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Technical aspects and learning curve of complex laparoscopic hepatectomy: how we do it

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Abstract

Introduction Laparoscopic liver surgery has advanced significantly, offering benefits, such as reduced intraoperative complications and quicker recovery. However, complex laparoscopic hepatectomy (CLH) is technically demanding, requiring skilled surgeons. This study aims to share technical aspects, insightful tips, and outcomes of CLH at our center, focusing on the safety and learning curve.

Methods We reviewed all patients undergoing liver resection at our center from July 2017 to December 2023, focusing on those who underwent CLH. Of 135 laparoscopic liver resections, 63 (46.7%) were CLH. The learning curve of CLH was also assessed through linear and piecewise regression analyses considering the operation time and intraoperative blood loss.

Results Postoperative complications occurred only in 4.8% of patients, with a 90-day mortality rate of 3.2%. The mean operation time and blood loss significantly decreased after the first 20 operations, marking the learning curve's optimal cut-off. Significant improvements in R0 resection ($p=0.024$) and 90-day mortality ($p=0.035$) were noted beyond the learning curve threshold.

Conclusion CLH is a safe and effective approach, with a relatively short learning curve of 20 operations. Future large-scale studies should further investigate the impact of surgical experience on CLH outcomes to establish guidelines for training programs.

Keywords Laparoscopy · Major hepatectomy · Learning curve · How we do it

Laparoscopic surgery has brought significant advancements to the field of surgery, offering clear benefits during and after the operation compared to traditional open surgery [1]. These advantages include less blood loss, reduced postoperative pain, shorter hospital stays, and quicker recovery [2, 3]. Randomized data also indicate fewer complications with laparoscopic approaches [4]. Despite these benefits, performing laparoscopic liver surgery requires extensive training in both open liver and minimally invasive surgeries, due to the technical challenges, complex nature, and steep learning curve associated with transitioning to laparoscopic methods in liver surgery [5]. Ongoing advancements in technology and techniques, along with better imaging and surgical instruments, have led to increased rates of laparoscopic liver surgeries, especially for minor procedures [6].

However, performing complex laparoscopic hepatectomy (CLH) is more challenging because of technical difficulties, fear of bleeding and embolism, and concern about meeting oncologic standards [7]. Hence, the necessity for new classification systems to define and classify CLH have also underscored [8]. Several studies have suggested that CLH should be carried out by highly skilled surgeons with a high number of previous open hepatectomies [5, 9], As a result, these represent only a small percentage (approximately 18–22%) of laparoscopic liver surgeries globally [2, 10]. It is widely recognized that the surgeon's experience plays a significant role in the intra- and postoperative outcomes of CLH. Moreover, numerous studies have examined the learning curve of laparoscopic liver resection [11–15].

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However, the specific threshold at which the surgeon's experience significantly impacts outcomes, especially for CLH is still controversial. Furthermore, establishing the minimum number of completed CLH procedures required to minimize perioperative complications could contribute to defining the qualifications for fellowship programs.

In 2017, our center initiated a laparoscopic liver resection program. This article aims to share our experiences with CLH, detailing the technical aspects, providing tips and tricks, and exploring the learning curve and safety of CLH. We will also present the short-term outcomes of patients who underwent CLH at our center.

Material and methods

Study population

We investigated all patients who underwent liver resection for primary, metastatic, or benign liver diseases at our center from July 2017 to December 2023. Our preference is to first attempt laparoscopic liver resection whenever feasible. Accordingly, patients requiring vascular reconstruction due to vascular infiltration, those needing a two-stage hepatectomy, advanced liver cirrhosis and portosystemic collaterals, patients who underwent more than two previous complex open surgeries, or those unable to tolerate pneumoperitoneum are not considered for laparoscopy. The study specifically focused on patients who underwent CLH, as defined by the classification proposed by Kawaguchi et al. [8]. Accordingly, CLH is classified as difficult anatomic liver resection includes posterosuperior segmentectomy (resection of segments 1, 4a, 7, and 8), right posterior sectionectomy (resection of segments 6 and 7), right hepatectomy, central hepatectomy (resection of segments 5 and 8, or segments 4, 5, and 8), and extended left/right hepatectomy. Patients under the age of 18 and those who underwent a two-stage hepatectomy were excluded from the study. Patients who underwent conversion to open surgery ($n=6$) were excluded from the primary analysis. Nonetheless, we conducted a comparison of conversion rate before and after reaching the learning curve. In total, 323 patients underwent liver resection in our center in this period. In a cohort of 135 laparoscopic liver resections (42% of all hepatectomies), 63 patients (46.7%) consecutively underwent CLH, all conducted by a single attending hepatobiliary surgeon serving as the primary (responsible) operator. Before conducting the first CLH in July 2017, this surgeon had extensive experience in open liver resections, having performed over 1000 cases, with approximately 50% classified as major hepatectomies. Additionally, the surgeon had accumulated experience in laparoscopic procedures for colorectal, gastric, and gallbladder diseases, having completed approximately 200 complex laparoscopic operations. Furthermore, prior to the first CLH, the surgeon had already performed 20 laparoscopic minor hepatectomies. This study received permission from the Ethics Committee of the Medical Association of Saarland, and written consent was obtained from all patients. The study is reported according to the STROBE Statement: guidelines for reporting observational studies [16].

Technical aspects of complex laparoscopic hepatectomy

Surgical procedures were carried out by a dedicated Laparoscopic Liver (Lap-Liver) team, consisting of an operating surgeon, two assistants, and a scrub nurse. The team underwent a comprehensive training program at the Oslo University Hospital, Intervention Center, Department of Hepato-Pancreato-Biliary Surgery before initiating the program.

Positioning and trocar placement

Patients are positioned in a supine posture on a short vacuum mattress for left resections and with a cushion placed under the right rib cage for right hepatectomies. For better access in case of a tumor in the right posterior segments, a lateral position with a 30- or 45-degree right side up can be utilized. The initial port access is established at the umbilicus for the camera (Fig. 1). Pneumoperitoneum is maintained at 12 mmHg, with the option to increase it to 15 mmHg in the event of bleeding. However, it is important to note that higher pressure increases the risk of $CO2$ embolism through hepatic veins. Subsequently, 3–4 ports are strategically placed in a rhomboid configuration. The lower two ports are positioned to the left and right of the mammillary line, approximately 3 cm below the ribs, serving as working ports for the operating surgeon (who stood on the right side). The suggested rhomboid configuration could be adjusted based on individual preferences and patient anatomy. An accessory port is placed in the left axillary line if a conventional Pringle maneuver is required (Fig. 1). Additional ports may be placed in cases of severe adhesions.

Intraoperative ultrasound examination and liver mobilization

The operation commences with a laparoscopic ultrasound examination of the liver and lesions, ensuring accurate anatomy and resection strategy (Fig. 2). For a right hepatectomy, the first step involves dissecting the falciform ligament and defining the venous confluence. Subsequently, the right lobe is fully mobilized using a retractor (Fig. 3a). The inferior V. cava is mobilized and freed from the short hepatic and caudate veins using Grena ligating Clips (Fig. 3b and c). For left-side resections, the left lobe is mobilized accordingly.

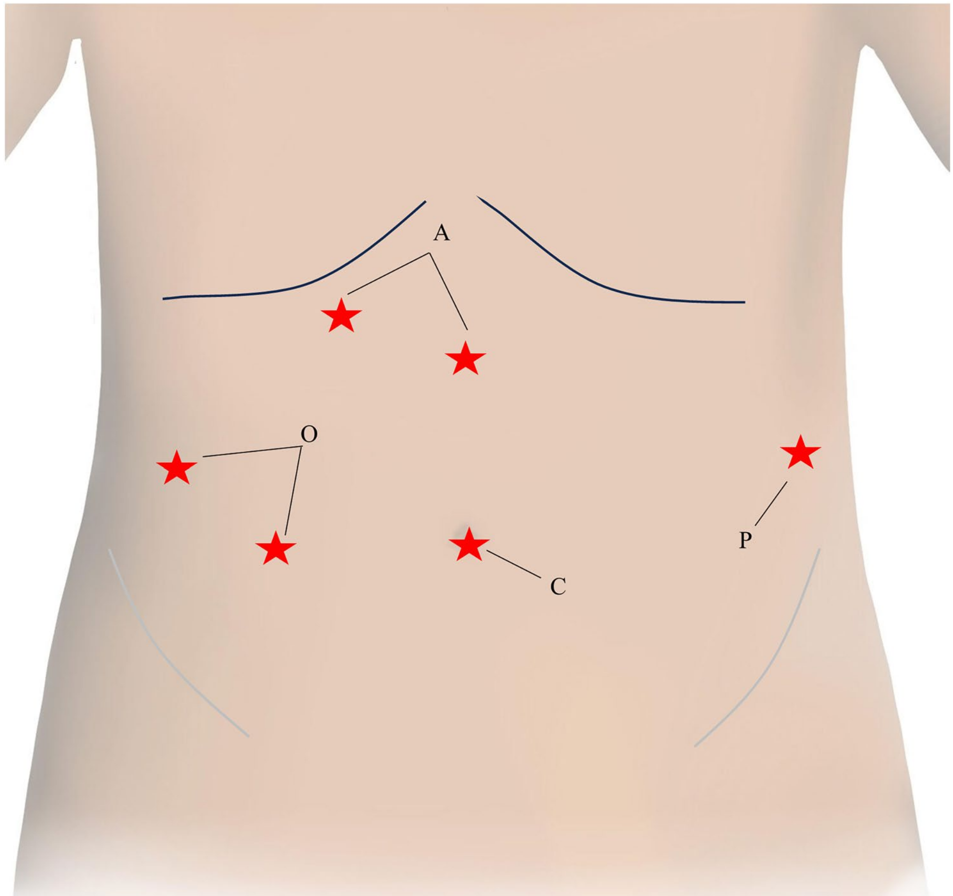

Fig. 1 Illustration showing the trocar placement for complex laparoscopic hepatectomy. *C* camera, *P* Pringle maneuver, *A* assistant, *O* main Operator

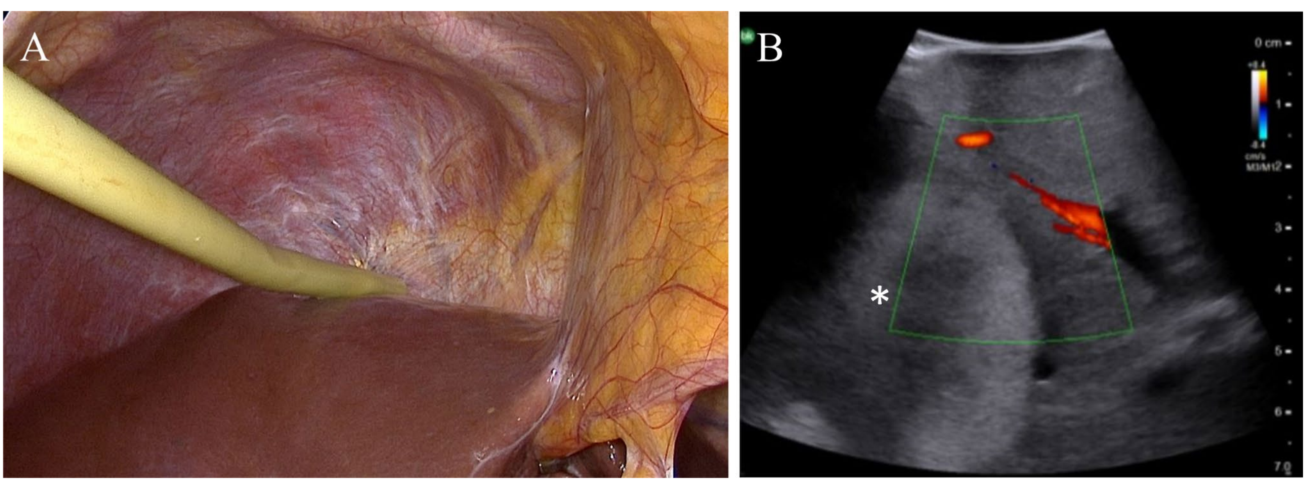

Fig. 2 Intraoperative ultrasound examination: **A** laparoscopic ultrasound examination of the liver and lesions and **B** ultrasound image showing a liver lesion (*, hepatocellular carcinoma) in the right liver lobe localized close to the portal pedicle

Preparation of the hepatic hilum

The next phase involves inflow control, which is followed by cholecystectomy and regional lymphadenectomy when necessary. For anatomic left or right hepatectomies, the common hepatic artery is defined first, followed by the dissection, ligation, and division of the right or left hepatic artery using Grena Clips (Fig. 4a and b). The portal vein is then dissected, and after identifying the portal bifurcation, the right or left portal trunk is divided using a vascular

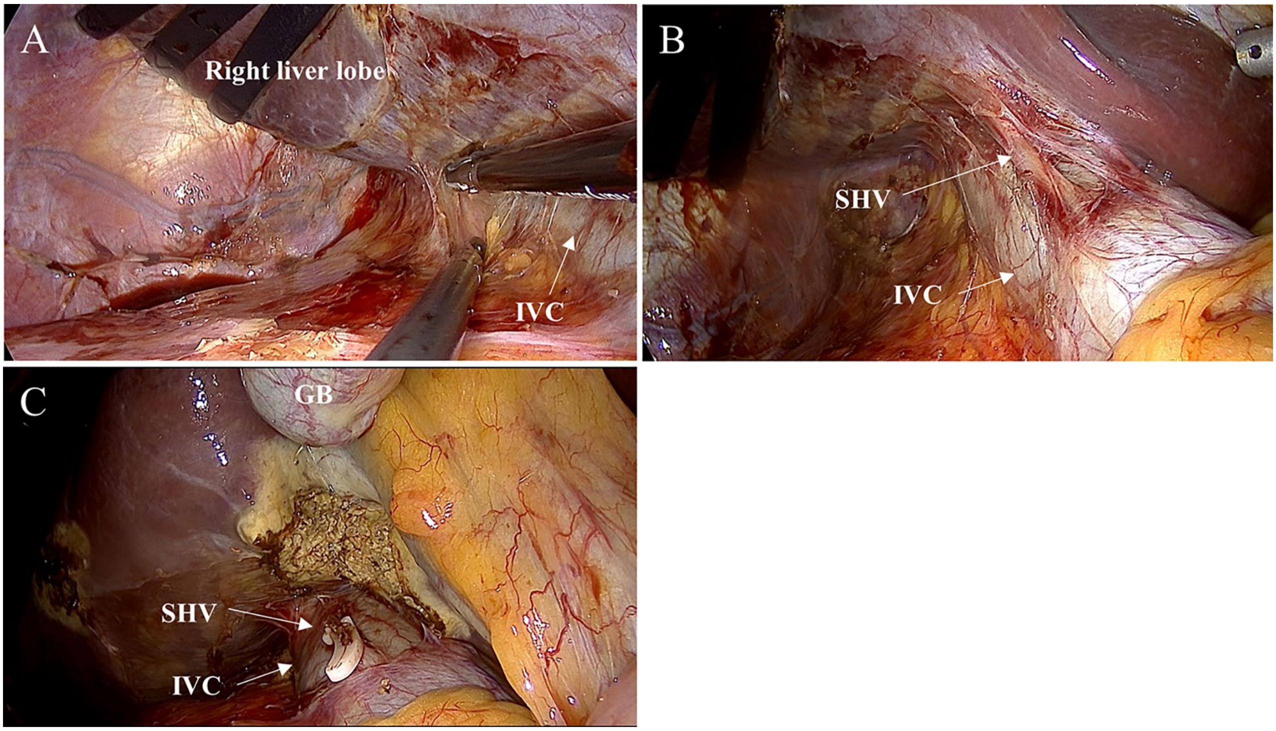

Fig. 3 Liver mobilization: **A** mobilization of the right liver lobe, **B** until full demonstration of the inferior vena cava (IVC) and short hepatic veins (SHV) / caudal veins, and **C** ligation of SHV with Grena ligating Clips. *GB* gallbladder

stapler or large Grena Clips (Fig. 4c and d). The bile duct is addressed during parenchymal transection.

Liver transection

After marking the resection line along the demarcation and under ultrasound guidance (Fig. 5), liver parenchymal transection is performed. It is crucial to maintain low central vein pressure (1–5 mmHg) during this step; close communication with anesthesia is recommended. The transection involves a combination of ultrasonic dissection (HEPACCS, Söring, Quickborn, Germany) and LigaSure (Medtronic, Minneapolis, USA), with Grena Clips used for large vascular structures. The parenchymal transection follows the "opening the book" principle, consistently opening the parenchyma on the outer part of the transection line before addressing deeper structures (Fig. 6). In some cases, a caudal-to-cranial approach or starting with the splitting of Segment 1/9 for easier access to the V. Cava may be preferred. Once the liver hilum is freed to the right or left side, the hepatic vein can be transected using a stapler (white or golden load, Fig. 7a and b), with a focus on maximizing distance from the bile duct confluence (Fig. 7c). In some cases, the Glissonian approach is utilized for performing CLH. For example, in the case of right posterior sectionectomy, following cholecystectomy, dissection of the liver hilum is undertaken to identify the right and left Glisson's pedicles at the inferior surface of the quadrate lobe. Subsequently, the right pedicle is further dissected into anterior and posterior pedicles. Each of these two pedicles is isolated separately. The posterior Glisson's pedicle is then divided extraparenchymally using a linear stapler.

Postresection phase

Hemostasis is achieved with irrigation and bipolar coagulation (Erbe Elektromedizin, Tübingen, Germany). Specimen extraction is performed in a plastic bag through a Pfannenstiel incision for better pain management and cosmetic results. Following specimen extraction and wound closure, a final laparoscopy is conducted to ensure there is no bleeding and application of the transabdominal plane Block for pain control (40-ml carbostesin in 4 sites). If bleeding persists, a stitch can be applied using a 3/0 vicryl cut to trocar length, secured under visual control with a Grena Clips. Severe bleeding, such as from hepatic veins, may require compression with a pad or hemostatic pad. Finally, laparoscopic ultrasound examination should be performed to document the regular in- and outflow of the remnant. If the ligamentum teres hepatis was dissected during surgery, the liver is re-fixated to the diaphragm using a V-Loc suture after a right hemi-hepatectomy. The use of a drain is rarely necessary.

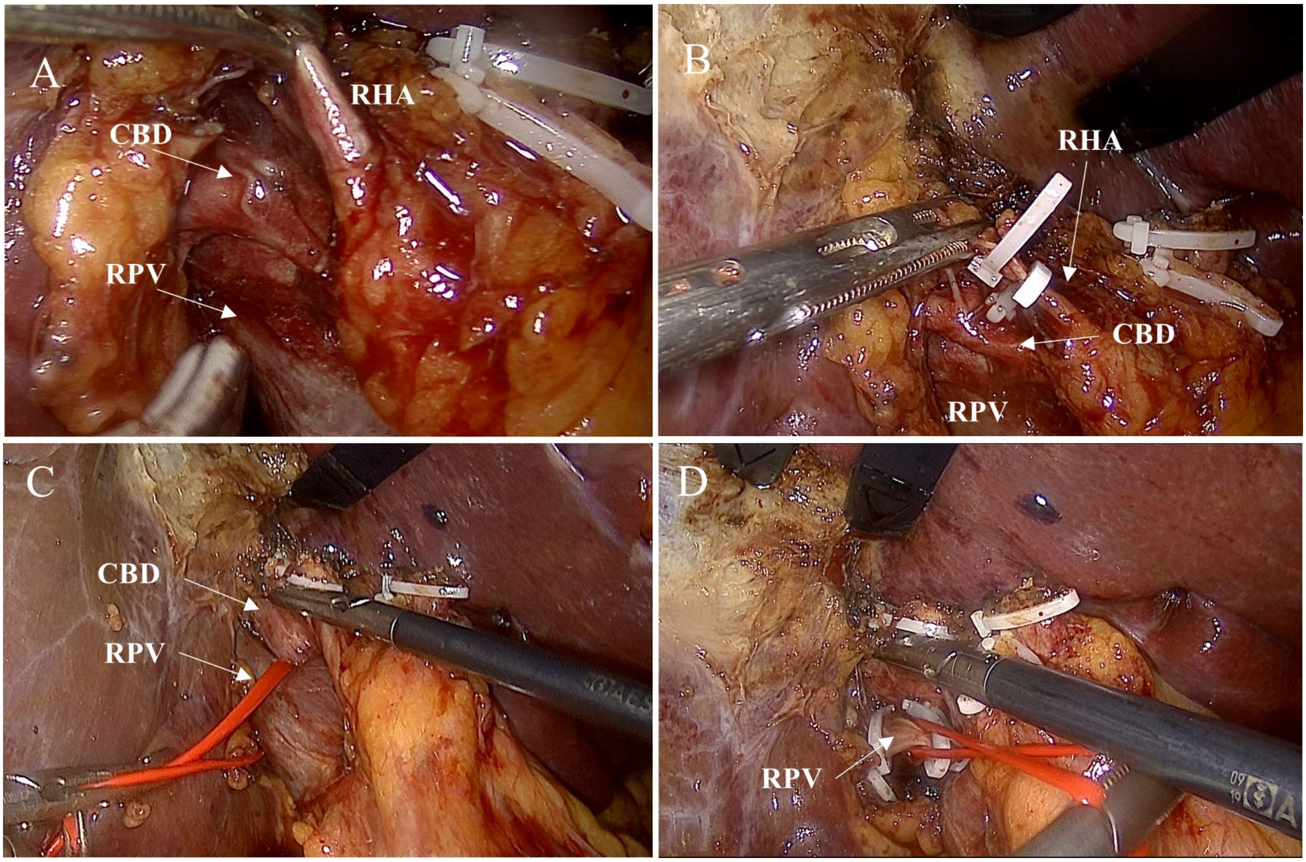

Fig. 4 Preparation of the liver hilum: intraoperative snapshot illustrating **A** the dissection and **B** ligation of the right hepatic artery (RHA), followed by **C** the dissection and **D** ligation of the right portal vein (RPV) using Grena ligating Clips. *CBD* common bile duct

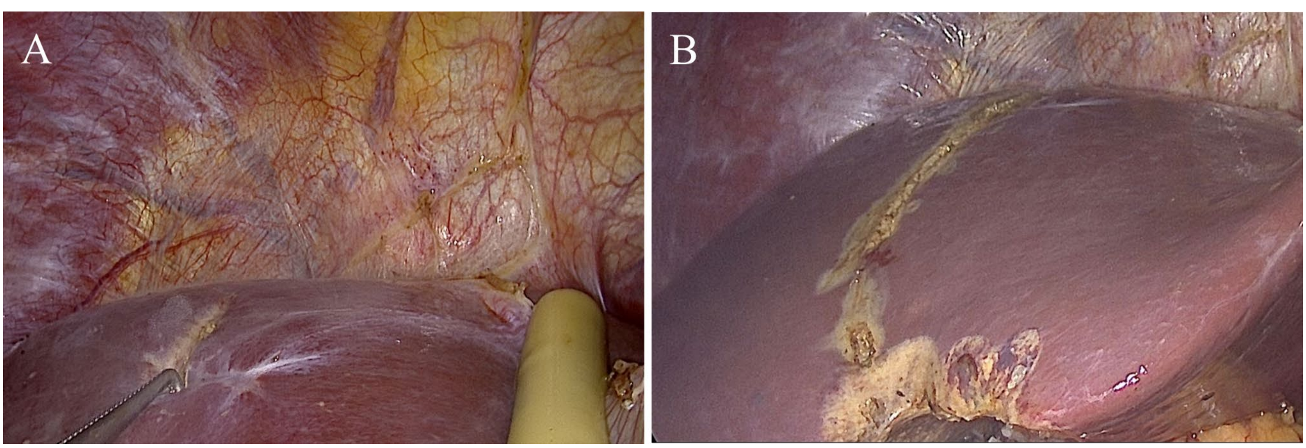

Fig. 5 **A** Identification of the demarcation line and a renewed ultrasound examination, **B** followed by marking the resection line along the demarcation under ultrasound guidance using a monopolar hook electrode

Postoperative outcomes

To assess the safety of CLH and evaluate the learning curve, additional data were extracted. The collected information included patient characteristics, indication for hepatectomy, utilization and duration of the Pringle maneuver, intraoperative blood loss, operation time, rate of a tumor-free resection margin (R0), postoperative complications (based on the Clavien–Dindo classification [17]), duration of hospitalization, and 90-day mortality.

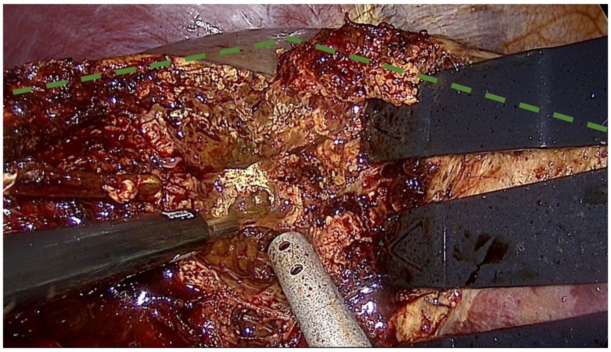

Fig. 6 Transection phase: parenchymal transection follows the "opening the book" principle using the combination of ultrasonic dissection and LigaSure

Statistical analysis

Statistical analysis was conducted using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., released 2013, Armonk, NY). Categorical data are presented as percentages, while continuous variables are expressed as means ± standard deviations. The chi-square test of association was employed for comparing categorical data, and Student's *t* test was used for comparing continuous data.

To assess the learning curve, we used two intraoperative factors, the operation times and intraoperative blood loss, which are one of the most used indicators for evaluating the learning curve of surgical techniques. Accordingly, we evaluated the changes of operation times and intraoperative blood loss in 63 consecutive CLH carried out by a single surgeon serving as the primary (responsible) operator. To do this linear regression analysis was initially employed to examine the overall trends in operation time and blood loss. This analysis aimed to determine if there were consistent trends and significant decrease in these two variables over consecutive surgeries. Following the linear regression analysis, we conducted piecewise regression analyses separately for operation time and blood loss. Piecewise regression allows for the identification of breakpoints or inflection points in the data, indicating shifts in the trend or slope. In this study, segmentation was performed based on the number of hepatectomies performed. Each hepatectomy represented a potential segment or interval in the analysis. Piecewise regression analysis was then performed for each segment. By doing this, we aimed to identify the optimal cut-off points

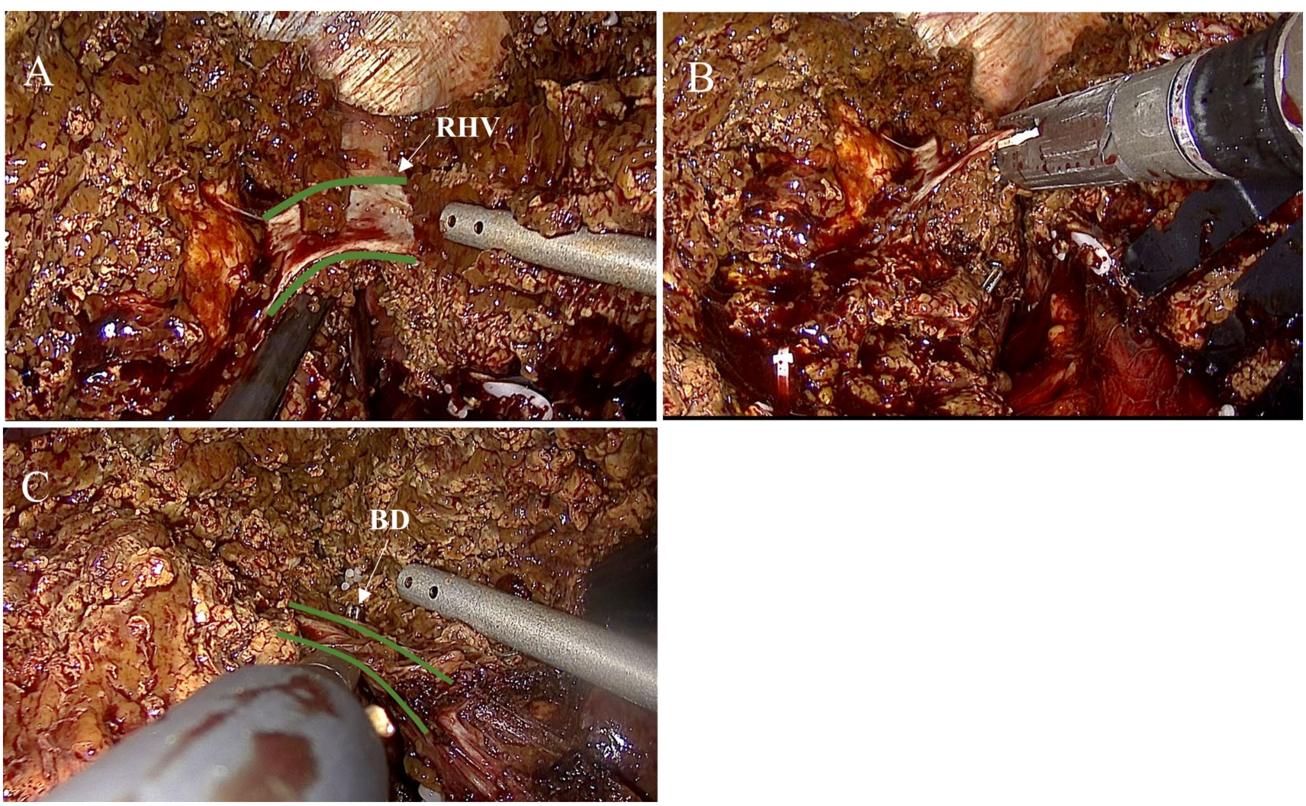

Fig. 7 Intraoperative snapshot illustrating **A** the dissection and **B** transection of the right hepatic vein (RHV) using the stapler, **C** along with the identification of the bile duct (BD) before hepatectomy

where significant changes occurred in both operation time and blood loss. In all analyses, a two-tailed p value less than 0.05 was considered statistically significant.

Results

Assessment of safety

The baseline characteristics, surgical variables, and postoperative outcomes of patients are summarized in Tables 1 and 2. The mean age of patients was 63 ± 15 years. Metastatic liver diseases were the most common indication for liver resection (44.4% of patients). Posterosuperior segmentectomy was the most frequently performed type of hepatectomy (23.8% of patients). A total of 81.0% of patients underwent intermittent Pringle maneuver, with a mean duration of 12.3 ± 5.7 min during liver transection. The mean intraoperative blood loss was 214.0 ± 145.6 ml, and the mean operation time was 182.3 ± 48.7 min. Postoperative complications were detected in 13 patients (20.6%), while only 4.8% of them classified as major morbidity (> Grade IIIb). Two patients (3.2%) died within the 90 days following CLH.

Learning curve

As illustrated in Fig. 8, linear regression analysis demonstrated a significant decrease for both the mean operation time and blood loss ($p < 0.001$ for both analyses) with an increasing number of previous CLH performed by the surgeon. Following a piecewise regression analysis, it was determined that 20 operations marked the optimal cut-off point for the learning curve, considering both variables. Subsequent to the initial 20 operations, there was a notable and statistically significant reduction in both mean operation time and blood loss ($p < 0.001$ for both analyses). The range of distribution also diminished as the number of performed CLH increased (Fig. 8). This reduction signifies a decrease in fluctuation and an increase in the stability of intraoperative parameters as surgical experience advanced. Moreover, upon incorporating the six patients (8.7%) who underwent conversion to open surgery (Table 3), it was revealed that only one of these conversions occurred after the completion of 20 operations ($p = 0.048$).

There were no significant differences regarding the extent of the resection before and after reaching the learning curve (Tables 1, 2). However, it is noteworthy that a significantly higher proportion of patients with a poorer general condition (60.0% vs. 88.4%, patients with > ASA 3, $p = 0.017$) and compromised liver parenchyma quality (0.0% vs. 18.6%, patients with Child A cirrhosis, $p = 0.047$) underwent CLH after reaching the learning curve (Table 1). Nevertheless, the rates of achieving R0 resection ($p = 0.024$) and 90-day mortality ($p = 0.035$) were significantly improved after the first 20 operations (Table 2).

Table 1 Demographic and preoperative clinical data of included patients

Variables	Total ($n = 63$)	First 20 CLH ($n = 20$)	After 20 CLH ($n = 43$)	p
Age (years)	63.3 ± 14.8	61.3 ± 19.1	64.3 ± 12.4	0.462
Sex				0.582
Female/male	28/35	9/11	19/24	
BMI (kg/m^2)	23.3 ± 9.2	22.5 ± 9.8	23.6 ± 9.1	0.684
ASA class				**0.017**
Class 2	13 (20.6%)	8 (40.0%)	5 (11.6%)	
Class 3	59 (79.4%)	12 (60.0%)	38 (88.4%)	
Liver cirrhosis (Child A)	8 (12.7%)	0 (0.0%)	8 (18.6%)	**0.047**
Indication of hepatectomy	11 (17.5%)	5 (25.0%)	6 (14.0%)	0.243
Benign liver disease	24 (38.1%)	9 (45.0%)	15 (34.9%)	
Primary malignancy	5 (7.9%)	3 (15.0%)	2 (4.7%)	
Cholangiocarcinoma	19 (30.2%)	6 (30.0%)	13 (30.2%)	
Hepatocellular carcinoma	28 (44.4%)	6 (30.0%)	22 (51.2%)	
Metastatic disease				
Preoperative chemotherapy				0.173
Yes	28 (44.4%)	6 (30.0%)	22 (51.0%)	

p values < 0.05 were considered statistically significant and highlighted in bold

CLH complex laparoscopic hepatectomy, *BMI* body mass index, *ASA* American society of anesthesiologists

Table 2 Intra- and postoperative data of included patients

Variables	Total ($n=63$)	First 20 CLH ($n=20$)	After 20 CLH ($n=43$)	p
Resection type				0.205
Posterosuperior segmentectomy	15 (23.8%)	6 (30.0%)	13 (30.2%)	
Right posterior sectionectomy	12 (19.0%)	4 (20.0%)	9 (20.9%)	
Right hepatectomy	14 (22.2%)	4 (20.0%)	8 (18.6%)	
Central hepatectomy	9 (14.3%)	3 (15.0%)	6 (14.0%)	
Extended right hepatectomy	5 (7.9%)	1 (5.0%)	4 (9.3%)	
Extended left hepatectomy	8 (12.7%)	2 (10.0%)	3 (7.0%)	
Intraoperative blood loss (ml)	214.0 ± 145.6	274.0 ± 214.5	186.0 ± 89.2	**< 0.001**
Pringle maneuver				
Yes	51 (81.0%)	15 (75.0%)	36 (83.7%)	0.496
Duration	12.3 ± 5.7	13.2 ± 6.5	10.9 ± 4.6	0.182
Operation time (min)	182.3 ± 48.7	218.3 ± 54.0	165.6 ± 35.7	**< 0.001**
R0 resection*	50 (96.2%)	13 (86.7%)	37 (100%)	**0.024**
Hospitalization (days)	8.3 ± 4.3	8.5 ± 4.2	8.2 ± 4.4	0.839
Overall complications	13 (20.6%)	4 (20.0%)	9 (20.9%)	0.932
Major morbidity**	3 (4.8%)	2 (10.0%)	1 (2.3%)	0.053
90-day mortality	2 (3.2%)	2 (10.0%)	0 (0.0%)	**0.035**

p values < 0.05 were considered statistically significant and highlighted in bold

*R-Status was only evaluated in 52 patients with malignant tumor

**Based on the Clavien–Dindo classification (> Grade IIIb)

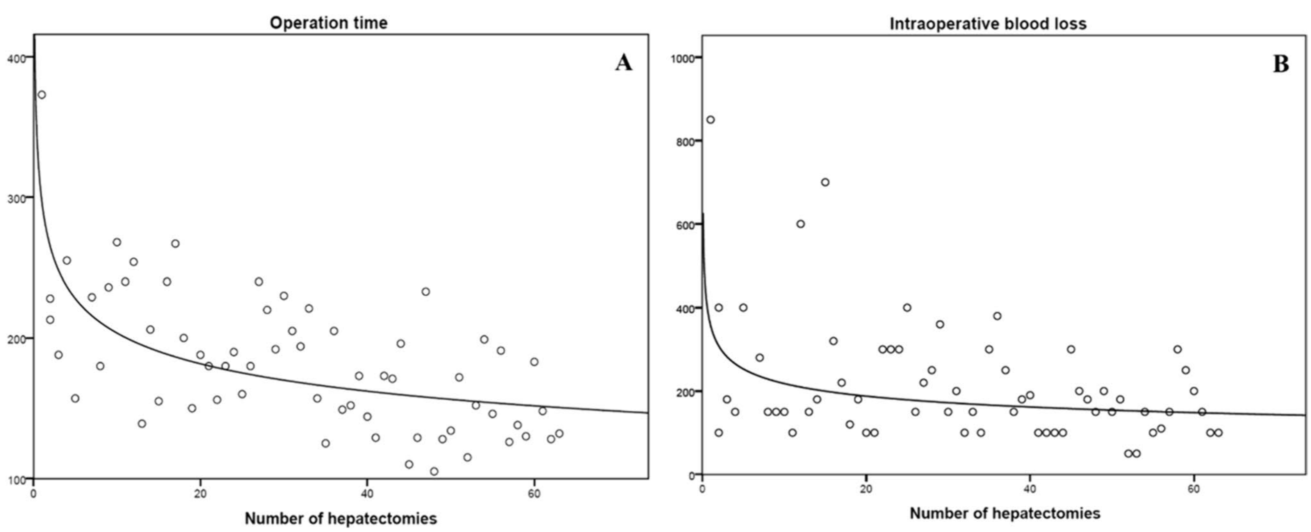

Fig. 8 **A** Operation times and **B** and intraoperative blood loss in relation to the number of previous complex laparoscopic hepatectomies performed by single surgeon ($p < 0.001$ for both analyses)

Discussion

Since the first liver resection in 1881, liver surgery has undergone substantial technical advancements and expanded in the scope of surgical resection methods [18, 19]. Traditionally, open access has been the standard approach for these procedures. Recent technical enhancements have significantly improved outcomes in cases over the past few years [20, 21]. However, the inherent physiological damage associated with open surgery has led to certain rates of morbidity and mortality, particularly after major hepatectomies, and it has been shown in randomized data that the laparoscopic approach has a clear advantage [2, 4, 22]. To mitigate invasiveness and enhance outcomes, laparoscopic-assisted liver surgery has

Table 3 Reasons for conversions to an open approach

Reasons	Total ($n=6$)
Active bleeding from the right hepatic vein	2 (33.3%)
Intraoperative identification of vascular infiltration*	2 (33.3%)
Advanced intra-abdominal adhesions	1 (16.7%)
Need to extend the resection and performing biliodigestive anastomosis	1 (16.7%)

*The reason for conversion after reaching the learning curve (after the completion of 20 operation)

been practiced since the 1980s [10]. Recent technological and technical improvements have extended its application to more complex procedures [1, 5, 6]. However, conducting laparoscopic liver surgery demands prior proficiency in both open liver procedures and minimally invasive surgeries. Previous studies have emphasized the significant learning curve, often exceeding 25 operations, even for minor laparoscopic liver resections [14, 23]. Despite the widespread adoption of laparoscopic minor hepatectomy by hepatobiliary surgeons, CLH has remained limited and is typically performed in high-volume centers [5, 6, 24]. This study provides a detailed description of CLH and analyzes the safety and feasibility of this method.

The results of this study demonstrate that the mean operation time and intraoperative blood loss, considered as indicators of the learning curve, significantly decreased with an increasing number of performed CLHs. The surgeon achieved a stable range of mean operation time and blood loss after completing 20 CLHs. The relatively short learning curve observed can likely be attributed to the extensive prior experience in open liver surgery. This experience greatly aids in visualizing intrahepatic anatomy, understanding potential pitfalls, and mastering various techniques for navigating challenging scenarios. These findings also align with results from other studies, even those performing major hepatectomies in an open manner (15 right hemi-hepatectomies) [11–15, 25]. Some studies investigating the learning curve in CLH showed various results ranging from 17 to 75 CLHs [12]. The variation in the number of CLHs required for the learning curve across studies can be attributed to different definitions of major/complex hepatectomy used.

Major hepatectomy is commonly defined based on the Brisbane 2000 Terminology (resection of 3 or more contiguous segments) [26]. In this study, we used the difficulty classification suggested by Kawaguchi et al. [8], which is widely accepted and externally validated [24]. This classification offers an advantage over other difficulty scoring systems due to its user-friendly nature and consideration of intraoperative parameters. According to this classification, aside from standard major hepatectomies like right hepatectomy and extended left/right hepatectomy, laparoscopic resection of the posterosuperior segments (1, 4a, 7, and 8), and the right posterior section (segments 6 and 7) are also categorized as complex hepatectomy. This designation is made because these approaches are considered challenging due to their difficult locations. Troisi et al. [27] demonstrated that laparoscopic posterosuperior segment resection independently increases the risk of conversion. Additionally, another study indicated a significantly lower rate of tumor-free margins from posterosuperior specimens compared to other resection methods [28]. In our study, there were no significant differences in perioperative data (including intraoperative blood loss, operation time, resection margin, and complications) among different resection types.

The mean intraoperative blood loss in this study was 213 ml. Additionally, total morbidity was observed in 20.6% of patients, with a 90-day mortality rate of 3.2%, which are comparable with other studies investigating CLH [29]. When comparing these results to open major hepatectomy, our study demonstrated a significantly lower amount of intraoperative blood loss, as well as a reduced rate of morbidity and mortality [29]. These outcomes affirm the safety of CLH when compared to other surgical methods, suggesting that perioperative results can notably improve after the learning curve is mastered.

The retrospective single-center design of our study is acknowledged as a limitation. Additionally, due to the small sample size, conducting a multivariate analysis to define the learning curve was not feasible. In assessing the learning curve, we focused on two intraoperative variables—operation time and blood loss—which are widely recognized and validated indicators for evaluating surgical technique proficiency [12, 30]. Furthermore, in this study, all surgeries were performed by a single senior surgeon, utilizing a standardized resection technique, which may help to reduce heterogeneity and bias in the study results. Nonetheless, it is essential to acknowledge the need for further large-scale studies of CLH to comprehensively evaluate the learning curve, including consideration of all potential cofactors.

In conclusion, laparoscopic approach has emerged as a safe procedure for complex hepatic resections over the past decades. The current study, along with existing literature, supports the notion that CLH is a safe approach, characterized by a relatively short learning curve of 20 operations and associated with low postoperative morbidity and mortality. Further multi-center prospective studies need to be conducted to validate the suggested threshold for the number of CLH in fellowship programs and to assess the impact of a surgeon's experience on the perioperative outcomes of CLH in future.

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Data availability The anonymized raw data used in this study are available upon request to the corresponding author.

Declarations

Disclosures Omid Ghamarnejad, Laura-Ann Sahan, Dimitrios Kardassis, Rizky Widyaningsih, Bjørn Edwin, and Gregor Alexander Stavrou have reported no conflicts of interest or financial ties to disclose.

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