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METHODOLOGY

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Surgical protocol of robotic liver resection using a two-surgeon technique (TAKUMI-3): a technical note and initial outcomes

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Abstract

Background Internationally, evidence supporting robotic liver resection (RLR) has gradually increased in recent years. However, a standardized protocol for RLR remains lacking. This study describes a surgical protocol and the initial outcomes of RLR in a high-volume center for robotic hepatopancreatobiliary surgery in Japan.

Methods Patients were placed in the reverse Trendelenburg position, with a supine position for anterolateral tumors and left lateral position for posterosuperior tumors. Our standard RLR protocol involved a two-surgeon technique. Liver parenchymal transection was performed by an assistant using the clamp crush technique with a console, with or without a laparoscopic Cavitron ultrasonic surgical aspirator (CUSA). Surgical techniques, including the tips, tricks, and pitfalls of RLR, are also demonstrated.

Results We performed 113 RLR at our institution for common primary diseases, including hepatocellular carcinoma ($n=52$, 46.0%) and metastatic tumors ($n=48$, 42.5%) between July 2022 and December 2024. The median operative time and estimated blood loss were 156 min (interquartile range [IQR], 121–209 min) and 20 mL (IQR, 0–100 mL), respectively. During liver parenchymal transection, a laparoscopic CUSA was used in 59 patients (52.2%), and a water-jet scalpel was used in 12 patients (10.6%). The incidence of mortality, major complications, and bile leakage was 0%, 6.2%, and 2.7%, respectively. The median hospital stay was 7 days (IQR, 6–9 days).

Conclusions We successfully introduced an RLR program using the two-surgeon technique. Safe implementation of RLR can be achieved upon completion of the training program and thorough understanding of the surgical protocols.

Keywords Liver resection, Robotic surgery, Training, Outcomes

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Background

In recent years, robotic liver resection (RLR) has been increasingly performed worldwide [1]. Robotic surgery offers several advantages, including a stable surgical view with three-dimensional vision and articulating instruments, addressing the limitations of laparoscopic surgery [2]. Although the safety and feasibility of RLR have been demonstrated, controversies still exist [3]. In Japan, the introduction and dissemination of RLR were officially allowed in 2022, relatively later than in Western countries. Subsequently, a standardized surgical protocol for RLR is urgently needed.

Okayama University Hospital is a high-volume center for robotic hepatopancreatobiliary surgery in Japan, performing more than 300 procedures to date. We introduced a robotic program based on clinical experience in the Netherlands, following the multicenter training program for robotic pancreatoduodenectomy (LAELAPS-3) [4]. Although the superiority of robotic surgery over laparoscopic surgery has been demonstrated in gastrointestinal surgical oncology [5, 6], only few studies have reported the feasibility of RLR using the two-surgeon technique [7].

This study aimed to demonstrate our surgical protocol and the initial outcomes of RLR, focusing on the two-surgeon technique, known as the *t*raining progr*a*m at O*k*ayama *U*niversity for *m*inimally *i*nvasive surgery (TAKUMI-3).

Methods

Training model and multidisciplinary team

The details of our robotic surgery training model have been reported previously [8]. The structured training system consists of a basic simulator and bio-tissue training in parallel with the clinical experience in robotic surgery.

Our multidisciplinary team, including surgeons, anesthesiologists, scrub nurses, ward nurses, physical therapists, and medical engineers, has been dedicated to robotic surgery owing to their experience in robotic pancreatectomy [8].

Surgical protocol for RLR using a two-surgeon technique

Our standard RLR protocol includes a two-surgeon technique. The procedures were performed by a team consisting of a console surgeon and an assistant. The two-surgeon technique emphasizes cooperation and rationality between the console surgeon and the assistant during the procedures, leading to reduced operative time. Additionally, this technique offers several educational benefits.

A robotic platform using the da Vinci Si or Xi system (Intuitive Surgical, Sunnyvale, CA, USA) was used. The instruments should be carefully selected depending on the type of procedure and the tumor characteristics (Table S1). The double-bipolar method with fenestrated and Maryland bipolar forceps was used for the dissection and liver parenchymal transection. In the da Vinci Xi system, intraoperative indocyanine green (ICG) fluorescence imaging using the Da Vinci Fluorescence Imaging Vision System (firefly fluorescence) can be performed to confirm tumor locations and demarcation lines [9].

For liver parenchymal transection, our protocol included the clamp-crush technique using the double-bipolar method. An assistant can use a laparoscopic Cavitron ultrasonic surgical aspirator (CUSA; Integra Lifesciences, Princeton, NJ, USA) or a water-jet scalpel (ERBEJET2; ERBE Elektromedizin, Tübingen, Germany). The use of a laparoscopic CUSA or water-jet was determined based on the depth of the parenchymal transection (Fig. 1A). In cases with a transection depth > 3 cm, a laparoscopic CUSA or water-jet can be helpful. The Pringle maneuver was normally performed using a tourniquet system for inflow control.

The protocol for the use of energy devices is shown in Fig. 1B. Energy devices were not used for simple resection. In contrast, the use of energy devices during abdominal surgery depends on the robotic system and the patient's medical history. Laparoscopic devices can be used in cases involving a robotic Si system or previous abdominal surgery. In other cases, the Da Vinci Vessel Sealer was used.

Patients were placed in the reverse Trendelenburg position in the supine position for anterolateral tumors (segments [S] 1, 2, 3, 4, and 5) or in the left lateral position for posterosuperior tumors (S7 and 8). The left semilateral or lateral position can be applied for S6 tumors. The benefits of the left lateral position are shown in Fig. 2. Approaching posterosuperior tumors in the supine position is challenging; however, adopting a left-lateral position allows these tumors to be repositioned to the superior aspect of the liver, facilitating easier access.

Figure 3 demonstrates our general rules for trocar placement in the supine or left-lateral positions. The placement of the trocar is crucial in the context of an assistant. Trocars for the assistant should be placed in the subcostal area to facilitate the assistant to operate comfortably between the robotic arms while avoiding interference with the robotic scope. One key strategy is to place a trocar to avoid a line between the robotic scope and the tumor. Therefore, the trocars for assistants should be placed after docking the robotic system to determine the best position.

Hepatic segment 1, 2, or 3 resection & left lateral sectionectomy

Following dissection of the left lateral lobe and gastrohepatic ligament, the left lateral lobe was lifted to approach the S1 tumor (Fig. 4A). The tumor was dissected from the

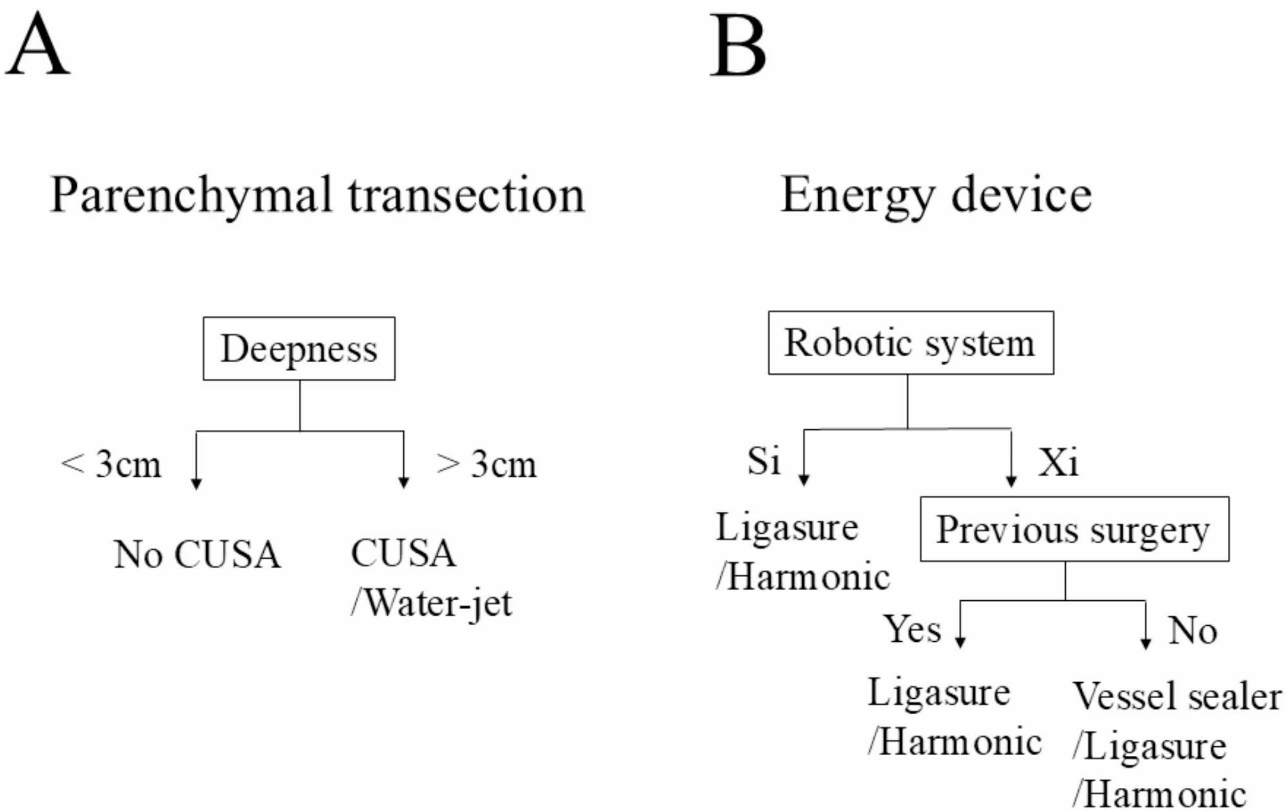

Fig. 1 Protocol for selecting devices. (**A**) During liver parenchymal transection, the clamp-crush technique is our standard protocol. In cases with a transection deepness of > 3 cm, laparoscopic CUSA or a water-jet scalpel can be used by an assistant. (**B**) Regarding energy devices, laparoscopic devices can be selected in cases with the robotic Si system or previous abdominal surgery

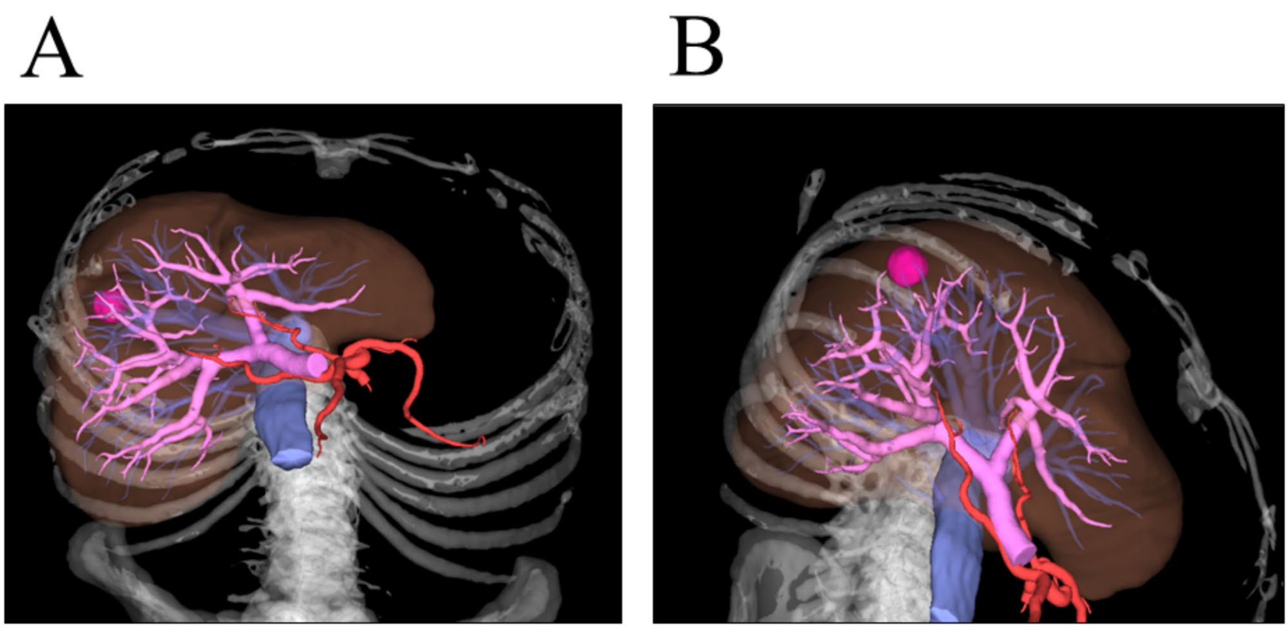

Fig. 2 Benefit of the left lateral position. (**A**) Posterosuperior tumors are invisible and inaccessible in the supine position. (**B**) Adopting the left lateral position repositions posterosuperior tumors to the superior aspect of the liver, facilitating easier access

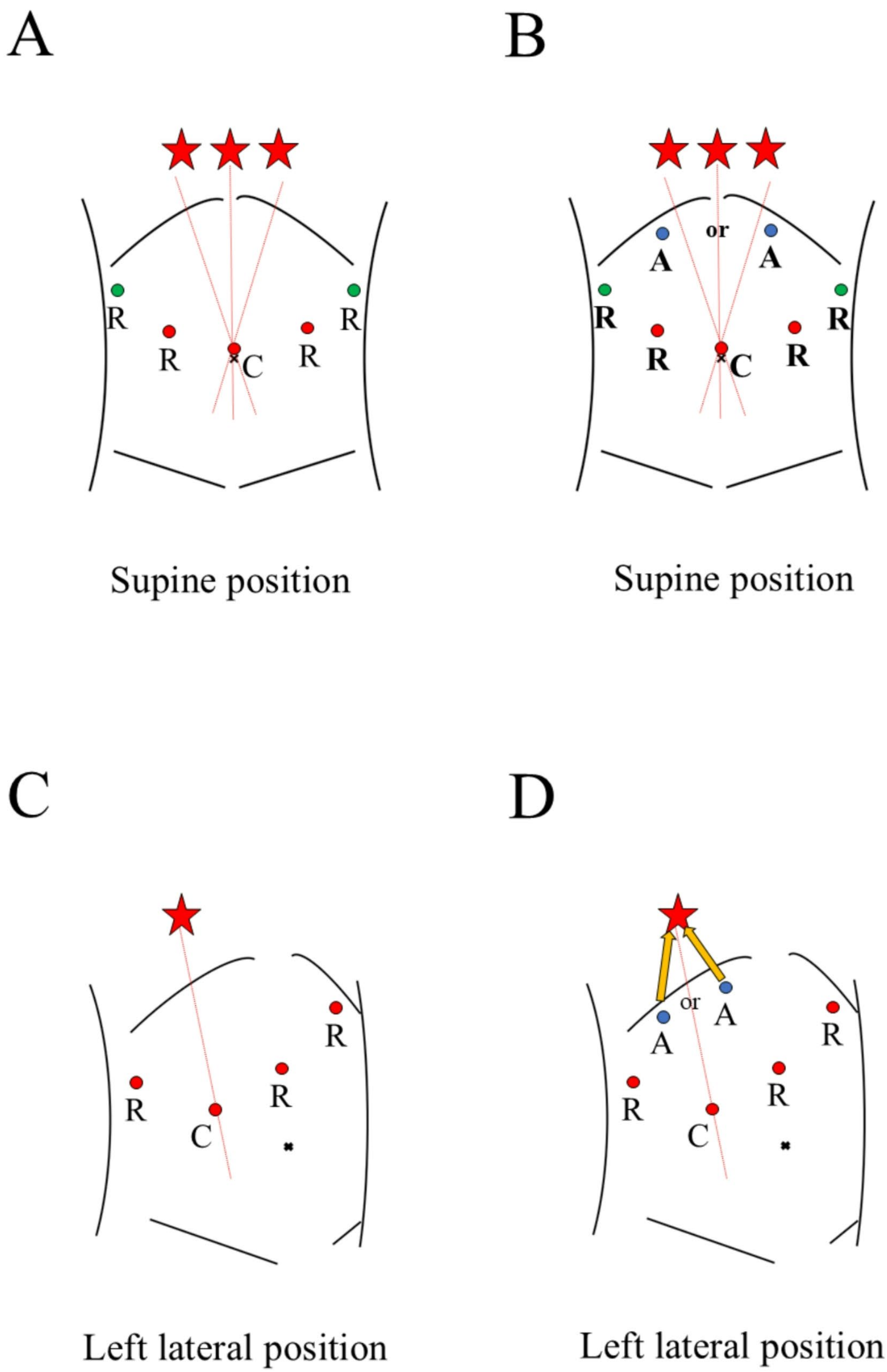

Fig. 3 (See legend on next page.)

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Fig. 3 Trocar placement in robotic liver resection. (**A**) In the supine position, the camera is placed at the umbilicus. Thereafter, three robotic trocars are placed, with two robotic trocars at the right or left side of the abdomen. After docking the robotic system, a trocar for an assistant is placed at the right or left side of the subcostal area. (**B**) In the left lateral position, the camera is placed on the right side of the abdomen, followed by placement of three robotic trocars. After docking, a trocar for an assistant is placed at the right side of the subcostal area. Trocars for an assistant should be placed in the subcostal area, facilitating comfortable operation between the robotic arms without interference from the robotic scope. Trocars for an assistant should not be placed in line with the camera and the tumor. A: trocar for assistant; C: camera; R: robotic trocar; red star: the targeted tumor

inferior vena cava with the short hepatic veins divided and resected using a caudal approach (Fig. 4B; Video S1) [10].

For the S2 or S3 resection, the round and falciform ligaments of the liver were initially dissected and pulled toward the right side of the patient using Cadiere forceps. Contrast-enhanced intraoperative ultrasonography using Sonazoid can help detect small liver tumors. ICG fluorescence imaging may also be useful for detecting tumors located on the liver surface (Fig. 4C). The tumors were resected with or without laparoscopic CUSA.

For left lateral sectionectomy, parenchymal transection was initiated on the left side of the umbilical portion to identify the Glissonean pedicles of S2 and 3, which could be divided using a stapler (Fig. 4D). Parenchymal transection was performed toward the root of the left hepatic vein. The left hepatic vein was encircled and stapled to resect the specimen (Video S2). The specimen can be removed through the Pfannenstiel incision.

Hepatic segment 4, 5, or 6 resection

Following division of the round and falciform ligaments, the round ligament was pulled toward the left side of the patient. Liver parenchymal transection was performed using the clamp-crush technique. The Glissonean pedicles at S4, S5, and S6 were carefully dissected and transected. Laparoscopic CUSA or water-jet may be helpful for dissection around the Glissonean pedicles (Fig. 4E; Videos S3, S4).

Hepatic segment 7 or 8 resection

Proper retraction using Cadiere forceps was essential for the successful resection of segments 7 and 8 (Fig. 4F). The combination of the clamp-crush technique with a

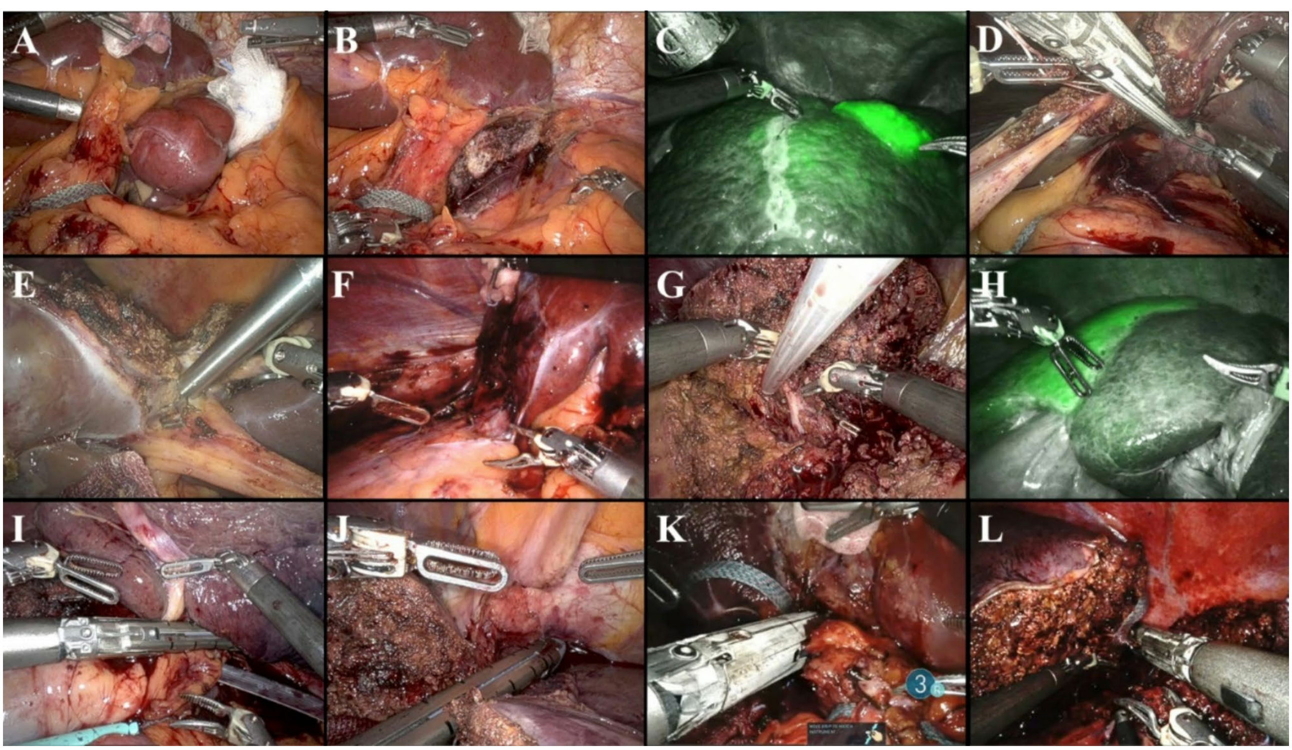

Fig. 4 Intraoperative findings. (**A**) A tumor of the segment 1 (S1) is approachable after the dissection of the left lateral lobe and the gastrohepatic ligament. (**B**) Surgical view after hepatic S1 resection. (**C**) A tumor is visible using ICG fluorescence imaging. (**D**) The division of the Glissonean pedicle of S3 in left lateral sectionectomy. (**E**) Use of water-jet to dissect the Glissonean pedicle of S4 in hepatic S4 resection. (**F**) Stable surgical view after the right lobe mobilization. (**G**) Use of laparoscopic CUSA to dissect the Glissonean pedicle of S8. (**H**) The demarcation line can be confirmed by clamping the left Glissonean pedicle during left hemihepatectomy. (**I**) The division of the left Glissonean pedicle using a stapler. (**J**) The division of the left hepatic vein. (**K**) The division of the right Glissonean pedicle during right hemihepatectomy. (**L**) The division of the right hepatic vein

Table 1 Short-term outcomes of robotic liver resection compared to pure laparoscopic liver resection

Variable	Robotic ($n = 113$)	Pure laparoscopic ($n = 136$)	*P* value
Patient factor			
Age, years	67 (58–76)	68 (58–73)	0.20
Sex (male/female)	74 (65.5)/39 (34.5)	82 (60.3)/54 (39.7)	0.40
BMI, kg/m^2	22.8 (20.6–26.1)	23.1 (20.7–26.0)	0.28
Child–Pugh score (A/B)	112 (99.1)/1 (0.9)	136 (100)	0.27
Primary disease			
Hepatocellular carcinoma	52 (46.0)	56 (41.2)	0.89
Intrahepatic cholangiocarcinoma	2 (1.8)	4 (2.9)	
Metastatic tumor	48 (42.5)	64 (47.1)	
Others	11 (9.7)	12 (8.8)	
Tumor factor			
Tumor size, median, mm	20 (15–37)	19 (12–39)	0.41
Tumor number (solitary/multiple)	94 (83.2)/19 (16.8)	115 (84.6)/21 (15.4)	0.77
Iwate Difficulty grade			
Low (1–3)	45 (40.2)	44 (32.4)	0.35
Intermediate (4–6)	51 (40.2)	64 (47.1)	
Advanced (7–9)	12 (10.7)	17 (12.5)	
Expert (10–12)	4 (3.6)	11 (8.1)	
Operative factor			
Type of liver resection			
Partial resection	80 (70.8)	78 (57.4)	< 0.001
Left lateral sectionectomy	11 (9.7)	20 (14.7)	
Segmentectomy	13 (11.5)	4 (2.9)	
Sectionectomy (except lateral sectionectomy)	6 (5.3)	20 (14.7)	
Hemihepatectomy	3 (2.7)	14 (10.3)	
Robotic system (da Vinci Xi/Si)	83 (73.5)/ 30 (26.5)		-
Use of CUSA/ water-jet	59 (52.2)/12 (10.6)	135 (99.3)/0 (0)	< 0.001
Operative time, min	156 (121–209)	241 (189–302)	< 0.001
Blood loss, mL	10 (0–100)	70 (6–200)	< 0.001
Pringle time, min	35 (15–51)	47 (0–72)	0.06
Conversion to open surgery	1 (0.9)	7 (5.2)	0.06
Postoperative factor			
Mortality	0 (0)	0 (0)	-
Major complications (CDc ≥ 3)	7 (6.2)	7 (5.2)	0.73
Bile leakage	3 (2.7)	1 (0.7)	0.23
Hospital stay, day	7 (6–9)	8 (7–10)	0.01

Values are presented as n (%) or median (interquartile range)

CUSA: Cavitron ultrasonic surgical aspirator; CDc: Clavien–Dindo classification

console and laparoscopic CUSA performed by an assistant may be helpful in shortening the parenchymal transection time, especially for technically challenging locations, such as segments 7 and 8 (Fig. 4G; Video S5).

Left and right hemihepatectomy

Following mobilization of the left lobe, extrahepatic or transfissural Glissonean approaches were used to encircle the left Glissonean pedicle and confirm the demarcation line (Fig. 4H, I) [11]. The liver parenchyma was dissected, and the left hepatic vein was divided using hanging tape (Fig. 4J). The robotic arm-hopping technique may be helpful for left hemihepatectomy (Video S6) [12].

During right hemihepatectomy, the right Glissonean pedicle was isolated and divided using a stapler (Fig. 4K). Liver parenchymal transection was performed along the Cantlie's line, and the right hepatic vein was finally transected (Fig. 4L; Video S7).

Data collection

The following data were obtained from the prospectively collected database: age, sex, body mass index, the Child–Pugh score, etiology of liver disease (hepatocellular carcinoma, intrahepatic cholangiocarcinoma, metastatic tumor, and others), tumor size and number, the Iwate difficulty grade (low, intermediate, advanced, and expert) [13], robotic system (da Vinci Xi or Si), type of liver resection, devices (CUSA or water-jet), operative time, blood loss, Pringle time, conversion to open surgery, and postoperative outcomes (mortality, major complication evaluated as the Clavien–Dindo classification ≥ 3, bile leakage, and hospital stay).

The outcomes of RLR were examined and compared with those of the pure laparoscopic liver resection (LLR) between March 2012 and December 2024. Values were presented as medians (interquartile range [IQR]) for continuous variables and as proportions for categorical data. All statistical analyses were performed using JMP software version 11 (SAS Institute, Cary, NC, USA).

Ethical approval

This study was approved by the Ethics Committee of Okayama University Hospital and was performed in accordance with the tenets of the Declaration of Helsinki. A prospective registry was created using data from the National Clinical Database (http://www.ncd.or.jp/) of Japan.

Results

We performed 113 RLR using the two-surgeon technique between July 2022 and December 2024 (Table 1). Our cohort included 74 men and 39 women, with a median age of 68 years (IQR, 58–76 years). The most common primary diseases were hepatocellular carcinoma (n = 52, 46.0%) and metastatic tumors (n = 48, 42.5%).

Regarding the type of hepatectomy, robotic partial resection was performed in 80 patients (70.8%). During liver parenchymal transection, laparoscopic CUSA was used in 59 patients (52.2%), and a water-jet was used in 12 patients (10.6%). The median operative time, estimated blood loss, and Pringle time were 156 min (IQR, 121–209 min), 10 mL (IQR, 0–100 min), and 35 min (IQR, 15–51 min), respectively. The incidence of mortality, major complications, and bile leakage was 0%, 6.2%, and 2.7%, respectively. The median hospital stay was 7 days (IQR, 6–9 days).

Between March 2012 and December 2024, 136 patients underwent pure LLR. The RLR and LLR outcomes are presented in Table 1. The RLR group exhibited a significantly shorter operative time (RLR vs. LLR; 156 vs. 241 min, $P < 0.001$) and less blood loss (10 vs. 70 mL, $P < 0.001$) than the LLR group. Although equivalent postoperative outcomes were observed, hospital stay was significantly shorter in the RLR group.

Discussion

This study demonstrated our standard protocol for RLR, including the tips, tricks, and pitfalls of resecting each segment, with the initial outcomes of RLR in 113 cases. Considering the growing number of reported RLR cases worldwide [14], this approach may be effective in the future.

Robot-specific surgical training is essential for the safe implementation of RLR. Through our structured training and clinical experience with robotic pancreatectomy [8], the learning curve for RLR could be limited. Moreover, our extensive experience in liver resection can help standardize the surgical protocol for RLR, including the approach and liver parenchymal transection methods [15]. The two-surgeon RLR technique offers several advantages, including reduced blood loss, shorter operative time, and inflow occlusion [7]. Although the clamp-crush and bipolar cautery techniques have been popular for parenchymal transection [16], our protocol of LLR included the use of laparoscopic CUSA. Therefore, the two-surgeon technique—where one console surgeon operates the robotic instruments and the assistant handles the laparoscopic CUSA—may help address the issue of longer operative time associated with RLR than laparoscopic surgery, particularly in the absence of a robotic CUSA [3, 17]. Regarding the educational benefits of the two-surgeon technique, an experienced console surgeon can guide an inexperienced assistant. Conversely, experienced assistants can support inexperienced console surgeons. Importantly, the roles of the console surgeons and assistants should be clarified based on their surgical experience and skills.

Our initial outcomes of 113 RLR were acceptable, with a shorter operative time and lower complication rates compared to those reported for large RLR series [18, 19]. Moreover, our outcomes were equivalent to global benchmarks for LLR [20]. Although the overall learning curve for RLR is reported to be 25 cases (range 16–50) [21], our learning curve may have been shorter due to our extensive experience in robotic surgery. In this study, one patient required conversion to open surgery because of additional resection of an invisible tumor. Although our protocol for liver parenchymal transection included the clamp-crush technique, laparoscopic CUSA or water-jet by an assistant was used in 66 cases (63%). Surgeons should select the best technique and devices for parenchymal transection [22]. Notably, the use of laparoscopic CUSA may be effective in dissecting the Glissonean pedicles or hepatic veins, as well as shortening the operative time and learning curve.

Nevertheless, this study has some limitations. First, this was a single-center experience of RLR using a two-surgeon technique. Second, as all procedures were performed using the two-surgeon technique and the da Vinci system during the study period, this study did not compare the one-surgeon technique with other robotic systems. This two-surgeon technique can be applied to other robotic systems [23]. Further research, particularly randomized controlled trials comparing RLR with other surgical approaches, is essential to confirm its role in liver resection. Third, further evidence regarding the best technique for parenchymal transection during RLR is required. Finally, long-term benefits should be investigated in future studies.

In conclusion, we present our standardized training program, surgical technique, and the initial outcomes of RLR. Safe implementation of RLR can be achieved upon completing a structured training model and learning the surgical protocol. Future studies should focus on comparing RLR with open and laparoscopic surgeries to evaluate and promote its feasibility.

Abbreviations

RLR	Robotic liver resection
ICG	Intraoperative indocyanine green
CUSA	Cavitron ultrasonic surgical aspirator
S	Segment
LLR	Laparoscopic liver resection
IQR	Interquartile range

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12957-025-03785-3.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Supplementary Material 6

Supplementary Material 7

Supplementary Material 8

Author contributions

KT: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - Original Draft, Project administration. TF, KY, YU: Investigation, Resources, Writing- Reviewing and Editing. MY, TN, YN, NK: Investigation. TF: Supervision, Writing- Reviewing and Editing.All authors edited, read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Okayama University Hospital and was performed in accordance with the tenets of the Declaration of Helsinki.

Consent for publication

The need for written informed consent was waived owing to the retrospective nature of the analysis of anonymized clinical data.

Competing interests

The authors declare no competing interests.

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