatectomy. (A) Dissected LHA and LPV; (B) transection of the LHA; (C) dissection of the LPV prior to ligation and transection. LHA, left hepatic artery; LPV, left portal vein.

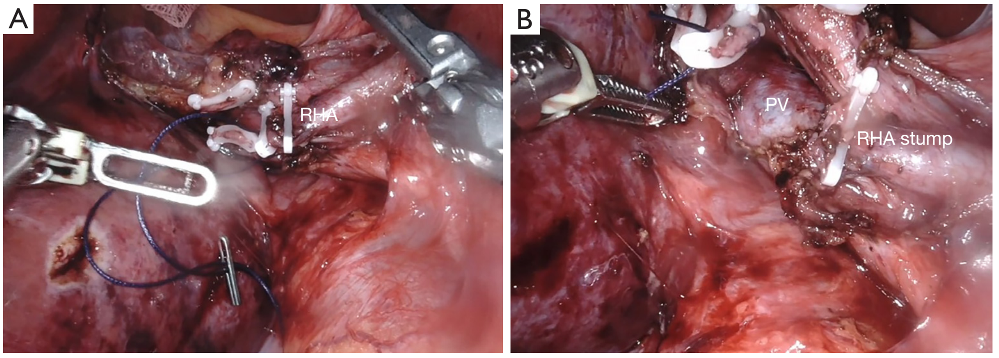


Figure 7 Dissection of the hepatic hilum in right hemihepatectomy following cholecystectomy. (A) Ligation of the RHA with Hem-O-Lok clips before transection; (B) dissection of the PV following RHA transection. RHA, right hepatic artery; PV, portal vein.

vessels have been identified, the RHA and RPV are ligated and divided. To complete the mobilization of the posterior liver the short hepatic vein branches are identified, ligated and consequently divided using the vessel sealer or titanium/Hem-o-Lok clips as appropriate. During this stage robotic arm 4 is helpful in mobilizing the liver to gain exposure to the posterior anatomy.

Step 7: resection demarcation

At this stage, the Firefly mode for fluorescence ICG imaging can be a valuable tool for identifying tumor and transection margins for demarcation. When administered perioperatively it also facilitates biliary tract identification.

Partial AL and PS

The robotic ultrasound is used to demarcate the tumor margins using the cautery hook (*Figure 8*).

LH and RH

Using the cautery hook a line is demarcated along the ischemic border based on visual identification of Cantlie's line (*Figure 9*). Identify the course of the MHV relative to the marked transection line using ultrasound.

Step 8: resection and parenchymal transection

A low central venous pressure (CVP) (<5 mmHg) can help to limit bleeding from the transected plane (24). Fluid restriction and administration of nitroglycerine can be used for achieving the desired CVP (25). Dependent on patient characteristics lowering CVP might not be possible, due to safety concerns. Note that CVP measurements may be difficult to read accurately intraoperatively due to the pneumoperitoneum. Monitoring of stroke volume variation is a good alternative to CVP measurements in minimally invasive resections (26).

At this stage, reducing positive end expiratory pressure (PEEP) can also help to limit blood loss by improving liver outflow (27). Sutures can be applied to the liver border to aid in retraction of the liver during the transection stage. The transection should take place gradually, layer by layer,

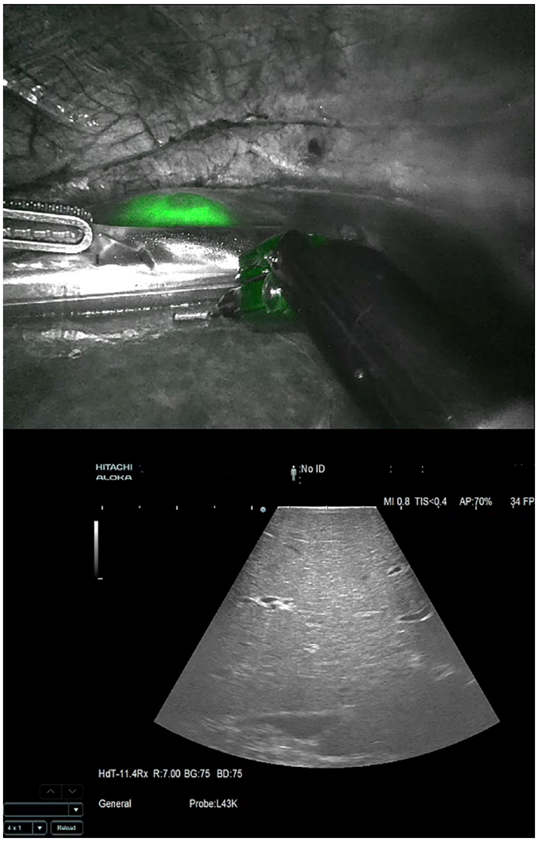


Figure 8 Delineation of the tumor using the cautery hook guided by intraoperative ultrasound and indocyanine green fluorescence imaging.

Figure 9 Demarcation of the border between right and left liver along Cantlie's line.

Table 2 Possible advantages and disadvantages of pure robotic and laparoscopic-assisted approaches to robotic hepatectomy, as perceived by the authors

Pure robotic approach
Advantages
Prevents conflicts during surgery and facilitates key steps
Robotic system is used for operating, not only exposing
Increase in independence of the console surgeon
Potential for machine learning and involvement of artificial intelligence
Lower numbers of ports with therefore a lower total incision length and possibly less pain
No need for a skilled bedside surgeon
Likely lower procedural costs
Disadvantages
No CUSA
Lack of haptic feedback
No possibility of shared decision making between surgeons
Higher threshold for implementation of robotic liver surgery
Laparoscopic-assisted approach
Advantages
Possibility to use ultrasonic parenchyma transection devices
Presence of bedside surgeon eases:
Emergent conversion
Sudden need for laparoscopic assistance (e.g., for bleeding control)
Haptic feedback for bedside surgeon
Shared decision making
Lower threshold to transfer from laparoscopy to robotic surgery
Likely faster learning curve in minimally invasive hepatectomy for bedside surgeon
Disadvantages
Difficult assistant trocar placement for CUSA
Uncomfortable position for bedside surgeon
Decrease in independence for console surgeon
Need for two experienced surgeons
Likely higher procedural costs

CUSA, cavitron ultrasonic surgical aspirator.

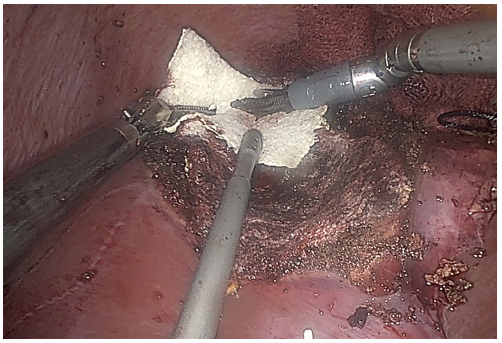


Figure 10 Application of a haemostatic agent to the exposed liver parenchyma following a wedge resection in segment 4a.

while keeping bleedings and bile leaks under control. There are various instruments available for parenchymal transection (a short description of each can be found in Table S1): Vessel Sealer Extend, SynchroSeal, Harmonic ACE, crush-clamp with bipolar and scissors and CUSA (RoboLap approach). The CUSA can only be utilized with laparoscopic assistance from the table surgeon, this technique is described in more detail elsewhere (28,29). The possible advantages and disadvantages of a pure robotic and laparoscopic assisted approach, as perceived by the authors, are summarized in *Table 2*. Depending on the instrument and surgeon preference, port placement may differ slightly (*Figure 2*).

Minor bleedings are controlled using cautery, vessel sealer and titanium clips. Larger vessels and bile ducts and the hepatic pedicle are controlled using Hem-o-Lok clips (Teleflex Inc., Morrisville, NC, USA), vascular stapler or sutures depending on surgeon preference and vessel anatomy. It can be helpful to loop a suture around vessels prior to clipping them in order to ease manipulation. Surgeons should remain cautious of collateral damage by staplers due to their bulky nature. Clamping of the vessel prior to stapling can help in achieving direct hemostasis. For bleeding vessels located intraparenchymally, sutures with large needles may prove helpful in achieving hemostasis. ICG imaging and intraoperative ultrasound can be used repeatedly by the console surgeon in real-time to control tumor margins and ensure important anatomy is sparred.

Partial AL and PS

Parenchymal transection follows the margin previously demarcated on the liver surface with the cautery hook. When encountered, major vasculature and bile ducts are ligated and divided using either sutures, Hem-o-Lok clips or a vascular stapler.

LH

Parenchymal transection takes place from the anterior cortex (along the previously demarcated line) towards the liver hilum. The left hepatic duct is encountered intraparenchymally, where it is ligated and divided using either sutures, Hem-o-Lok clips or a vascular stapler (laparoscopic by table-side surgeon or robotic via a 12-mm port for arm 3). The same is done for the venous branch from segment 4a which typically drains in the MHV. The last phase of the transection is the division of the LHV.

RH

Parenchymal transection takes place from the anterior cortex (along the previously demarcated line) towards the liver hilum. The right hepatic duct is encountered intraparenchymally, where it is ligated and divided using a vascular stapler. The same is done for venous branches draining in the MHV. The last phase of the transection is the division of the RHV. In the presence of accessory branches of the RHV, ligate and divide them as appropriate.

Step 9: hemostasis and biliostasis

If still in place, the Pringle is released. The transection plane is controlled for potential bleeding or bile leaks. At this step it may help to decrease the pneumoperitoneum to under 5 mmHg and increase CVP to 12–14 mmHg. A hemostatic sealant can be applied to the transected surface (*Figure 10*). The Firefly mode can be helpful in detecting bile leakage as it may sometimes be obscured by minor bleeding or blood clots. The timely administration of ICG, 30–45 minutes before, is essential when intending to utilize it for this function. Once adequate hemo- and biliostasis is reached, the falciform ligament is reattached to the anterior abdominal wall in RH. This prevents postoperative displacement of the liver possibly causing torsion of vascular structures with flow obstruction as a consequence.

Step 10: drain placement

In uncomplicated liver resections in patients with low risk for bile leak, drain placement is not indicated (30). Evidence with regards to drain placement in patients with higher risk for bile leak is inconclusive and the choice is therefore left to the discretion of the surgeon. If a drain is placed, consider placing it at locations from which postoperative bleeding and bile leaks are most likely to occur (transected parenchymal plane or liver hilum).

Step 12: specimen extraction

The specimen is placed in an endoscopic retrieval pouch. After undocking the robot, the specimen is removed through a Pfannenstiel incision, site of previous scar or widened trocar incision (if the size of the specimen allows for this). Extraction site should be planned at the time of trocar placement. Once removed, inspect the specimen for the possibility of macroscopically irradical margins. A final inspection of the abdomen is performed after specimen extraction to check for hemo- and biliostasis and confirm drain positioning (if placed).

Step 13: closure

Trocars are removed under direct vision. The port and extraction sites are closed.

Postoperative considerations and tasks

Postoperative management should occur following recommendations of the ERAS Society Guidelines and local protocols (22).

Tips and pearls

Incremental progression

The authors strongly advocate for a gradual stepwise implementation of the robotic hepatectomy technique. Novice robotic liver surgeons are advised to begin with and master technically simple resections such as small anterolateral wedge resections and left lateral sectionectomy before progressing to larger resections. With increasing experience, the technical complexity of the selected procedures can be gradually built up. Even surgeons with extensive laparoscopic experience should implement the robotic technique in a stepwise manner.

Conversions

Conversion to open surgery may be opted for in cases of uncontrolled bleeding, extensive abdominal adhesions or oncological uncertainty. Conversions are performed according to the instructions described by the manufacturer, which can be found at https://manuals.intuitivesurgical.com/home for the da Vinci robotic system. The whole surgical team must be apt in the conversion process to ensure it is done as safely and effectively as possible. Before starting robotic hepatic resections, it is recommended to do more than one conversion dry run with the surgical team and evaluate if instructions are clear and no obstructions in the conversion procedure are met. A swift conversion saves blood loss and helps to prevent postoperative complications.

Discussion

Above, we described a step-by-step protocol for robotic hepatectomy agreed upon by an international group of expert liver surgeons in an attempt to standardize the surgical technique. It is the intention that this protocol be used for educational purposes. Additionally, it can act as a starting point for further optimization and refinement of the robotic hepatectomy technique.

Standardized tools for training surgeons in robotic hepatectomy are currently lacking. The LIVEROBOT training program for robotic liver surgery, endorsed by the European-African Hepato-Pancreato-Biliary Association (E-AHPBA), and the European Registry of Minimally Invasive Liver Surgery (E-MILS), offers a stepwise proficiency-based curriculum (NCT05723705) (31). Similar program formats have proved effective for training surgeons in robotic pancreatoduodenectomy (32,33). A standardized technique description helps trainees to familiarize themselves with the procedure and ensures consistency in the implementation of the technique. Furthermore, a well-defined step-by-step protocol could help to homogenize and harmonize the functioning of an operating team.

The robotic platform is a relatively new tool for performing minimally invasive liver surgery. New surgical techniques should follow the IDEAL framework of innovation; idea, development, exploration, assessment and long-term follow-up (34). It can be said that robotic hepatectomy is simultaneously in the latter four stages. Various studies have already reported on the outcomes of robotic hepatectomy compared with the more widely used laparoscopic technique (corresponding with IDEAL stages E, A and L) (1,8). However, there is still much heterogeneity in the surgical techniques being used (corresponding with IDEAL stage D) (35).

The authors recognize there is large intraoperative variability in surgical methods for robotic hepatectomy and take this into account in the protocol. In certain steps, like for parenchymal transection, multiple viable techniques are outlined, and the choice of method is left to the surgeons' discretion. The current heterogeneity of operative techniques between robotic liver surgeons impedes the creation of one uniform protocol. To our best knowledge, there are no studies comparing the above techniques for robotic hepatectomy and so evidence-based recommendations are yet to be made. Future studies should address the impact of surgical technique on patient outcomes to determine the most appropriate methods. Meanwhile, the choice of technique will remain a matter of surgeon preference.

Robotic hepatectomy is still in its early developmental stages. Surgeons feel there is still room for improvement with regards to the available hardware (10). New developments in robotic instrumentation could facilitate parenchymal transection.

It is important to safeguard patients' health and safety when adopting novel surgical techniques. Patient outcomes should be monitored to ensure a certain level of surgical quality is being met. The textbook outcome in liver surgery (TOLS) is a composite measure taking a multitude of operative and postoperative outcomes into account (36). Such tools are helpful for auditing and monitoring surgical success.

High procedural costs are a major concern for the implementation of robotic hepatectomy in standard practice (37). Studies have shown advantages for the robotic technique in terms of patient outcomes, especially in more technically complex resections (6-9). However cost-effectiveness for the technique still remains to be demonstrated. Future studies should continue to explore the potential benefits of robotic hepatectomy in comparison with conventional techniques.

Conclusions

An expert consensus on the surgical technique for robotic hepatectomy is described, highlighting key steps and important considerations. Standardization of the robotic hepatectomy procedure is an important preliminary step for further widespread dissemination and ascertaining surgical quality.

Acknowledgments

Funding: This work was supported by a grant from Intuitive Foundation for the development of the LIVEROBOT European training program in robotic liver surgery.

Footnote

Reporting Checklist: The authors have completed the SUPER reporting checklist. Available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-23-510/rc

Peer Review File: Available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-23-510/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-23-510/coif). L.A. serves as an unpaid editorial board member of *HepatoBiliary Surgery and Nutrition*. J.A., L.A., D.J.L., J.H., M.D.H., N.K. and R.J.S. are proctors for Intuitive Surgical (Intuitive Surgical Inc., Sunnyvale, CA, USA). The other author has no conflicts of interests to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this article were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this article and accompanying video and images. A copy of the written consent is available for review by the editorial office of this journal.

References

1. Görgec B, Zwart M, Nota CL, et al. Implementation and Outcome of Robotic Liver Surgery in the Netherlands: A Nationwide Analysis. Ann Surg 2023;277:e1269-77.
2. Zhang XL, Liu RF, Zhang D, et al. Laparoscopic versus open liver resection for colorectal liver metastases: A systematic review and meta-analysis of

studies with propensity score-based analysis. Int J Surg 2017;44:191-203.
3. Abu Hilal M, Aldrighetti L, Dagher I, et al. The Southampton Consensus Guidelines for Laparoscopic Liver Surgery: From Indication to Implementation. Ann Surg 2018;268:11-8.
4. van der Poel MJ, Besselink MG, Cipriani F, et al. Outcome and Learning Curve in 159 Consecutive Patients Undergoing Total Laparoscopic Hemihepatectomy. JAMA Surg 2016;151:923-8.
5. Ayabe RI, Azimuddin A, Tran Cao HS. Robot-assisted liver resection: the real benefit so far. Langenbecks Arch Surg 2022;407:1779-87.
6. Tranchart H, Ceribelli C, Ferretti S, et al. Traditional versus robot-assisted full laparoscopic liver resection: a matched-pair comparative study. World J Surg 2014;38:2904-9.
7. Casciola L, Patriti A, Ceccarelli G, et al. Robot-assisted parenchymal-sparing liver surgery including lesions located in the posterosuperior segments. Surg Endosc 2011;25:3815-24.
8. Chong CC, Fuks D, Lee KF, et al. Propensity Score-Matched Analysis Comparing Robotic and Laparoscopic Right and Extended Right Hepatectomy. JAMA Surg 2022;157:436-44.
9. Cipriani F, Fiorentini G, Magistri P, et al. Pure laparoscopic versus robotic liver resections: Multicentric propensity score-based analysis with stratification according to difficulty scores. J Hepatobiliary Pancreat Sci 2022;29:1108-23.
10. Zwart MJW, Görgec B, Arabiyat A, et al. Pan-European survey on the implementation of robotic and laparoscopic minimally invasive liver surgery. HPB (Oxford) 2022;24:322-31.
11. Couinaud C. Definition of hepatic anatomical regions and their value during hepatectomy (author's transl). Chirurgie 1980;106:103-8.
12. Tanaka S, Kawaguchi Y, Kubo S, et al. Validation of index-based IWATE criteria as an improved difficulty scoring system for laparoscopic liver resection. Surgery 2019;165:731-40.
13. Kawaguchi Y, Tanaka S, Fuks D, et al. Validation and performance of three-level procedure-based classification for laparoscopic liver resection. Surg Endosc 2020;34:2056-66.
14. Halls MC, Berardi G, Cipriani F, et al. Development and validation of a difficulty score to predict intraoperative complications during laparoscopic liver resection. Br J Surg 2018;105:1182-91.
15. Linn YL, Wu AG, Han HS, et al. Systematic review and meta-analysis of difficulty scoring systems for laparoscopic and robotic liver resections. J Hepatobiliary Pancreat Sci 2023;30:36-59.
16. Goh BKP, Prieto M, Syn N, et al. Validation and comparison of the Iwate, IMM, Southampton and Hasegawa difficulty scoring systems for primary laparoscopic hepatectomies. HPB (Oxford) 2021;23:770-6.
17. Barron JO, Orabi D, Moro A, et al. Validation of the IWATE criteria as a laparoscopic liver resection difficulty score in a single North American cohort. Surg Endosc 2022;36:3601-9.
18. Labadie KP, Droullard DJ, Lois AW, et al. IWATE criteria are associated with perioperative outcomes in robotic hepatectomy: a retrospective review of 225 resections. Surg Endosc 2022;36:889-95.
19. Wakabayashi T, Cacciaguerra AB, Abe Y, et al. Indocyanine Green Fluorescence Navigation in Liver Surgery: A Systematic Review on Dose and Timing of Administration. Ann Surg 2022;275:1025-34.
20. Franz M, Arend J, Wolff S, et al. Tumor visualization and fluorescence angiography with indocyanine green (ICG) in laparoscopic and robotic hepatobiliary surgery - valuation of early adopters from Germany. Innov Surg Sci 2021;6:59-66.
21. Felli E, Ishizawa T, Cherkaoui Z, et al. Laparoscopic anatomical liver resection for malignancies using positive or negative staining technique with intraoperative indocyanine green-fluorescence imaging. HPB (Oxford) 2021;23:1647-55.
22. Joliat GR, Kobayashi K, Hasegawa K, et al. Guidelines for Perioperative Care for Liver Surgery: Enhanced Recovery After Surgery (ERAS) Society Recommendations 2022. World J Surg 2023;47:11-34.
23. Huang JW, Su WL, Wang SN. Alternative Laparoscopic Intracorporeal Pringle Maneuver by Huang's Loop. World J Surg 2018;42:3312-5.
24. Li Z, Sun YM, Wu FX, et al. Controlled low central venous pressure reduces blood loss and transfusion requirements in hepatectomy. World J Gastroenterol 2014;20:303-9.
25. Sand L, Lundin S, Rizell M, et al. Nitroglycerine and patient position effect on central, hepatic and portal venous pressures during liver surgery. Acta Anaesthesiol Scand 2014;58:961-7.
26. Ratti F, Cipriani F, Reineke R, et al. Intraoperative monitoring of stroke volume variation versus central

venous pressure in laparoscopic liver surgery: a randomized prospective comparative trial. HPB (Oxford) 2016;18:136-44.
27. Sand L, Rizell M, Houltz E, et al. Effect of patient position and PEEP on hepatic, portal and central venous pressures during liver resection. Acta Anaesthesiol Scand 2011;55:1106-12.
28. Aldrighetti L, Catena M, Ratti F. Maximizing Performance in Complex Minimally Invasive Surgery of the Liver: the RoboLap Approach. J Gastrointest Surg 2022;26:1811-3.
29. Aldrighetti L, Cipriani F, Fornoni G, et al. Robo-Lap Approach for Anatomical Resections of Postero-Superior Liver Segments by Indocyanine Green Fluorescence: Intraoperative Navigation Based on Vascular Landmarks. Chirurgia (Bucur) 2023;118:170-9.
30. Arita J, Sakamaki K, Saiura A, et al. Drain Placement After Uncomplicated Hepatic Resection Increases Severe Postoperative Complication Rate: A Japanese Multi-institutional Randomized Controlled Trial (ND-trial). Ann Surg 2021;273:224-31.
31. Swijnenburg RJ. Impact of a European Training Program for Robotic Liver Surgery (LIVEROBOT) ClinicalTrials.gov2023. Available online: https://clinicaltrials.gov/ct2/show/NCT05723705
32. Zwart MJW, Nota CLM, de Rooij T, et al. Outcomes of a Multicenter Training Program in Robotic Pancreatoduodenectomy (LAELAPS-3). Ann Surg 2022;276:e886-95.
33. Hogg ME, Tam V, Zenati M, et al. Mastery-Based Virtual Reality Robotic Simulation Curriculum: The First Step Toward Operative Robotic Proficiency. J Surg Educ 2017;74:477-85.
34. McCulloch P, Altman DG, Campbell WB, et al. No surgical innovation without evaluation: the IDEAL recommendations. Lancet 2009;374:1105-12.
35. Ho CM, Wakabayashi G, Nitta H, et al. Systematic review of robotic liver resection. Surg Endosc 2013;27:732-9.
36. Görgec B, Benedetti Cacciaguerra A, Lanari J, et al. Assessment of Textbook Outcome in Laparoscopic and Open Liver Surgery. JAMA Surg 2021;156:e212064.
37. Miller HP, Hakim A, Kellish A, et al. Cost-Benefit Analysis of Robotic vs. Laparoscopic Hepatectomy: A Propensity-Matched Retrospective Cohort Study of American College of Surgeons National Surgical Quality Improvement Program Database. Am Surg 2022;88:2886-92.

Cite this article as: Pilz da Cunha G, Lips DJ, Ahmad J, Kvarnström N, Aldrighetti L, D'Hondt M, Hagendoorn J, Swijnenburg RJ. A European expert consensus surgical technique description for robotic hepatectomy. HepatoBiliary Surg Nutr 2024;13(6):991-1006. doi: 10.21037/hbsn-23-510

Supplementary

Table S1 Parenchymal transection techniques

Instrument	Description	Advantages and disadvantages	Robotic arm
Vessel Sealer Extend	Robotic energy device for sealing and cutting. The liver parenchyma is placed and pinched in between the instrument jaws. With a pedal press the tissue can be sealed and with another pedal press cut. Larger intraparenchymal vessels and bile ducts are first dissected before being addressed individually	(+) articulating wrist (–) relatively bulky instrument jaws	3
Harmonic ACE	Robotic energy device that utilizes ultrasonic vibration as a means to coagulate and cut tissue. Due to its inability to articulate, the Harmonic ACE must be aligned correctly with the transection plane at introduction in the abdomen.	(–) no articulating function	3
SynchroSeal	Robotic energy device for sealing and cutting. The liver parenchyma is placed and pinched in between the instrument jaws. With a single pedal press the tissue can be cut and sealed. Its articulating wrist and thin, curved jaws allow for finer tissue dissection compared with the vessel sealer. Larger intraparenchymal vessels and bile ducts are first dissected before being addressed individually	(+) articulating wrist (+) fine instrument jaws for dissection	3
Clamp-Crush (Bipolar and Scissors)	The clamp-crush technique is the conventional method for liver transection. The liver parenchyma is 'crushed' between the jaws of the bipolar instrument. Remaining vessels and bile ducts are consequently ligated and divided	(+) no specialized equipment (–) requires intermittent inflow obstruction	1—Bipolar 3—Scissors
CUSA (Laparoscopic-assisted)	The Cavitron Ultrasonic Surgical Aspirator (CUSA) uses ultrasonic energy to fragment and aspirate the parenchymal tissue. Biliary and vascular structures are mostly spared and can then consequently be ligated and divided. The CUSA is not available as a robotic instrument.	(+) Sparing of vessels and biliary structures (-) laparoscopic device thus no wrist articulation	Assistant port 1 in LH, partial PS and AL Assistant port 2 in RH

https://dx.doi.org/10.21037/hbsn-23-510