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Liver parenchyma dissection in Totally robotic liver surgery - Results of the first 100 patients using the Robotic Harmonic curved shears

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Abstract

Aim: Robotic liver surgery (RLS) is a feasible and safe procedure. However, limitations of the robotic instruments used for liver parenchyma dissection compared to laparoscopic and open approaches are major drawbacks of RLS. There is no established technique for liver parenchymal dissection in RLS. The aim of this study is to discuss the surgical outcomes of Totally RLS using Robotic Harmonic curve shears at the University Hospital of Copenhagen, Denmark.

Methods: Between June 2019 and June 2022, RLS was performed with 100 patients. Patient variables and short-term outcomes were retrospectively analysed.

Results: The mean patient age was 63.1 years; the median operating time was 246 min; and the median estimated blood loss was 100 mL. Thirty-two patients underwent subsegmentectomy, 18 mono-segmentectomies, 25 bi-segmentectomies, and 25 major hepatectomies. One patient (1.0%) required conversion to open surgery. Five patients experienced postoperative major complications (Clavien-Dindo classification ≥ IIIa) while no mortalities occurred. Median length of hospital stay was 3 days. There were no significant differences between minor and major hepatectomies in any of the factors.

Conclusion: Based on our study of minor and major hepatectomies in Totally RLS, we conclude that the use of the Robotic Harmonic curve shear for liver parenchyma dissection is feasible and safe.

Keywords: Robotic liver surgery, technique, liver parenchyma dissection, the Robotic Harmonic curved shears, Trans-parenchymal Glissonian first approach

INTRODUCTION

Although open liver surgery (OLS) used to be associated with a high mortality rate, recent advances in surgical techniques, preoperative assessment of liver reserve, and improved patient management in the pre- and postoperative period have now resulted in safe surgery and evidence[1]. Since the first report of laparoscopic liver surgery (LLS) in 1991, a number of techniques have been reported with good results[2-8]. Robotic liver surgery (RLS) was first presented in 2003 by Giulianotti[9,10]. By 2011, 70 cases of RLS had already been successfully performed. Considering the growing body of evidence, a consensus has emerged around the safety of RLS, and it may be that more surgeons will take advantage of robotics in the future[9-14].

With regard to both OLS and LLS, a variety of techniques and devices have been developed for liver parenchyma dissection, including clamp-crushing techniques, ultrasonic surgical aspirators (CUSA), sealing devices, staplers, and mono and bipolar devices. However, one of the major challenges in RLS concerns the technique of liver parenchyma dissection. This is due to the lack of optimal robotic instruments and the absence of standardised techniques for dissection. This is a great concern for hepato-pancreato-biliary (HPB) surgeons performing RLS.

Currently, common liver parenchyma dissection during RLS is most frequently classified into the following four groups. (1) Crush/clamp using a robotic bipolar device; (2) Crush/clamp using a Vessel Sealer; (3) Robotic Harmonic curved shears with laparoscopic CUSA/Water jet: Hybrid RLS; and (4) Robotic Harmonic curved shears. For robotic surgery, there is no established technique for the liver parenchyma dissection in RLS. The aim of this study is to describe the technique for liver parenchymal dissection using Robotic Harmonic Curved Shears in Totally RLS and report the surgical results of continuous RLS.

Context and relevance

RLS was first introduced by Giulianotti in 2003. Several different studies of RLS have been reported to date, and a consensus is forming on its safety. One of the major challenges in RLS concerns the technique of liver parenchymal dissection. This is due to the lack of optimal robotic instruments and the absence of standardised techniques. As a result, the choice of liver parenchymal dissection methods varies from one centre to another and is often based on individual surgeon preferences. However, these techniques cannot be considered as the gold standard since there are several limitations. We have established safe and effective techniques for liver parenchyma dissection in Totally RLS by further developing and refining the use of robotic Harmonic curved shears.

METHODS

During the study period, the indications for the use of the minimally invasive robotic approach were discussed at a conference prior to admission for all patients requiring liver resection. A robotic approach in liver surgery was offered to selected patients based on the clinical status and characteristics of the liver lesion. The clinical factors investigated were assessed in terms of demographics, surgical procedures, and postoperative outcomes. Estimated blood loss (EBL) was identified in anaesthetic records, and operative time (OT) was defined as the time from skin incision to wound closure. No adjustment of OT for lysis of adhesions was made. One of the measures to assess surgical difficulty was the IWATE criteria introduced by

Wakabayashi *et al*. in 2016[15,16]. Postoperative complications were classified according to the Clavien-Dindo classification (CD). Major complications were defined as events requiring surgical, endoscopic, or radiological intervention (CD grade ≥ IIIa). We assessed differences in outcomes between patients who underwent minor hepatectomies compared with major hepatectomies.

Definition of the surgical procedure

Minor liver resection was defined as a Couinaud's resection of two or fewer segments, i.e., a subsegmentctomy mono or bisegmentectomy[17]. A major hepatic resection was defined as a Couinaud's trisection or greater[17] and a technically difficult liver resection, i.e., either right posterior sectionectomy (S6 + S7), extended right posterior sectionectomy (S6 + S7 + right hepatic vein), or right anterior sectionectomy (S5 + S8). In addition, subsegmentectomy and monosegmentectomy were defined by the Methods section of the literature reported by Wakabayashi *et al*.[18].

Exclusion criteria

Exclusion criteria included general contraindications to insufflation, cardiac or respiratory failure, and/or an American Society of Anaesthesiologists (ASA) physical status of III or higher; liver cirrhotic cases with Child-Pugh score B and patients with a history of OLS or LLS were excluded.

Developing an RLS program

Approximately 400 liver operations are performed annually at the hospital. For minimally invasive approaches, LLS was introduced in 2009 and has been offered at a rate of 10%-15% in all liver surgery performed per year. Robotic systems have several clear advantages over conventional laparoscopic surgery. For example, in the Endowrist technology, these are a 7° degree of freedom, the ability to reach upper posterior lesions, improved suturing capabilities, elimination of physiological tremor and superior surgeon ergonomics. Nevertheless, disadvantages of robotic surgery have been additional costs and longer OT compared to laparoscopic approaches[19]. However, due to the above-mentioned advantages and a strong belief that these robotic surgeries will become established and gradually develop, our centre decided to introduce robotic systems for liver surgery starting in 2019. With regard to the expansion of surgical indications for RLS, we incorporated the recommendations of the Morioka Conference on LLS (2014) into our RLS programme and introduced it, starting with minor hepatectomies. With increasing experience and proficiency, we gradually increased the difficulty level and performed a major hepatectomy in line with the IWATE Criteria[15,16].

Surgical procedures of RLS

All 100 consecutive RLS procedures were performed using the da Vinci® Si surgical system (Intuitive Surgical, Inc., Sunnyvale, CA, USA). All operations were provided by senior surgeons. The patient was positioned supine in a 10° reverse Trendelenburg position with the legs apart and the operating table tilted 30° to the left for right lobe tumours. Pneumoperitoneal pressure was maintained at 8-12 mmHg, and the Airseal® system was used. Usually, seven trocars were used for RLS and were concentrically positioned in the targeted liver region. With regard to the robotic arm, the Maryland bipolar forceps/Fenestrated bipolar forceps are very useful for both the control of small amounts of bleeding from the liver resection surface and the dissection and isolation of major vessels deep in the liver parenchyma due to the EndoWrist function. The robotic approach also uses a laparoscope. Therefore, due to the superiority of the laparoscopic field of view, dissection of the liver parenchyma in RLS is best performed by a caudal-dorsal approach[20,21]. A third arm is always used to develop the dissection plane and to preserve the field. Vessels and bile ducts > 3 mm in diameter are ligated with Weck® Hem-o-lok® clips, and Glissonian pedicles and major hepatic veins are dissected using Endo GIA™ Reload with Tri-Staple™ technology [Figure 1]. The Pringle manoeuvre was mainly used for anatomical liver resections requiring more than one segment. Occlusion is performed

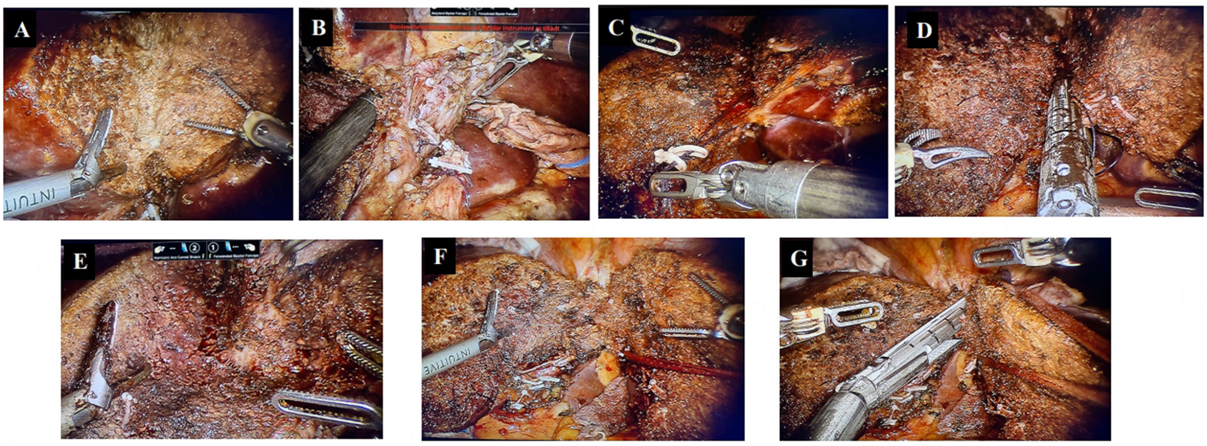

Figure 1. LPD (Liver Parenchymal dissection) using Robotic Harmonic curved shears with caudal approaches for Extended left hemi-hepatectomy: Trans-parenchymal Glissonian first approach. (A) LPD using Robotic Harmonic curved shears; (B-D) Exposure of the left Glissonian pedicle with Maryland and the pedicle is then transected through a laparoscopic Endo-GIA; (E) After the left Glissonian pedicle, the remaining liver was resected along the right side of the middle hepatic vein (MHV) with hanging tape; the MHV was fully exposed on the resection plane; (F) The main root of the MHV is encountered, and LPD with Robotic Harmonic curved shears towards the centre while exposing MHV; (G) MHV is then transected through a laparoscopic Endo-GIA.

intermittently, alternating between 15-20 min of occlusion and 5 min of reperfusion. Central venous pressure is maintained below 5 mmHg during liver parenchymal dissection. Intraperitoneal pressure is set at 8 mmHg during hemostatic evaluation to ensure bipolar hemostasis. The amputation surface is finally sprayed with SURGICEL®.

Technique of liver parenchyma dissection using the Robotic Harmonic curved shears

Harmonic curved shears and CUSA share the same operating principle of utilising ultrasonic vibrations. CUSA uses ultrasound energy to crush and aspirate liver parenchyma tissue, exposing biliary and vascular structures. Therefore, we applied this principle to RLS using the Robotic Harmonic curved shears and focused on the fact that only the liver parenchyma can be selectively crushed while leaving the blood vessels and biliary structures intact. For our standardised method for liver parenchyma dissection, we use the Robotic Harmonic curved shears at power level 3 while applying only the tip of the Harmonic curved shears to the liver parenchyma. With a gentle movement to the left and right side controlled by visual haptics, the transection takes place with minimal blood loss. This power level 3 is particularly useful for dissecting major hepatic veins to reduce the risk of accidental venous injury. Parenchymal dissection generally begins by dissecting both the capsule and the superficial layer of the liver (1 cm into the liver parenchyma), where no major vascular or bile duct structures are located. If the Robotic harmonic shear is activated first before the device is completely closed, it is possible to achieve coagulation and haemostasis of the liver parenchyma at the same time. Dissection of deep liver parenchyma carries a high risk of bleeding from fine intraparenchymal structures (e.g., hepatic veins, blood vessels, and bile ducts). We carefully expose these and use robotic harmonic curve shears in combination with robotic bipolar forceps for haemostasis and dissection. To achieve hemostasis, both the Robotic Harmonic curved shears and the Robotic bipolar forceps are used concomitantly. The Robotic Harmonic curved shears can be handled using the right or left side of the transection plane at the surgeon's preference.

In a systematic review of hepatic vein injuries, Monden *et al*. classified them into two categories[22]. They report that pull-up injuries occur when the CUSA moves from the root to the peripheral side and can be controlled by compression. However, split injuries cause major haemorrhage at the bifurcation of the hepatic veins or at the confluence of the hepatic veins. Therefore, with regard to biliary and vascular structures, the basic approach is to expose the hepatic veins and Glissonian pedicle by gently moving the tip of the Robotic Harmonic curved shears from the root side to the peripheral side while carefully excising and exposing the surrounding liver parenchymal layer to prevent splitting injuries in our method. A video of the left hemi hepatectomy [Supplementary Video 1] is provided as a supplementary file to enhance understanding of liver parenchymal dissection using Robotic Harmonic curved shears.

Methods for exposing the target Glissonian pedicle for anatomical resection

In anatomical liver resection for LLS, the Glissonian pedicle isolation using the extrahepatic Glissonian pedicle approach with or without liver parenchymal dissection is becoming widely accepted as an essential procedure from the viewpoint of safety and curativeness[14]. However, the surgical technique has not been standardised due to a lack of anatomical understanding. These problems are the risk of damage to adjacent Glissonian pedicles and the risk of transection due to misidentification of the Glissonian pedicles, and we are very concerned about these complications. Moreover, in RLS or LLS, hilar dissection remains a difficult technique[14]. Therefore, we first perform a one-way liver parenchymal dissection from the extrahepatic caudal or dorsal side to the deep part of the liver and then expose the root of the target Gleason pedicle intrahepatically (Trans-parenchymal Glissonian first approach). This method can be applied safely and easily by using a Pringle manoeuvre. After the liver parenchyma has been completely dissected, the target Glissonian pedicle can be exposed and transected with little risk of accidental damage to the posterior surface of the vessel. Identification of the target Glissonian pedicle was performed directly using an intraoperative ultrasound probe by the console surgeon, involving both the surgical field and a fully robotic ultrasound examination in real time. This approach helped accurately understand the anatomy, blood vessels, and the sequential detection and dissection of tumours. After identification of the target Glissonian pedicle, a robotic monopolar scissor was used to mark the liver surface. ICG fluorescence was also performed in RLS. A further advantage of the robotic system is the integrated near-infrared fluorescent Firefly® camera. This feature enables real-time anatomical visualisation with ICG tumour staining, angiography, and cholangiography[23]. To expose the root of the Glissonian pedicle for anatomical resection, a one-way liver parenchymal dissection was first advanced from the extrahepatic to the deep part of the liver by a caudal or dorsal approach. The target Glissonian pedicle root was then exposed. The Glissonian pedicle root or hepatic vein was carefully dissected from the central to the peripheral side essentially to prevent splitting damage with Robotic Harmonic curved shears[22]. After exposing these, confirm that it was the target Glissonian pedicle by intraoperative ultrasonography or the Firefly mode. It was then temporarily clamped using laparoscopic bulldog forceps to create an ischemic zone on the liver surface. Intraoperative ultrasonography or the Firefly mode confirms that this was the tumour site, and the ischemic area was used as the boundary for resection. The target Glissonian pedicle or hepatic vein was then exposed and transected safely and accurately. The cyanotic area was delineated on the liver surface with a Robotic Monopolar Curved instrument, and the liver parenchymal dissection was made along that line with Robotic Harmonic curved shears.

For sub-segmentectomy, we first advanced one-way liver parenchymal dissection from the extrahepatic area to the deep part of the liver by a caudal or dorsal approach (Trans-parenchymal Glissonian first approach). Then, we exposed the third or fourth target Glissonian pedicle, which was then isolated and transected within the liver.

The use of the Pringle manoeuvre is usually routine in the anatomical resection of one or more areas. However, in sub-segmentectomy, it has been added when haemorrhage during parenchymal dissection cannot be effectively controlled.

Liver resection in the left-sided liver [Figure 1 and Supplementay Video 1]

When performing a left or extended left hemihepatectomy with a caudo-dorsal approach in LLS, the middle or left hepatic vein root is first exposed, and the liver parenchymal dissection proceeds along the hepatic vein from its root to the periphery[20-22]. In the future, our centre plans to use the robotic approach for donor liver surgery for living donor liver transplantation (Left-side hepatectomy in living donors). The disadvantage of the dorsal approach is that it does not ensure donor safety, as it has the potential to damage the root of the left hepatic vein or the middle hepatic vein or possibly cause air embolisation due to venous injury. Furthermore, exposure of the main hepatic vein root through an extrahepatic approach in the early stages of operation remains a difficult procedure in both LLS and RLS[14]. For this reason, we have preferred the caudal approach for liver resection in the left-sided liver. With regard to liver resection in the left-side liver with robotic approaches, surgery begins with mobilisation of the left liver lobe.

For anatomical resection, the target Glissonian pedicle was identified by intraoperative ultrasound and a liver parenchymal dissection was performed with a caudal approach to expose them intrahepatically (Trans-parenchymal Glissonian first approach).

For the left hemihepatectomy, the left hepatic artery and left portal vein are identified along the left side of the resected hepatoduodenal ligament and divided with robotic Hem-o-lok clips and sutures after ensuring correct anatomical interpretation. Extrahepatic Hilar dissection was always performed on these structures. Liver parenchymal dissection was performed in a layer-by-layer fashion using a Robotic harmonic shear from the caudal side of the liver to the centre of the liver [Figure 1A]. A third robotic arm was used to hold the liver resection line. Bipolar forceps and Robotic Harmonic shear were used for haemostasis. Then, a one-way liver parenchymal dissection was first advanced from the extrahepatic to the deep part of the liver by a caudal approach to identify the root of the target Glissonian pedicle or main hepatic vein with a Trans-parenchymal Glissonian first approach [Figure 1B]. After exposing these, the Robotic Harmonic curved shears were used to carefully dissect the liver parenchyma approximately 1 cm peripherally from the root of the main hepatic vein or target Glissonian pedicle. Then, these were isolated with robotic Maryland forceps [Figure 1B and C]. Hem-o-lok or Laparoscopic Endo-GIA was used to transect the main hepatic veins and the target Glissonian pedicle [Figure 1E-G]. The surface of the remaining liver was identified, and a specimen was taken through a small midline incision.

Liver resection of the right-side liver

In liver resection of the right-side liver, a retrograde cholecystectomy is performed as the initial step.

For anatomical resection, the right hemi liver was first mobilised, and a one-way liver parenchymal dissection proceeded with a caudal or dorsal approach from the extrahepatic region to the deep part of the liver. The target Glissonian pedicle root or hepatic vein was exposed intrahepatically and then transected (Trans-parenchymal Glissonian first approach).

For the right hemihepatectomy, a combination of individual dissection of the hepatic artery, portal vein, and intrahepatic bile duct should be used before liver parenchyma dissection is performed. Extrahepatic Hilar dissection was always performed on these structures. The right hepatic artery and right portal vein were ligated and then transected with a Robotic Hem-o-lok clip. The right bile duct was either dissected extrahepatically or intrahepatically, depending on the case. ICG fluorescence can be easily used at any point to help identify the biliary anatomy[23]. The second stage of the procedure was liver mobilisation. First, the falciform and coronary ligament were dissected. The inferior surface of the right hepatic lobe was then lifted with the third arm to expose the inferior vena cava. The short hepatic vein was dissected with a robotic Hem-o-lok. Dissection of the inferior vena cava should proceed until the root of the right hepatic vein is visible close to the diaphragm. Thirdly, liver parenchymal dissection was performed. It was performed along the ischaemic border using Robotic Harmonic curved shears with a caudo-dorsal approach to liver parenchymal dissection. Ligation and division were performed for the branch of the S1 pedicle. Minor haemorrhages were controlled using bipolar forceps, and large vessels were selectively sutured with Prolene sutures. The dissection of the liver parenchyma proceeds deeper into the liver, exposing the large hepatic veins, such as branches of segment V and segment VIII from the middle hepatic vein. These were identified and transected with robotic Hen-o-lok or Laparoscopic Endo-GIA. Finally, the exposed root of the right hepatic vein was transected by laparoscopic Endo-GIA. The remaining peritoneal attachments were incised, and the liver was mobilised completely. The surface of the remaining liver was checked for any signs of haemorrhage or bile leakage after liver resection. Finally, the specimen was placed in an endoscopic bag and removed through a small midline incision.

Postoperative care

All patients of RLS were managed according to the previously published enhanced recovery after surgery (ERAS) programme[24].

Comparison of different liver parenchymal dissection methods

A literature search (PubMed/MEDLINE and EMBASE) was performed to identify published studies from 2010 to 2022 on techniques of robotic hepatectomy. Mesh terms used: “Robot-Assisted liver surgery”, “Robot-Assisted liver resection”, “Robot-Assisted Laparoscopic liver surgery”, and “Robot-Assisted Laparoscopic liver resection”.

Statistical analyses

Statistical analysis was carried out using IBM SPSS v.27. To detect statistically significant differences, Fisher’s exact probability test was applied to categorical data and Student’s *t*-test to continuous data. Differences in outcomes were considered statistically significant when $P < 0.05$.

RESULTS

Patient demographics and perioperative outcomes

Clinical characteristics are presented in Table 1. The mean patient age was 63.1 ± 16.2 years. The body mass index (BMI) was 26.5 ± 4.6 kg/m^2. There were 78 malignant and 22 benign liver tumours. Benign tumours accounted for 22% of all cases. The mean surgical margin for malignant lesions was 51.1 ± 46.1 mm. The distribution of IWATE Criteria in RLS was detailed in 57 cases in the low difficulty and intermediate difficulty group and 43 cases in the advanced difficulty and skilled difficulty group, with a mean value of 5.9 ± 2.9. A history of abdominal surgery was found in 45%. In four patients (5.2%), the surgical margin was positive (R1). We performed 32 subsegmentectomy, 18 mono-segmentectomies, 25 bi-segmentectomies, and 25 major hepatectomies [Table 2]. One patient (1.0%) receiving a subsegmentectomy on the surface of S6 was converted to open surgery because of poor visual field due to massive bleeding from the hepatic vein.

The median OT was 246.0 min (range, 60-544 min), and the median EBL during surgery was 100 mL (range, 10-1,200 mL). Three patients (3.0%) needed perioperative blood transfusions [Table 3].

Morbidity and mortality

The 30-day morbidity rate for all cases was 8.0% (8/100). In detail, Grade I was present in (3.0%) and Grade III/IV in five cases (5.0%). Grade III complications included two cases (2.0%) requiring UL-guided percutaneous drainage due to intraperitoneal fluid retention and two cases (2.0%) requiring UL-guided percutaneous drainage and ERCP due to biliary leakage. Grade IV complication was postoperative acute kidney injury (AKI) after major hepatectomies. The median hospital length of stay was 3 days (range, 1-14 days). No mortality occurred [Table 3].

Table 1. Clinical characteristics

Variable	*n* = 100
Age, year, mean ± SD	63.1 ± 16.2
Gender, male:female	52:48
BMI kg/m^2, mean ± SD	26.5 ± 4.6
ASA-score	
I	6
II	44
III	50
Diagnosis	
Liver metastasis with colorectal cancer	31
HCC/CCC	22/14
Gallbladder cancer	5
Benign	22
Other	6
IWATE standard, mean ± SD	**5.9 ± 2.9**
Previous abdominal surgery	45/100 (45%)
Laparotomy	8/100 (8%)
Laparoscopy	37/100 (37%)
Tumour size, mm, mean ± SD	**51.1 ± 46.1**
Resection margins for malignant lesions	***n* = 76**
R0	72/76 (94.7%)
R1	4/76 (5.2%)

Data are expressed as mean ± SD or as number (percentage). ASA: American Society of Anaesthesiologists; BMI: body mass index; CCC: Cholangiocellular carcinoma; HCC: Hepatocellular carcinoma; R0: resection margin; R1: positive resection margin; SD: standard deviation.

Comparison of major and minor robotic liver resections

Perioperative outcomes of major and minor hepatectomies were compared [Table 4]. No significant differences were found between the two groups in any factor.

Comparison of different liver parenchymal dissection methods

We detected six series describing techniques and devices for liver parenchyma dissection in RLS [Table 5]. In total, 313 RLS procedures were performed, including both benign and malignant cases[10,12-14,25,26], of which 223 (71.2%) were minor resections. Median OT ranged from 164 to 457 min, and median blood loss ranged from 100 to 457 mL. The number of patients who were converted to laparotomy ranged from 0% to 6.3%, and 10% to 25% of patients suffered serious complications. Mortality was observed in 0% to 3% of patients. Various devices for liver parenchymal dissection in RLS have been applied.

DISCUSSION

The first 100 cases of RLS using the Robotic Harmonic curved shear for dissection of the liver parenchyma were reported. The use of this device for liver parenchymal dissection was able to provide safe liver resection without compromising the postoperative clinical outcome in both minor and major hepatectomies. No cases of postoperative bleeding were observed, but biliary leakage occurred in two patients (2%). Our outcomes were also in line with data from other published series on RLS [Table 5][10,13,14,25,26]. Despite the small numbers, initial reports on RLS provide equivalent results for OLS, LLS, and RLS with regard to the R status[10,13-14,19,25,26].

Table 2. Surgical procedures and open conversion

Type of resection	*n* = 100	Pringle manoeuvre	Open conversion	Reasons for conversion
Minor liver resection	**75/100 (75%)**	**36/75 (48%)**	**1/75 (1.3%)**	
Subsegmentectomy	**32/100 (32%)**	**10/32 (31.2%)**	**1/32 (3.1%)**	Poor visual field due to massive bleeding from the hepatic vein
Monosegmentectomy	**18/100 (18%)**	**13/18 (72.2%)**	**0 (0%)**	
Segment 2	1	0/1		
Segment 3	3	0/3		
Segment 4/4b	3	3/3		
Segment 5	7	7/7		
Segment 6	4	3/4		
Bisegmentectomy	**25/100 (54%)**	**13/25 (52%)**	**0 (0%)**	
Left lateral segmentectomy	13	2/13		
Segment 4b/5	6	6/6		
Segment 5/6	6	6/6		
Major hepatectomy	**25/100 (25%)**	**10/25 (40%)**	**0 (0%)**	
Right posterior resection	1	1/1		
Extended right posterior resection	2	2/2		
Central resection	1	1/1		
Right anterior resection	1	1/1		
Left hemi hepatectomy	15	2/15		
Extended left hemi-hepatectomy	1	0/1		
Right hemi-hepatectomy	4	3/4		

Table 3. Perioperative outcomes

Variable	Subsegmentectomy (*n* = 32)	Monosegmentectomy (*n* =18)	Bisegmentectomy (*n* = 25)	Major hepatectomy (*n* = 25)	Total (*n* = 100)
Operative time, min mean ± SD	175.5 ± 81.3	279.2 ± 91.5	246.2 ± 70.2	372.2 ± 98.5	261.0 ± 112.5
Blood loss, mL mean ± SD	166.1 ± 272.0	221.1 ± 225.4	161.0 ± 135.9	243.4 ± 221.2	194.0 ± 222.5
Transfusion (%)	2/32 (6.2%)	0/7 (0%)	1/25 (4.0%)	0/25 (0%)	3/100 (3.0%)
CD I/II compl. (%)	1/32 (3.1%)	1/18 (5.5%)	0/0 (0%)	1/25 (4%)	3/100 (3%)
CD III/IV compl. (%)	0/32 (0%)	1/18 (5.5%)	1/25 (4.0%)	3/25 (12.0%)	5/100 (5.0%)
Hospitalisation, median day Mean ± SD	2.6 ± 1.8	3.7 ± 2.9	3.8 ± 2.9	4.2 ± 2.5	3.5 ± 2.5
Mortality within 90 days	0/32 (0%)	0/18 (0%)	0/25 (0%)	0/25 (0%)	0/100 (0%)

Data are expressed as mean ± SD or as number (percentage). CD: Clavien-Dindo classification; SD: standard deviation.

In our study, one case (1%) was converted to open surgery, and this case underwent a subsegmentectomy in S6. The reason for the conversion was that the Hem-o-lok clip used to divide S6 branches of hepatic veins was dislodged during deployment of the third arm over the liver resection surface, causing haemorrhage in the visual field. Despite repeated hemostasis, the operative field remained poor. After consulting with the anaesthetist, the vital signs of the patient remained stable; however, we decided to convert to laparotomy for the sake of the patient's safety.

Table 4. Comparison of surgical outcomes between minor and major hepatectomies in RLS

Variables	Minor (*n* = 75)	Major (*n* = 25)	*P*-value
Operative time, min	223 ± 90.1	372.2 ± 96.5	*P* = 0.37
Estimated blood loss, mL	177.8 ± 220.3	243.4 ± 216.8	*P* = 0.69
Conversion to open, *n* (%)	1/75 (1.3%)	0/13 (4.0%)	*P* = 1.0
CD I/II, *n* (%)	2/75 (2.6%)	1/25 (7.6%)	*P* = 0.57
CD III/IV, *n* (%)	2/75 (2.6%)	3/25 (12.0%)	*P* = 0.10
Length of hospital stay (day)	3.3 ± 2.5	4.2 ± 2.4	*P* = 0.50

Data are expressed as mean ± SD or as number (percentage). CD: Clavien-Dindo classification; RLS: robotic liver surgery; SD: standard deviation.

A discussion of the impact of the Pringle manoeuvre on EBL in RLS. In our study, 46% of patients underwent Pringle manoeuvre. Comparisons were made between the Pringle manoeuvre group and the non-performed groups regarding EBL (mean ± SD). There was a trend towards significantly more in the Pringle manoeuvre group compared with the non-performed group in EBL. (243.1 ± 237.9 *vs.* 152.2 ± 201.4 mL, $P = 0.006$). In addition, the allocation of IWATE criteria was examined for the Pringle manoeuvre group and the non-performed group. The Pringle manoeuvre group tended to be significantly more difficult than the non-performed group. (6.3 ± 5.0 *vs.* 4.7 ± 2.4, $P = 0.002$). These findings are reasonable in view of the greater extent and complexity of hepatectomy. However, in our study, we could not investigate whether the use of the Robotic Harmonic curved shears reduces the application rate of the Pringle manoeuvre.

With regard to LLS in the posterosuperior segments, mobilisation of the right liver lobe is often difficult with the laparoscopic approach. However, several studies about liver resection in the posterior superior segment in RLS[10,12,27,28] reported that liver resection in more difficult segment 2, 7, and 8 lesions is possible in a robotic approach. About liver resection in the posterosuperior segments through a laparoscopic approach, one of the surgical difficulties appears to be due to the rigid laparoscopic instrumentation. From a technical point of view, the angle of the instruments is restricted by the rib margin, making it difficult to control bleeding and resect tumours. Conversely, in a robotic approach, these laparoscopic limitations are eliminated, the contour line is not oblique, and the wrist-operated instruments are in a better position to approach these segments due to the advantages of the 3D view and instrumentation freedom, facilitating resection.

The disadvantage of RLS is that the instruments of the robotic arm used during liver parenchyma dissection are limited and quite restrictive. Due to the current lack of clear data for comparing liver parenchymal dissection methods in RLS, the decision of liver parenchymal dissection methods varies from one medical centre to another and is often based on individual surgeon preferences. However, based on existing data and the authors' experience, specific general recommendations for RLS could be made. Currently, the common liver parenchyma dissection methods in RLS are most frequently categorised into the following four groups. (1) Crush/clamp using a Robotic bipolar device; (2) Crush/clamp using a Vessel Sealer; (3) Robotic Harmonic curved shears with CUSA/Water jet: Hybrid RLS; (4) Robotic Harmonic curved shears [Table 5][10,13,14,25,26].

Giulianotti *et al.*[10] and Kato *et al.*[14] recommended a technique utilising monopolar shears and bipolar forceps to provide secure ligation of veins and bile ducts in liver parenchymal dissection during RLS. In this method, Maryland bipolar forceps and PK dissecting forceps enable meticulous anatomical identification and liver parenchymal dissection, while clamp crushing is a low-cost technique. However, considerable

Table 5. Summary of studies with RLS

Author	Period	Cases	Age (range)	Method Hybrid/Totally (Device)	Type of resection (Minor/Major)	Operative time, min (range)	EBL, mL (range)	Conversions rate (%)	Morbidity rate (%)	Mortality rate (%)	LOS (days)	Malignant (%)	R0 (%)
Kingham *et al.*[12]	2010-2014	64	64 (median) (40-91)	Totally robotic approch Vessel Sealer	59/6	163 (median) (56-480)	100 (median) (10-1,700)	6.3%	10.9%	3%	4 (median) (1-25)	78.3%	97.8%
Lee *et al.*[25]	2010-2015	70	58 (median) (20-82)	Hybrid approach Harmonic + tissuelink	56/14	251.5 (median) (97-620)	100 (median) (2-2,500)	5%	11.4%	0%	5 (median) (2-22)	74.2%	96%
Giulianotti *et al.*[10]	2002-2009	70	57 (mean) (21-84)	Totally robotic appraoch Crush clamp Robotic bipolar forceps	43/27	270 (median) (90-660)	262 (median) (20-2,000)	5.7%	21.4%	0%	7 (median) (2-26)	60%	100%
Giulianotti *et al.*[13]	2005-2010	24	55 (median) (21-84)	Pure robotic approach Harmonic	0/24	337 (mean) (240-480)	457 (mean) (100-2,000)	4%	25%	0%	9 (mean) (3-23)	70.8%	94.2%
Perrakis *et al.*[26]	2019-2020	28	63.5 (mean)	Hybrid approach Water jet, Maryland forceps and monopolar scissors	16/12	307.6 (mean) (SD 98.4)	358.9 (mean) (SD 369.0)	0%	10.7%	0%	13.3 (mean) (8SD 11.1)	75%	100%
Kato *et al.*[14]	2005-2020	57	71 (median) (20-82)	Totally robotic approach Crush clamp (Maryland forceps or Harmonic)	49/8	612 (median) (58-2,154)	194 (median) (5-6,900)	2%	11% (Over CD IIIa)	0%	15 (median) (8-82)	100%	98%
Our study	2019-2022	100	63.1 (mean) (25-92)	Totally robotic approach Harmonic	75/25	246 (median) (60-544)	100 (median) (10-1,200)	1%	5%	0%	3.0 (median) (1-14)	76%	94.7%

CD: Clavien-Dindo classification; EBL: estimated blood loss; LOS: length of hospital stay; NR: not reported; R0: resection margin; RLS: robotic liver surgery; SD: standard deviation.

experience is required to use these effectively for liver parenchymal dissection. Furthermore, necrosis and coagulated tissue often adhere to the tips of scissors and forceps, preventing accurate haemostasis, and they appear to be less efficient when the liver resection surfaces are large.

The Vessel Sealer has been adapted and promoted recently in RLS. A few cases of using the Vessel Sealer in RLS have been reported by Kingham *et al.*[12], Nota *et al.*[29] and Varshney *et al.*[30]. Use a slimmer jaw profile for more precise dissection, grasp with a textured surface to secure tissue, and then approach anatomy from the angle you prefer by articulating the wrist. With the instrument in position, a longer electrode 2 helps you confidently seal and transect vessels up to 7 mm in diameter or tissue bundles that fit in the jaws. However, with regard to liver parenchyma dissection using the Vessel Sealer, the tip of the instrument is considered too bulky and not suitable for anatomical liver resections since the identification of important structures is difficult and is not particularly selective. Therefore, the use of more sophisticated instruments for the dissection of liver parenchyma and transection of liver structures is recommended.

The most common and preferred method is the CUSA method in LLS or OLS, which allows precise dissection of the liver parenchyma and exposes only vascular and biliary structures. With regard to hybrid RLS using laparoscopic CUSA or Water jet, Perrakis *et al*.[26] and Varshney *et al*.[30] report that Hybrid RLS have the following common disadvantages. First, these instruments are not compatible with the da Vinci robotic surgical system and require a skilled laparoscopic HPB surgeon to be tableside. Furthermore, common strategies, techniques, and good communication between the console-side surgeon and the tableside surgeon are essential; Second, water reflects off the camera and reduces visibility, requiring the camera to be removed and cleaned several times, affecting operating time; Third, the cost of CUSA is very expensive. In hybrid RLS, the costs of these devices and tableside surgeons are added on top, making the total cost even higher than in Totally RLS. The main perceived disadvantage of RLS has always been its cost. This is particularly true for robotic surgery and is one of the main reasons why it is not widely accepted by hospitals and surgeons[31].

Our outcomes were also in line with data from other published series on RLS [Table 5]. The Harmonic scalpel can coagulate vessels up to 5 mm and is a stronger and more reliable sealing device with less tissue damage[32]. Our method focuses on the fact that the Robotic Harmonic curved shears have the same function as the CUSA. In our method, through the development of techniques for utilising the Robotic Harmonic curved shears akin to the use of CUSA, more selective local control of intrahepatic blood vessels and bile ducts became possible, and as a result of enhancing the hemostatic effect, it is suggested that liver parenchyma dissection can be performed more safely. The reports of Giulianotti *et al*.[33] and Choi *et al*.[34] clearly demonstrated the feasibility and safety of all types of anatomical liver resection using the Robotic Harmonic and concluded that this device could be used in Totally RLS. In addition, Chen *et al*. reported a paper on a totally robotic major hepatectomy performed without a tableside surgeon using the robotic Harmonic that suggests that robotic major hepatectomy is safe and feasible in the absence of a tableside surgeon[35].

The learning curve, which is considered to be a constraint on the spread of LLS, cannot be non-negligible[36]. However, the learning curve for RLS has proven to be shorter than the LLS equivalent[37-39]. It is expected that RLS will rapidly spread and a new generation of HPB surgical fellows will join RLS in the future. One of the advantages of the da Vinci robotic surgical system is the possibility to perform surgery using a robotic dual console. This advantage is an excellent system from an HPB fellow education perspective, as performing surgery at the console with a skilled HPB surgeon can speed up the learning curve[40]. Our strategy is to maximise the benefits of the robotic system and further promote safe totally RLS by combining the key elements that make this possible.

The lack of EndoWrist® functionality is a major limitation of liver parenchymal dissection using the Robotic Harmonic curved shear. This shortcoming can be addressed by using the third robotic arm for optimal exposure and retraction to deploy the hepatic resection line[33]. However, although the Robotic Harmonic curved shears are useful for straight liver parenchymal dissection such as semi-resection, they appear to be difficult to use for curved or complex resection surfaces such as the posterior superior segment[14,33,34]. Further development of instruments suitable for parenchymal resection is, therefore, needed.

The study has several limitations that should be considered. First, it is not a prospective randomised trial and is, therefore, limited by patient selection bias. Furthermore, the study is retrospective. Secondly, its usefulness for liver resection in the posterosuperior segments is unclear from the present study, and further experience is needed. In addition, further randomised and multicentre trials are needed to compare liver parenchymal dissection methods in RLS using different instruments.

Conclusion

Based on the results of our study, we conclude that liver parenchyma dissection using the Robotic Harmonic curved shears in Totally RLS is a feasible and safe procedure, resulting in favourable short-term results for patients undergoing minor and major hepatectomy.

DECLARATIONS

Author's contributions

Study conception and design: Fukumori D, Tschuor C, Hillingsø J, Svendsen LB, Larsen PN
Data collection: Fukumori D
Analysis and interpretation of results: Fukumori D, Tschuor C, Penninga L
Draft manuscript preparation: Fukumori D
All authors reviewed the results and approved the final version of the manuscript.

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All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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