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Robotic extrahepatic Glissonean pedicle approach for anatomic liver resection in the right liver: techniques and perioperative outcomes

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Abstract
Background The Glissonean pedicle approach is one of the most popular methods of anatomic liver surgery. Liver surgeons have attempted to reproduce this method laparoscopically. In this study, we introduce our technique of the extrahepatic Glissonean approach for anatomic liver resections, using a robotic system, and report on short-term perioperative outcomes.
Methods From December 2008 to July 2014, 10 patients underwent robotic anatomic liver resection in the right liver. The procedure is as follows: (1) mobilization of the liver and isolation and clamping of a selected Glissonean pedicle; (2) transection of the liver parenchyma using a rubber band retraction technique; (3) division of the Glissonean pedicle after full exposure, followed by completion of parenchymal transection.
Results The median age of the patients was 52.50 (range 28–59) years, and seven were male. All patients had hepatocellular carcinoma. The types of resections performed were as follows: segmentectomy 6 ($n = 1$), segmentectomy of 4b + 5 ventral segments ($n = 2$), right posterior sectionectomy ($n = 3$), extended right hepatectomy ($n = 1$), extended right posterior sectionectomy ($n = 2$), and central bisectionectomy ($n = 1$). Only one case was converted to open surgery due to severe tumor adhesions on the diaphragm. The median operative time was 555 min (range 413–848), and the median estimated blood loss was 225 ml (range 30–700), with no perioperative transfusions. The overall complication rate was 70 % (grade I, 5; grade II, 1; grade III, 1; grade IV, 0). The median length of hospital stay postsurgery was 7 days (range 6–11).
Conclusion Robotic surgery allowed for successful anatomic liver resections via an extrahepatic Glissonean pedicle approach in the right liver and can be safely performed in selected patients.

Keywords Robotic liver resection · Glissonean approach · Anatomic resection

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Anatomic liver resection is a preferred method of oncologic clearance for hepatocellular carcinoma (HCC), as well as a method of securing resection margins in metastatic tumors, which located deep in the liver [1–3]. Open liver resection, or the Glissonean pedicle approach, was introduced by Couinaud and Takasaki in the early 1980s and is one of the safest and most reproducible methods for liver resection [4–6]. Recently, this method has been adapted to suit laparoscopic liver resection through either an extrahepatic [7] or intrahepatic approach [8].

However, dissection and control of the Glissonean pedicle at the liver hilum is challenging issue in the laparoscopic field due to the anatomic complexity of the liver and the inherent limitations of the laparoscopic technique and its instruments. The recently introduced robotic system provides distinct advantages in these intricate procedures, providing a highly magnified three-dimensional visual field, wristed instruments with seven degrees of freedom, a stable camera platform, and tremor filtration [9]. In this study, we introduce a novel technique for anatomic liver resection via extrahepatic Glissonean access using a robotic system and present the short-term outcomes in our consecutive series of robotic extrahepatic Glissonean pedicle approach for anatomic liver resection in the right liver.

Materials and methods

From December 2008 to July 2014, a total of 50 patients underwent liver resection using the Da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA, USA). Among them, 10 patients who underwent robotic anatomic liver resection in the right liver via the extrahepatic Glissonean pedicle approach are reported here. All patients were fully informed about risks and benefits of robotic surgery and signed written informed consent forms prior to surgery.

Surgical procedure

The patient's position and port placements were described in our previous study [10]. Four robotic ports and one assistant port were used. For right-sided liver resections, camera port was placed in the right periumbilical area, and the assistant port at umbilicus. Two working ports for the first and second robotic arms were introduced in the right and left upper quadrants, respectively. For left-sided resections, the positions of the camera and assistant ports were switched. The third robotic arm port was placed in the left flank area in all series of robotic extrahepatic Glissonean pedicle approach for anatomic liver resection in the right liver.

Mobilization of the liver and isolation and clamping of the selected Glissonean pedicle

The round, falciform, and ipsilateral coronary ligament ligaments were sectioned. In right posterior sectionectomies, the right inferior and posterior sides of the liver were freed from the diaphragm and dissected to the inferior vena cava (IVC) with ligation of the short hepatic vein (Fig. 1A). The IVC ligament and a few short hepatic veins were divided during the mobilization of the right liver in extended right posterior sectionectomies.

The selected Glissonean pedicles were dissected via an extrafascial approach from the root, at the liver hilum in right-sided resections and at the round ligament in medial and lateral sectionectomies. When resection was conducted along either the right or left side of the round ligament at first, parenchymal transection was performed to expose the Glissonean pedicles of either segment 4b or 4a (Fig. 2A); following this, the pedicles were divided in order. In right posterior sectionectomies, the gallbladder was retracted upward to expose the right-sided liver hilum. The small portal pedicles, which usually supply the caudate lobe, were carefully dissected and divided to expose the pedicles, particularly the right posterior or right anterior portal pedicle (Fig. 2B). After the selected Glissonean pedicle was identified, it was encircled by umbilical tape and secured with a laparoscopic bulldog clamp (Figs. 1B, 2C). Clamping of the inflow produced an ischemic demarcation line on the liver surface, along which a transection line was marked by an electrocautery hook. Intraoperative ultrasound was performed to confirm tumor location and surgical resection margins.

Parenchymal transection using the rubber band retraction technique

Usage of rubber bands during parenchymal transection has been previously introduced for open [11], laparoscopic [12], and robotic liver resections [10] (Fig. 2D). Rubber bands fixed on both resection margins were pulled out using the trocar site closure device, Endo Close^{TM} (Covidien, New Haven, CT, USA), which conveniently holds rubber bands and requires only a 1- to 2-mm incision. These abdominal incisions should be blocked using a small piece of surgical gauze to prevent CO_2 leakage. As parenchymal transection progressed, the traction of each rubber band was adjusted to optimize the surgical field. Liver parenchyma was transected using the harmonic scalpel and Maryland bipolar forceps (Figs. 1C, 2D). The harmonic scalpel, mounted on the second robotic arm (surgeon's left hand), was used mainly for parenchymal transection. The Maryland bipolar forceps on the first robotic arm (surgeon's right hand) were used either to control minor bleeding or for fine dissection of liver parenchyma around hepatic vein branches or the portal pedicle, as in the crash-clamping method. To maintain a proper transection plane in the deep liver parenchyma during right-sided sectionectomy, the right hepatic vein, which is exposed on the transection plane, can be a useful anatomic landmark (Fig. 1C).

Division of the selected Glissonean pedicle and completion of parenchymal transection

At the halfway point of parenchymal transection, the Glissonean pedicle was completely exposed (Fig. 2E). After the bulldog clamp was removed, the Glissonean pedicle was ligated using a laparoscopic linear stapler (Figs. 1D, 2E). Because parenchymal transection was conducted along an ischemic demarcation line, there was no significant crossing portal pedicle. However, in right

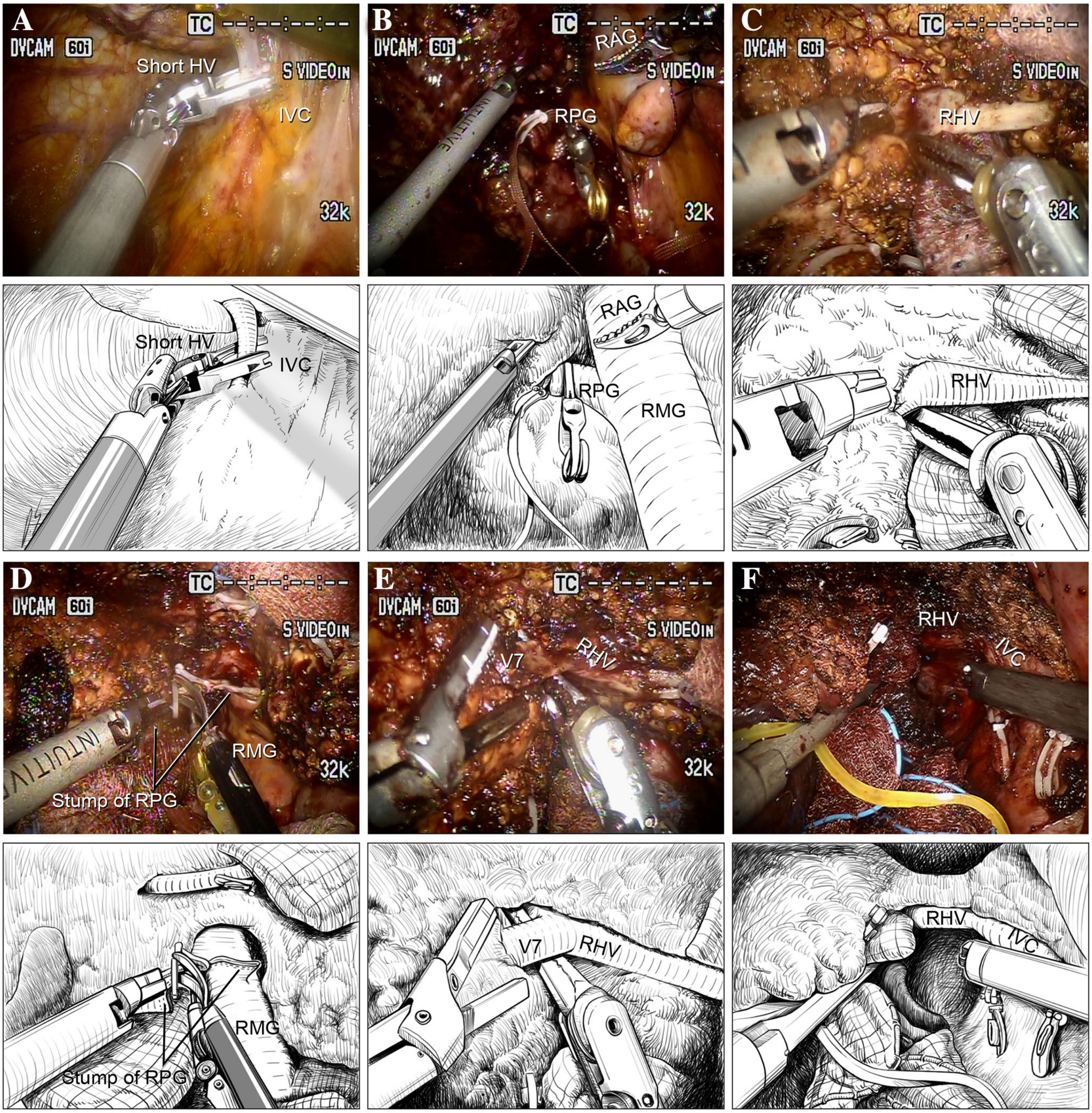

Fig. 1 Right posterior or extended right posterior sectionectomy. **A** Mobilization of the right liver and ligation of the short hepatic vein. **B** Clamping the right posterior Glissonean pedicle with laparoscopic bulldog clamp. **C** Parenchymal transection was conducted, exposing the right hepatic vein on the resection plane in a right posterior sectionectomy. **D** The right posterior Glissonean pedicle was divided using a laparoscopic linear stapler and robotic Hem-o-lok clips. **E** The major hepatic vein branch of segment 7 was identified and divided in a right posterior sectionectomy. **F** The division of the right hepatic vein in an extended right posterior sectionectomy. *IVC* inferior vena cava, *HV* hepatic vein, *RAG* right anterior Glissonean pedicle, *RHV* right hepatic vein, *RMG* right main Glissonean pedicle, *RPG* right posterior Glissonean pedicle, *V7* hepatic vein branch of segment 7

posterior sectionectomy, a significant right hepatic vein branch in segment 7 was carefully dissected and ligated (Fig. 1E). At final stage, the right hepatic and middle hepatic veins were divided using a laparoscopic linear stapler in extended right posterior sectionectomy (Fig. 1F) and central bisectionectomy (Fig. 2F), respectively.

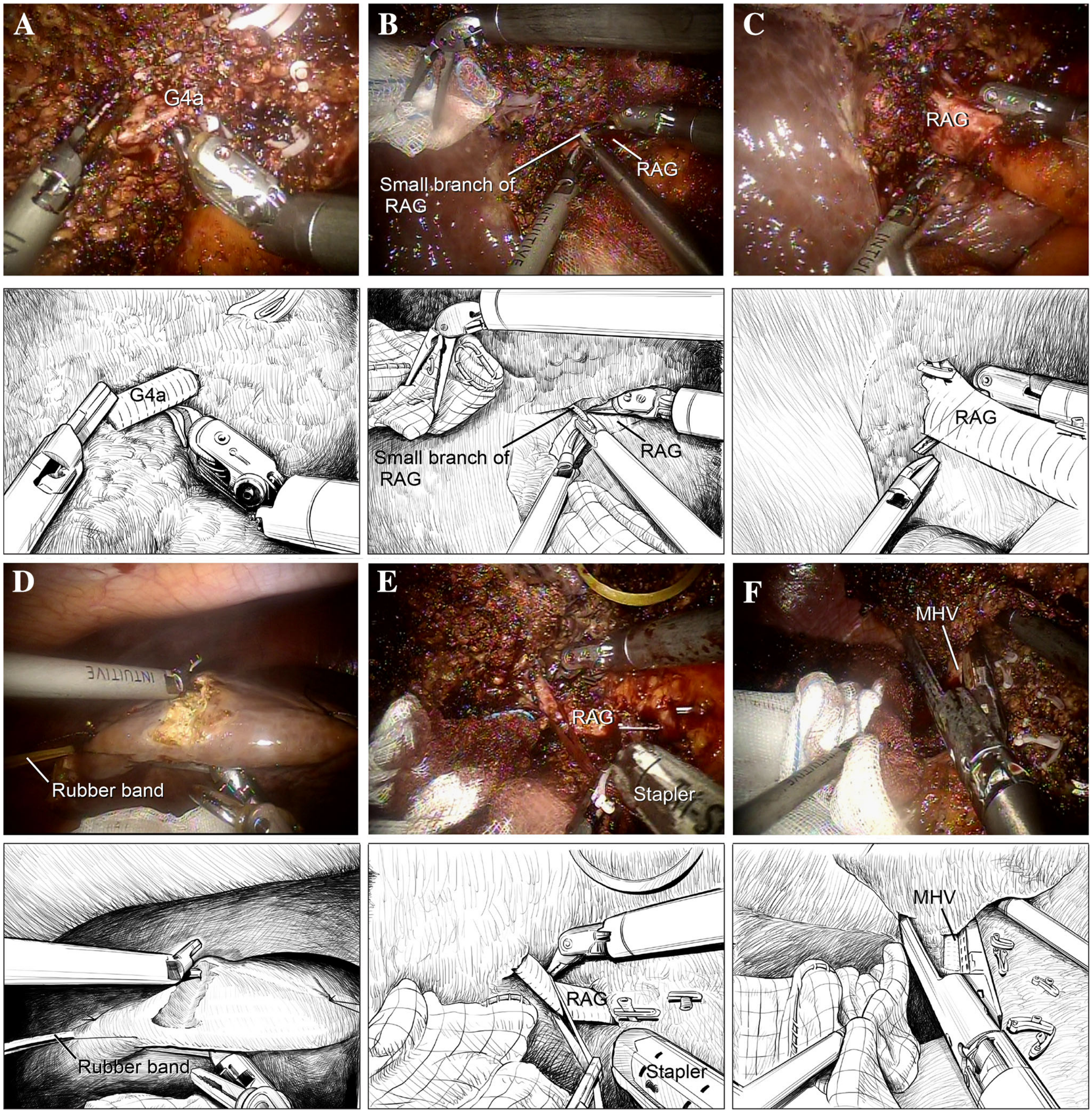

Fig. 2 Robotic central bisectionectomy. **A** The main Glissonean pedicle of segment 4a was exposed and dissected, during parenchymal transection along the right side of the round ligament. **B** Small Glissonean branches should be identified and ligated to help identify the right anterior Glissonean pedicle. **C** The complete isolation of the right anterior Glissonean pedicle. **D** Stable retraction was achieved using rubber bands, and parenchymal transection was conducted using the harmonic curved shears and the Maryland bipolar forceps. **E** The right anterior Glissonean pedicle was fully exposed and divided using a laparoscopic linear stapler. **F** The division of the middle hepatic vein using a laparoscopic linear stapler in the final stage of the procedure. *G4a* Glissonean pedicle of segment 4a, *MHV* middle hepatic vein, *RAG* right anterior Glissonean pedicle

Results

The median age of the patients was 52.50 (range 28–59) years, with seven being male. Seven patients had chronic active hepatitis and three had liver cirrhosis. HCC was the most common disease. The median tumor size was 2.5 cm, with 80.0 % (8/10) of tumors being singular. The liver stiffness was measured preoperatively by FibroScan. The median liver stiffness was 11.90 kPa (range 10.9–21.5), median indocyanine green retention rate at 15 min was

Table 1 Patient demographics and clinicopathological characteristics ($n = 10$)

Age (median, range)	52.50 (28–59)
Sex	
Male	7
Female	3
Underlying liver disease	
Normal	0
Chronic active hepatitis	7
Cirrhosis	3
Pathology	
Hepatocellular carcinoma	10
Colorectal liver metastasis	0
Tumor size (median, range)	2.5 (range 1–7)
Tumor number	
Single	8
Multiple	2
Liver stiffness (median, range (kPa))	11.90 (range 10.9–21.5)
ICG R15 [median, range (%)]	15.85 (range 3.4–26.0)
AFP [median, rang (ng/mL)]	9.37 (range 4.37–12,550.7)
PIVKA II [median, range (mAU/mL)]	44.0 (range 17.0–174.0)

AFP alpha-fetoprotein, *ICG R15* indocyanine green retention rate at 15 min, *PIVKA II* prothrombin induced by vitamin K absence-II

15.85 % (range 3.4–26.0), median alpha-fetoprotein was 9.37 (range 4.37–12,550.7) ng/mL, and median prothrombin induced by vitamin K absence-II was 44.0 (range 17.0–174.0) mAU/mL (Table 1).

The type of operation and respective perioperative outcomes with complications are summarized in Table 2. Ten patients received liver resections involving the right liver, including segmentectomy 6 ($n = 1$) and segmentectomy of 4a and ventral segment of S5 ($n = 2$), right posterior sectionectomies ($n = 3$), extended right hepatectomy ($n = 1$), extended right posterior sectionectomy ($n = 2$), and central bisectionectomy ($n = 1$). Among these, seven patients received major hepatectomies. There was only one conversion to open surgery during parenchymal transection, due to unexpectedly extensive tumor adhesions to the diaphragm. The median operation time was 555 min (range 413–848), and the median estimated blood loss was 225.0 ml (range 30–780). There were no perioperative transfusions. The overall complication rate was 70 % (grade I, 5; grade II, 1; grade III, 1; grade IV, 0), which was classified according to the modified Clavien system [13]. The median length of hospital stay was 7 days (range 6–11).

Discussion

We previously have published our early experience with robotic liver resections, composed mainly of hemihepatectomies [10]. In this report, though the individual ligation of the liver hilum has been the preferred technique for hemihepatectomy, resection along the round ligament was performed in the Glissonean pedicle approach. As our experience with robotic liver resections has increased, we have adopted the Glissonean pedicle approach to several sectionectomies of the right liver.

The identification of the right anterior or posterior pedicle is a challenging issue, even in open surgery, as it is located deep in the liver, and requires fine dissection. Recently, some experts in laparoscopic surgery have introduced their own techniques for liver resection using an extrahepatic Glissonean pedicle approach [7, 14] or an intrahepatic approach [8]. However, because of the limitations of laparoscopic surgery, some special devices such as the Endo Retract Maxi were used to dissect and encircle the posterior side of the Glissonean pedicle [14]. While the intrahepatic approach is simple and effective, it was developed to handle the challenge of dissecting and controlling the Glissonean pedicle laparoscopically. Though the intrahepatic approach is safe for the normal liver, it could be dangerous in cirrhotic livers, as fibrotic parenchyma resists blind clamp insertion, and injuries to small Glissonean pedicles may cause significant bleeding in context of portal hypertension. The extrahepatic approach appears to be ideal for the laparoscopic field pending surgeon's level of skill. Robotic surgery, however, is less dependent on operator proficiency and presents another option for the extrahepatic Glissonean pedicle approach. The camera system provides magnified 3-D vision, as well as a stable surgical field with elimination of the fulcrum effect; combined with the robot's EndoWrist instrument function, motion scaling, and tremor filtration, these enable laparoscopic replication of open surgical field techniques [15]. In our series, the right Glissonean pedicles were completely identified via the extrahepatic approach in eight patients.

Parenchymal transection is as important as inflow control in anatomic liver resection. Because an ultrasonic dissector is not available for robotic surgery, the liver parenchyma is usually transected using the harmonic curved shears and the Maryland bipolar forceps. Despite limited instrumentation options, our unique techniques allowed for safe and effective parenchymal transection. First, we achieved steady retraction of liver parenchyma using rubber bands, as introduced in our previous report [10]. This traction method allowed for simultaneous use of all three robotic arms during parenchymal transection, while the third arm can also be used to compress a site of bleeding or to retract deep parenchyma, as an assistant might do during open surgery. The port for the harmonic curved shears should be carefully selected because it does not have EndoWrist function. Second, the surgeon's left hand holds the harmonic curved shears, enabling proper

Table 2 Type of operation and perioperative outcome

Procedure	*N*	OP time (min)	Estimated blood loss (mL)	Transfusion	Conversion to open	Resection margin	Complications (Clavien and Dindo)	Hospital stay (days)
Right ($n = 10$)								
Segmentectomy (S4a + ventral segment of S5)	2	457 (420–490)	138 (30–175)	0	–	Negative	Fluid collection (G I, $n = 1$)	7
Segmentectomy 6	1	521	780	0	–	Negative	Fluid collection (G 1)	7
Right posterior sectionectomy	3	572 (413–807)	177 (100–250)	0	–	Negative	Fluid collection (G I, $n = 2$)	7 (6–8)
Extended right posterior section	2	725 (601–848)	485 (270–700)	0	1 (diaphragm adhesion)	Negative	Small PV thrombosis (G I, $n = 1$)	9 (7–11)
Extended right hepatectomy	1	807	500	0	–	Negative	Biliary stricture (G IIIa)	8
Central bisectionectomy	1	590	200	0	–	Negative	Postoperative ileus (GII)	9
Total	10	555 (413–848)	225.0 (30–700)	0	1 (10 %)	Negative	Total: 70 % (7/10) GI: 5 (50 %), G II: 1 (10 %) G III: 1 (10 %)	7 (6–11)

tracking of the transection plane during caudocranial parenchymal transection. This location also allows lower placement of the active blade, as well as activation of the active blade prior to insertion into the liver parenchyma, preventing minor bleeding. The EndoWrist bipolar forceps in the right hand, which is typically dominant, is used for finer dissection around the hepatic vein and portal pedicles and to guide the transection of the harmonic scalpel, especially in the deep liver parenchyma. In this study, there were no conversions to open surgery and no significant bleeding during parenchymal transection.

Robotic technology and instruments have continuously developed. Newer wristed robotic instruments, such as the Endowrist One Vessel Sealer, Endowrist One Suction/Irrigator, Endowrist ultrasound [16, 17], and angulated vascular stapler have been introduced [18]. Among these, the Endowrist One Vessel Sealer and the angulated vascular stapler are expected to be useful for robotic liver resections. The da Vinci Si system provides a 12-mm-sized rigid telescope, which has limited vision for the posterior side of the liver. Extensive adhesions to or tumor invasion of the diaphragm can block dissection of the liver from the diaphragm using this rigid visual telescope and instruments and necessitated one conversion to open surgery in this series. In the latest model, the da Vinci Xi system, the camera system was simplified by decreasing its lens diameter to 8 mm. The camera system can be inserted into four robotic arms, creating a wider surgical view than in previous models [19, 20].

In our series, there were only minor blood loss and a single conversion to open surgery in 10 consecutive procedures. Though mean operative time was slightly prolonged, grade III complications were limited to one cases (10 %), and included a biliary stricture. All patients received R0 resection. In conclusion, the robotic system permitted anatomic liver resection via an extrahepatic Glissonean pedicle approach, particularly in cases involving the right liver, and can be safely performed in selected patients. Continually advancing robotic technology and instruments can be expected to facilitate robotic liver resections in future.

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Compliance with ethical standards

Disclosure Dr. Jin Ho Lee, Dr. Dai Hoon Han, Don-Su Jang, Dr. Gi Hong Choi, and Dr. Jin Sub Choi have no conflicts of interests or financial ties to disclose.

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