HOW-I-DO-IT ARTICLES

Robotic simultaneous resection for colorectal liver metastasis: feasibility for all types of liver resection

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Abstract

Background A laparoscopic approach is increasingly being utilized in simultaneous colorectal and liver resection (SCLR) for colorectal cancer with liver metastasis. However, this approach is technically challenging and hence has not been widely adopted. Robotic surgical systems could potentially overcome this problem. We aim to describe the feasibility and outcomes of robotic SCLR for colorectal carcinoma with liver metastasis.

Methods The medical records of 12 patients who underwent robotic SCLR for colorectal cancer with liver metastasis between January 2008 and September 2018 were reviewed retrospectively.

Results The mean age was 59 years (range, 37–77 years). The liver resections were comprised of two right hepatectomies, one left hepatectomy, one left lateral sectionectomy, one segmentectomy of S3 and wedge resection (segment 7), one caudate lobectomy, one associated liver partition and portal vein ligation for staged hepatectomy, and five wedge resections involving segments 4, 5, 6, 7, or 8. The colorectal procedures involved seven low-anterior resections, two anterior resections, two right hemicolectomies, and one left hemicolectomy. The mean operative time was 449 min (range, 135–682 min) with a mean estimated blood loss of 274.3 mL (range, 40–780 mL). The mean length of hospital stay was 12 days (range, 5–28 days). No patients required conversion to laparotomy. Liver resection–related complications were two liver abscesses (Clavien-Dindo classification, one grade II and one grade III) and one case of ascites (grade I), whereas colorectal resection-related complications included one anastomosis leak (grade III) and one superficial wound infection (grade II). There were no deaths reported within 30 days of the procedure. With a mean follow-up duration of 31.5 ± 26.1 months, the overall survival and disease-free survival values were 75.2 and 47.1 months, respectively.

Conclusion Robotic SCLR for colorectal neoplasm with liver metastasis can be performed safely even in cases requiring major liver resections, especially in a specialized center with a well-trained team.

Keywords Robotic simultaneous resection · Colorectal cancer · Liver metastasis

Introduction

Several studies have reported comparable outcomes in patients with synchronous colorectal carcinoma and liver

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metastasis who underwent one-stage colorectal and liver surgery [1–3]. Advances in perioperative care and surgical techniques, particularly in liver surgery, have greatly decreased the morbidity associated with simultaneous colorectal and liver resection [4]. To further improve the quality of life and reduce the associated morbidity of patients with synchronous colorectal carcinoma and liver metastasis, the use of minimally invasive surgical techniques for simultaneous colorectal and liver resection (SCLR) has been increasingly explored [5–7]. However, due to the innate complexity of these sophisticated procedures, they have been adopted in only a few centers with high case volumes and experienced surgeons.

Nevertheless, the inherent limitations of laparoscopic surgery for one-stage colorectal and liver surgery could potentially be overcome by adopting a robotic approach. There are several

key advantages of robotic surgery compared to laparoscopy: augmented three-dimensional view, stable camera, greater freedom of motion of the surgical instruments, no tremors, and improved ergonomics for the operator [8]. Thus, robotic colorectal surgery has been reported to produce better short-term outcomes, such as shorter lengths of hospital stays, more lymph nodes harvested, and longer resection margins, compared to the laparoscopic approach [9, 10]. Recently, however, two randomized studies concluded that there were no advantages in terms of short-term outcomes between robotic and laparoscopic surgeries for rectal cancer [11, 12]. On the other hand, several reports have documented the superiority of the laparoscopic approach over open-liver resection for colorectal liver metastasis [13]. A few centers have also reported the safety and feasibility of robotic liver surgery in colorectal liver metastasis [14, 15]. However, with regard to the potential feasibility of a robotic approach to synchronous robotic resection of colorectal carcinoma and liver metastasis, only case series have been published [16, 17]. Thus, we aim to describe the technical feasibility and outcomes of robotic one-stage resection for colorectal carcinoma with liver metastasis within our institution.

Materials and methods

Patient data

The medical records of patients with colorectal liver metastasis who underwent robotic SCLR between January 2008 and September 2018 were reviewed retrospectively using the electronic medical records at Severance Hospital, Yonsei University College of Medicine. The demographic profile, preoperative workup, co-morbidities, surgical techniques, and follow-up data were reviewed and analyzed. The detailed preoperative evaluation included multi-detector computed tomography (CT) scan, magnetic resonance imaging (MRI), and endoscopic ultrasonography (EUS) for selective colorectal carcinoma. The study protocol has been approved by the Yonsei Institutional Review Board and has been performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Indication

Generally, patient selection for the type of surgical approach (open, laparoscopy, and robotic) was based on the complexity of the liver procedure. A laparoscopic approach was preferred for patients with tumor size < 5 cm with no major vascular or other organ involvement, favorable tumor location (segment 2, 3, 4, 5, and 6), achievable R0 resection, adequate future liver remnant volume, and a general health condition able to tolerate prolong pneumoperitoneum. However, patients with bilobar tumor involvement and unfavorable segment location (segments 1, 7,

and 8) were enrolled for robotic approach. Otherwise, patients who did not agree to the robotic approach will be offered for simultaneous laparoscopic colorectal and open liver resection, or open colorectal and liver resection if appropriate. All possible surgical options were discussed with the patient to allow her/him to provide informed consent for the procedure.

Operative procedures

Operating room set-up using the da Vinci Si and Xi systems

Figure 1 illustrates the different operating room (OR) set-ups for the da Vinci Si and Xi robotic systems. Docking of the robot depended on the type of robotic system used. When using the da Vinci Si robotic system, the robotic surgical cart was positioned lateral or caudal to the patient's surgical table depending on the procedure performed by the colorectal surgeon (Fig. 1a). For the liver surgery, the robot surgical cart was positioned at the head of the patient (Fig. 1b). Thus, the patient and the anesthesia machine were repositioned during the colorectal and liver resection phases. In contrast, when using the new da Vinci Xi system, there was no repositioning of the patient or anesthesia machine. Instead, the robotic cart was placed on the lateral side of the patient's surgical table, and the surgical arms were rotated in the cranial or caudal direction for colorectal and liver surgery, respectively (Fig. 1c).

Patient position and trocar placement

The surgery was performed with the patient in the lithotomy position. Generally, we completed the colorectal procedure before performing the liver resection. As such, the trocars were inserted according to the type of colorectal surgery. For rectal and left-sided colon surgery, a dual-docking technique was utilized as previously described [18]. In addition, port placement for right-sided colon surgery was the same as previously described by Bae et al. [19]. Figure 2a, b illustrates trocar placement for low-anterior resection (LAR), anterior resection, and sigmoidectomy. Generally, no additional trocars were inserted for liver resection. For resection of anterolateral segments and conventional caudocranial anatomic resections, the 5-mm assistant port of colorectal surgery was changed to an 8-mm port for the harmonic scalpel in liver surgery (Fig. 2c, d). The 12-mm-sized paraumbilical port was used for the camera, and two working ports at the right flank and left paramedial area were used. However, for resection of the hepatic caudate lobe and posterosuperior segments, the left paramedian port was used as the camera port without changing the port size from 8 to 12 mm. In this cohort, the da Vinci Xi robotic system was utilized for resection of the caudate lobe and posterior-superior segment tumors. Insertion of an additional 8-mm port in the right flank area for the harmonic scalpel was sometimes required for liver resection involving the superior segment.

Fig. 1 **a** da Vinci Si robotic system for colorectal and **b** liver surgery. **c** da Vinci Xi robotic system
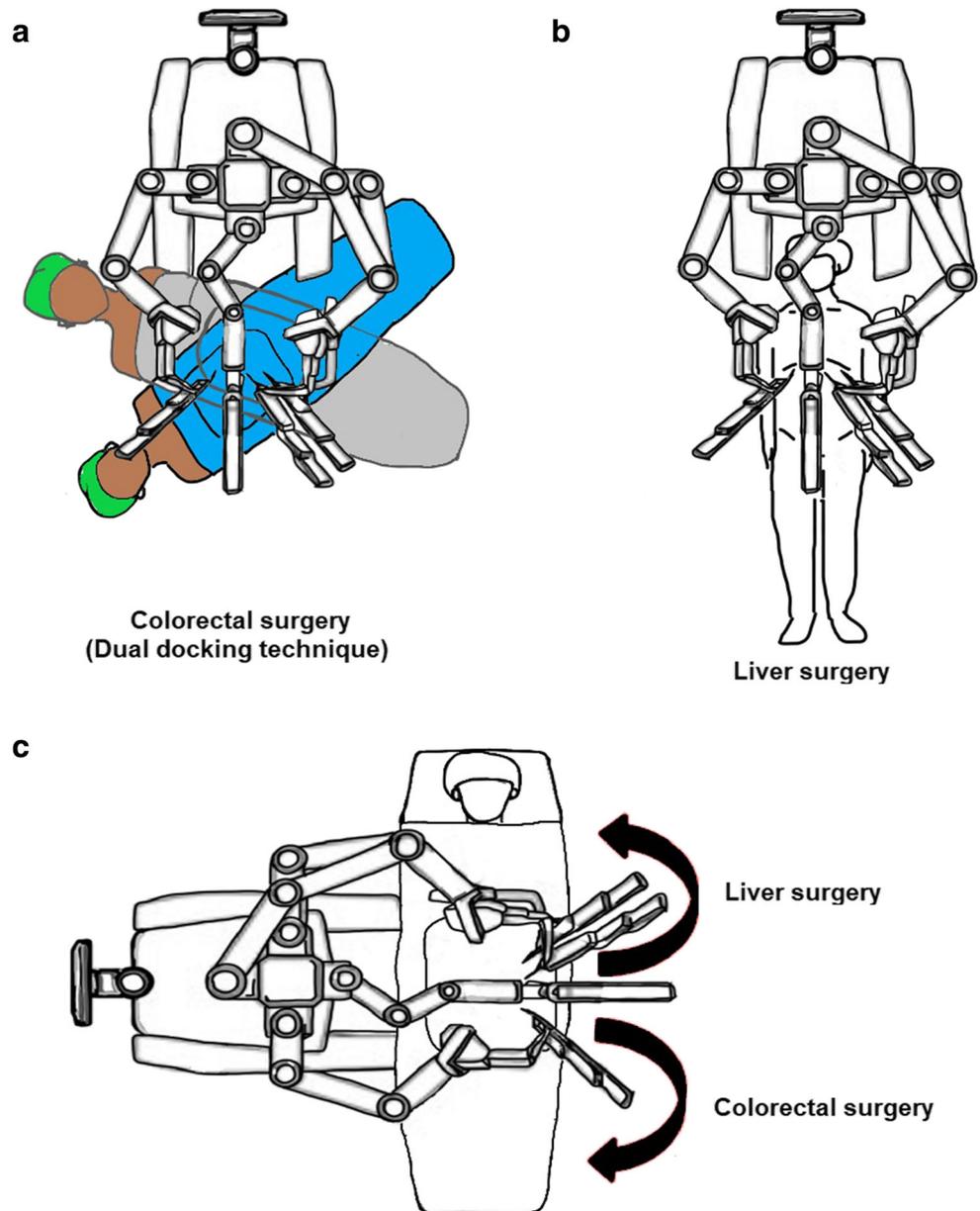
Liver resection phase

Robotic liver resection was performed according to the surgical technique as previously described [20]. Liver traction is very important during any type of robotic liver resection. The rubber band liver traction technique [21] was utilized in all liver resections in this case series; posteriorly located tumors, such as those in segments 7 and 8, can be effectively exposed using this technique, as demonstrated by Choi et al. [21]. The Pringle maneuver was not used in any case.

Liver mobilization Liver resection began with transection of the falciform ligament to freely expose the anterior surface of the liver (Fig. 3a). Dissection of the coronary and triangular ligaments depended on the type of procedure. The right coronary and triangular ligaments were dissected in right hepatectomy and tumors involving segments 6, 7, and 8. In contrast, the coronary and left triangular ligaments were dissected in tumors located in segment 2 and during left hepatectomy and left lateral sectionectomy. For right lobe mobilization, the liver was retracted using the third robotic arm, which provided a wider and more steady work area (Fig. 3b). Dissection of the triangular ligament up to the inferior vena cava was facilitated using a cautery of the first robotic arm.

Hilar dissection For major hepatectomy, hilar dissection through individual isolation of the right or left portal vein

Fig. 2 Trocar placement for robotic simultaneous liver and colorectal resection for colorectal carcinoma with liver metastasis. a Trocar placement for colorectal procedures using low-anterior resection, anterior resection, or sigmoidectomy. b For liver resection, the 5-mm port in the left upper quadrant was changed to an 8-mm port (blue arrow) as a first working port (red arrows)
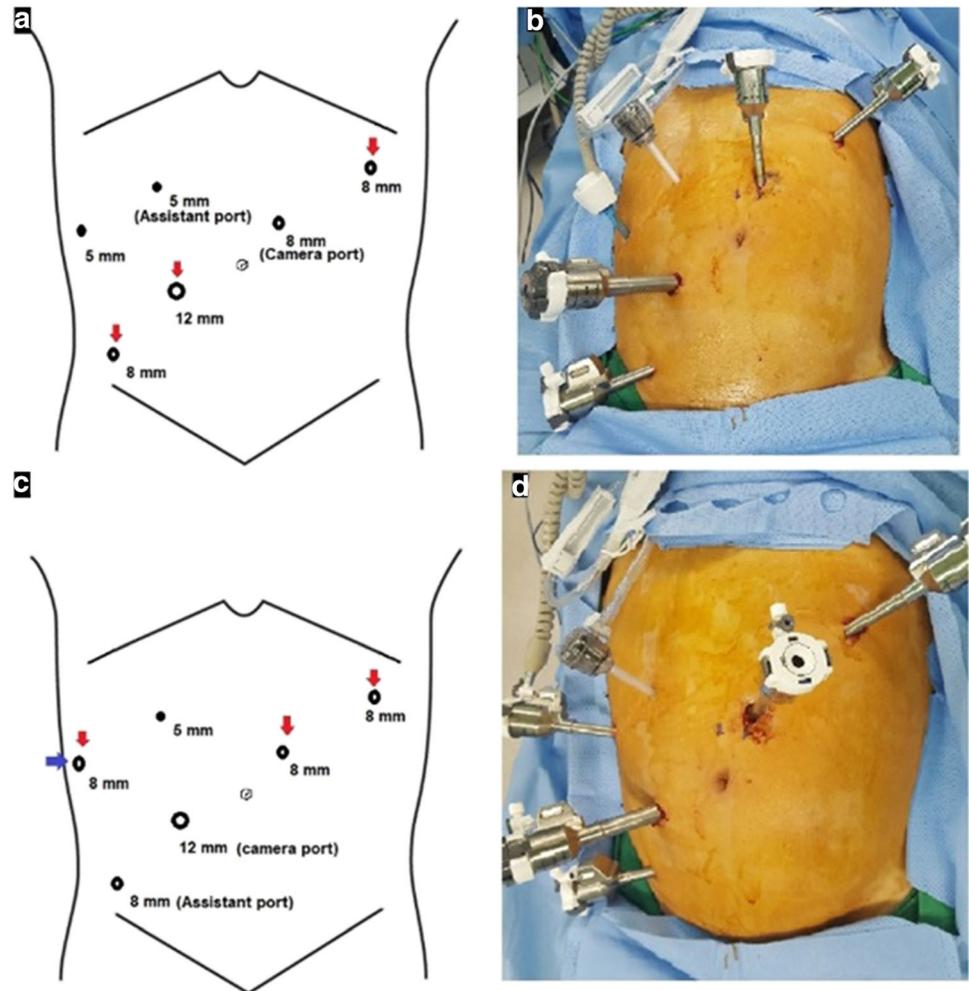
and artery was performed. For right-sided resection, cholecystectomy was performed first. The cystic duct was then retracted upward using the third robotic arm to expose the right lateral border of the right portal vein. This was then followed by identification of the right hepatic artery. The right hepatic artery and right portal vein were subsequently ligated and transected while leaving the division of the right hepatic duct during the parenchymal transection. Figure 4 illustrates the procedure for hilar dissection.

Parenchymal transection Transection commenced following the ischemic demarcation line. In addition, we usually applied fluorescence imaging using indocyanine green (ICG) to clearly define a demarcation line for anatomic liver resections (Fig.

Fig. 3 Liver mobilization. a Dissection of the falciform ligament. b Dissection of the triangular ligament
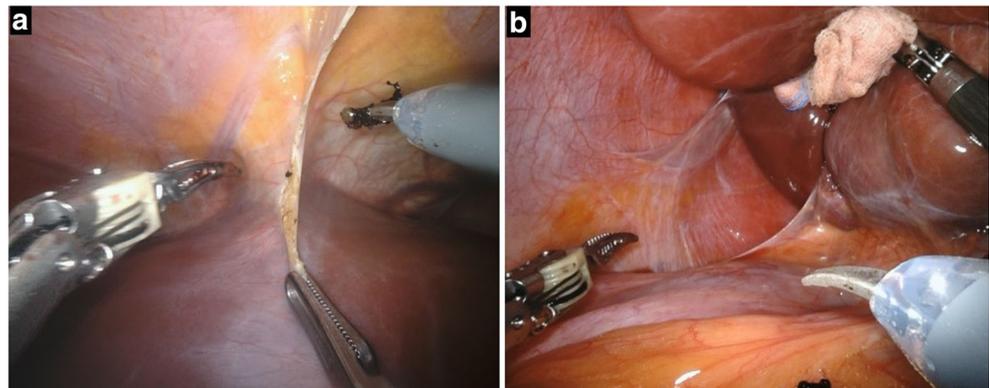
Fig. 4 Hilar dissection. **a** Hilar structures can be properly exposed by upward traction of the cystic duct stump with the third robotic arm. **b** Dissection started along the right lateral border of the RPV. **c** Clipping and transection of the RHA. **d** The portal vein branch to the caudate lobe should be transected. Clipping (**e**) and transection (**f**) of the RPV. RPV, right portal vein; RHA, right hepatic artery; CD, cystic duct
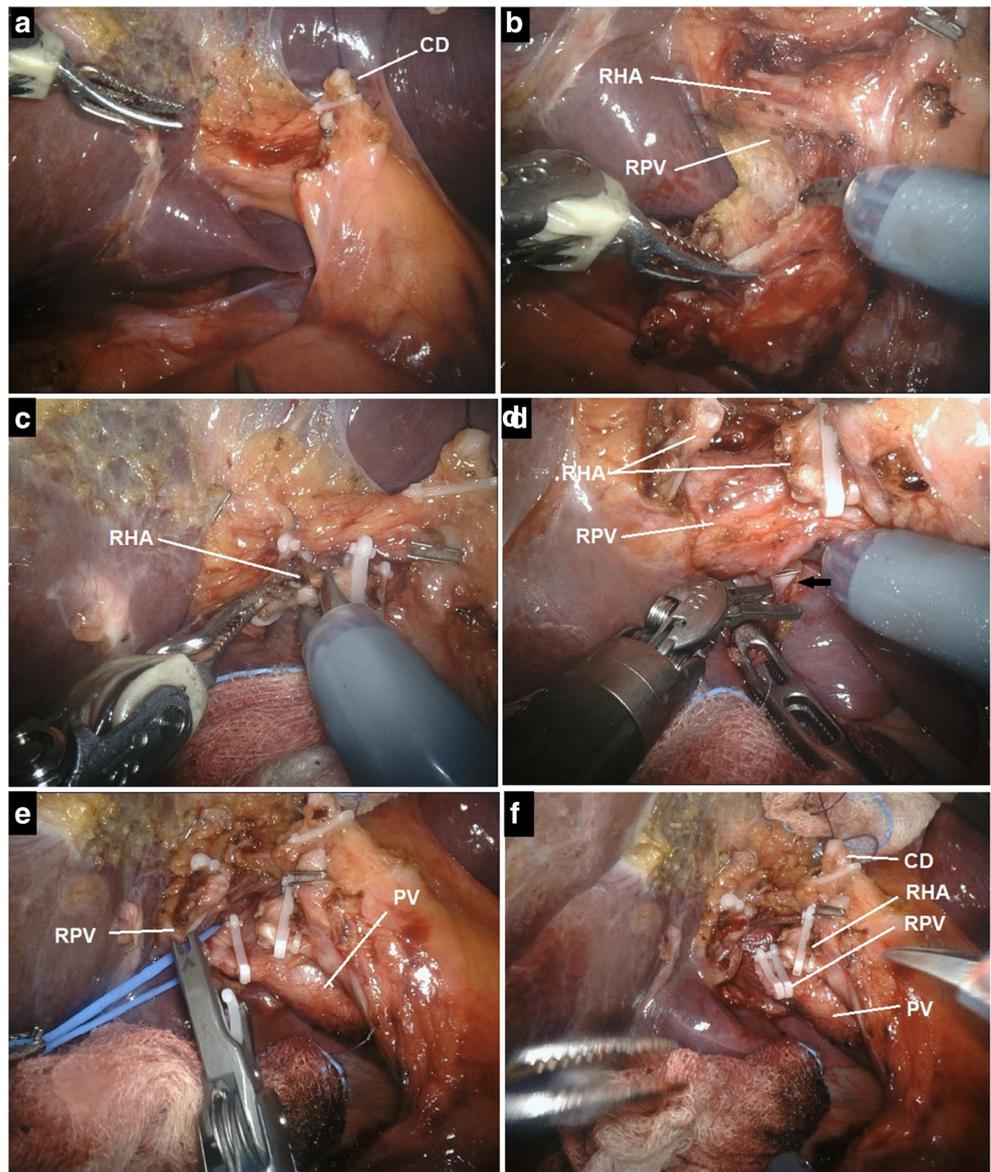
5). During dissection, application of the rubber band traction technique provides constant and steady counter-traction on both sides of the liver (Fig. 6a). Parenchymal transection was performed with the harmonic scalpel attached to the left robotic arm (Fig. 6b). The superficial layer of the liver parenchyma can be safely transected using a full bite of the

Fig. 5 Fluorescence-guided robotic liver surgery. An ischemic demarcation line after ligation of the right portal vein and right hepatic artery (**a**) for right hepatectomy was clearly demonstrated using indocyanine green (ICG) technology (**b**)
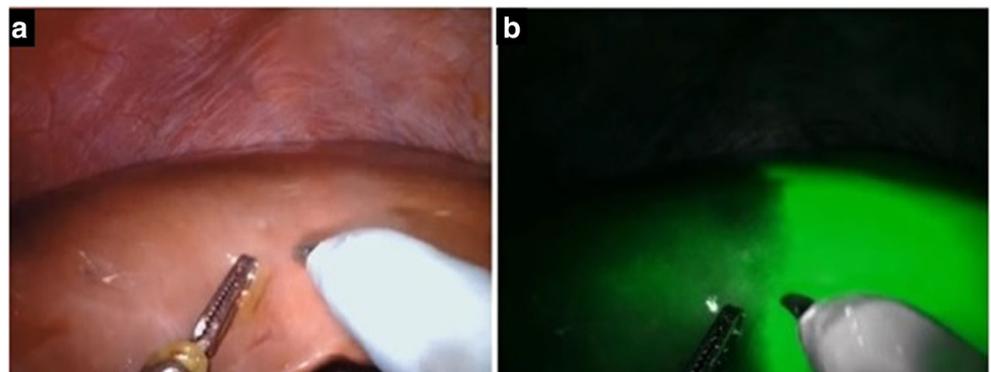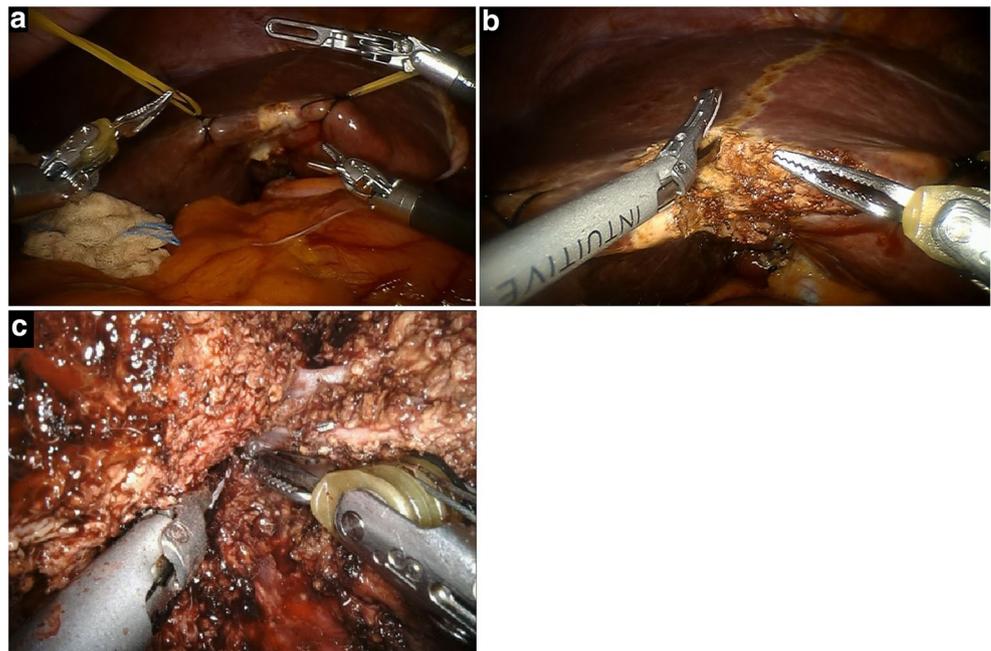
Fig. 6 Parenchymal transection.
a Application of rubber band
traction. **b** The use of harmonic
and bipolar devices for
parenchymal transection. **c**
Dissection around major vessels
can be safely performed using the
bipolar device

harmonic scalpel. However, when the deep areas of the liver
were dissected, small bites of the harmonic scalpel were nec-
essary to avoid injury to the large vessels. A bipolar instru-
ment was more effective and safer during dissection near or
around the major vessels (Fig. 6c). Large vessels encountered
during dissection were secured using metal clips or Hem-o-
lok. Small bleeders were effectively controlled with a bipolar
instrument in the second working port or the second right
robotic arm. In major liver resection, the right or left hepatic
duct and right or left hepatic veins were secured using an
endovascular stapler.

Segmentectomy and wedge resection The Glissonian ap-
proach was usually utilized when performing a
segmentectomy. An intraoperative ultrasound facilitates the
identification of intrahepatic pedicles. For a wedge resection,

tumor localization and identification of adequate surgical mar-
gin using laparoscopic ultrasound was paramount. Moreover,
fluorescence imaging using ICG was very helpful in identify-
ing liver metastases (Fig. 7).

Colorectal resection phase

Rectal surgery For robotic rectal surgery, the robotic surgical
cart was positioned on the left caudal side of the surgical table,
and the standard procedure for LAR or anterior resection was
carefully observed. As presented in Fig. 1a, six ports were
utilized to perform rectal cancer surgery. This port placement
was able to accommodate a dissection field spanning the
splenic flexure to the pelvic floor. A 12-mm port was used
for the endolinear stapler during the colo-anal anastomosis.
Medial-to-lateral dissection was performed from the sacral

Fig. 7 Fluorescence-guided
robotic liver surgery.
Intraoperative non-detectable liv-
er metastasis (**a**) was clearly
identified after intravenous ad-
ministration of indocyanine green
(ICG) (**b**)
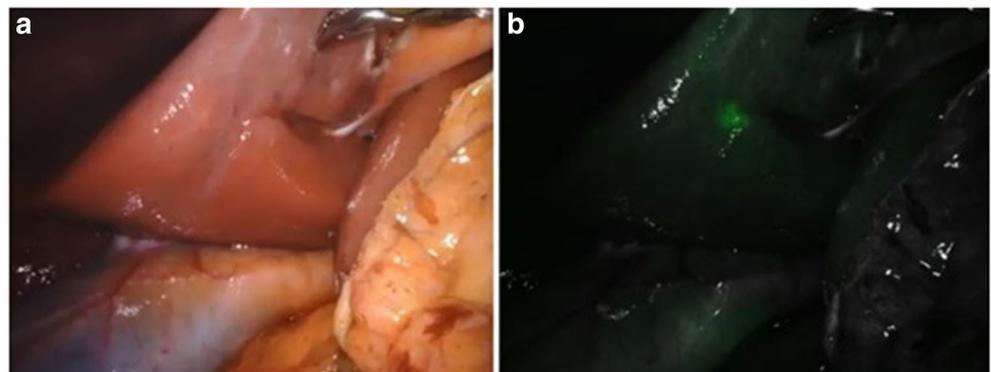
promontory up to the splenic flexure. The root of the inferior mesenteric artery was identified and ligated. All lymph-node-bearing tissues were included in the dissection. Next, total mesorectal excision was accomplished by dissecting the plane between the mesorectal fascia and the parietal pelvic fascia. An endolinear staple was utilized to divide the distal rectum.

Colon surgery For right hemicolectomy, the ileocolic and right colon vessels were identified and dissected together with the mesentery. The proximal third of the transverse colon and 10 cm of the ileal segment immediately distal to the ileocecal valve were secured and transected using an endolinear staple, and an intracorporeal end-to-side anastomosis was performed. For left hemicolectomy, the inferior mesenteric vein was dissected and ligated at the inferior border of the pancreas. The inferior mesenteric artery was dissected at its base. The distal third of the transverse colon and proximal sigmoid were transected with an endolinear staple, and intracorporeal anastomosis was then performed.

Results

Patient characteristics

A total of 477 consecutive patients underwent curative simultaneous resection for synchronous colorectal liver metastasis during the study period. Among them, 351 patients (73.6%) received conventional open surgery, 55 (11.5%) underwent laparoscopic colorectal resection and open hepatectomy, and 71 (14.9%) received minimally invasive colorectal and liver resection. Robotic simultaneous resection of colorectal liver metastasis was performed in only 12 (3%) patients, which constituted 16.9% of the total patients who received minimally invasive colorectal and liver resection.

Table 1 summarizes the clinical characteristics of the 12 patients. The colorectal procedures were performed before liver resection in all cases. Microscopically, negative margin (R0) was achieved in both colorectal and liver resections. There were no deaths reported within 30 days of the procedures. All colorectal surgeries were performed by three colorectal surgeons, with each surgeon completing 10 surgeries, whereas all liver surgeries were performed by one hepatobiliary surgeon.

Our case series encompassed all types of liver resection in accordance with the involved liver segments (Table 2). There were seven patients with multiple liver metastases and five patients with a single liver metastasis. For patients with a single liver metastasis, segments 1, 6, or 8 were involved. Wedge resection was performed in four patients with lesions in segments 6 or 8. Caudate lobectomy was successfully per-

Table 1 Patient characteristics and operative data

Patient characteristics	$N = 12$
Age, years (range)	59 (37–77)
Sex, n (%)	
Male	7 (58.3%)
Female	5 (41.7%)
BMI (kg/m^2)	24.9 ± 2.4
ASA classification (1/2/3), n (%)	3 (25%)/6 (50%)/3 (25%)
Primary tumor site, n (%)	
Cecum	1 (8.3%)
Ascending colon	1 (8.3%)
Descending colon	1 (8.3%)
Sigmoid colon	3 (25%)
Rectum	6 (50%)
Synchronous liver metastasis, n (%)	
Single	6 (50%)
Multiple	6 (50%)
Neoadjuvant treatment, n (%)	7 (58.3%)
Robotic platform, n (%)	
Si	5 (41.6)
Xi	7 (58.3)
First step of the procedure, n (%)	
Colorectal approach	12 (100)
Liver approach	0 (0)
Operation for primary tumor, n (%)	
Right hemicolectomy	2 (16.6)
Left hemicolectomy	1 (8.3)
Anterior resection	2 (16.6)
Low-anterior resection	7 (58.3)
Operation for liver metastasis, n (%)	
Right hepatectomy	2 (16.7%)
Left hepatectomy	1 (8.3%)
Left lateral segmentectomy	1 (8,3)
Wedge resection	6 (50%)
Caudate lobectomy	1 (8.3)
ALPPS	1 (8.3)
Resection margin	
Liver, mean, cm	1.25 (0.20–6.50)
Colon	
Distal margin	6.8 (1–31)
Proximal margin	13.4 (5.5–32.5)
Rectal	
CRM	0.24 (0.10–0.30)
Operative time, min (range)	449 (135–682)
Blood loss, mL (range)	274.3 (40–780)
Transfusion, n (%)	0
Conversion to laparotomy, n (%)	0

ALPPS, associated liver partition and portal vein ligation for staged hepatectomy; *CRM*, circumferential resection margin

Table 2 Surgical procedures among 12 patients who underwent simultaneous colorectal and liver resection

Patient #	da Vinci system	Procedures		Involved liver segments
		Liver resection	Colorectal resection	
1	Si	Right hepatectomy	Left hemicolectomy	6, 7
2	Si	Left hepatectomy	Anterior resection	3, 4
3	Si	Wedge resection	LAR	4/5, 6, 7, 8
4	Si	Wedge resection	LAR	6
5	Si	Wedge resection	LAR	8
6	Xi	Right hepatectomy	LAR	5/8, 7, 8
7	Xi	Left lateral sectionectomy	Ultra LAR	2, 3
8	Xi	Caudate lobectomy	Anterior resection	1
9	Xi	ALPPS	Right hemicolectomy	1, 3, 4/5, 7, 8
10	Xi	Segmentectomy (S3) and wedge resection (S7)	LAR	3, 7
11	Xi	Wedge resection	Right hemicolectomy	6
12	Xi	Wedge resection	LAR	8

ALPPS, associated liver partition and portal vein ligation for staged hepatectomy; *LAR*, low anterior resection

Fig. 8 Procedure for caudate lobectomy using the same port as in colorectal dissection (anterior resection). Caudocranial dissection was initiated (**a**) in the caudate lobe from the vena cava (**b**). Using the rubber band technique (**c**), stable lateral traction was achieved. Inflow branches from the left main pedicle (white arrow) were ligated. **e** Image of completed caudate lobectomy. **f** Biopsy specimen of liver metastasis in the caudate lobe showing an adequate resection margin (0.3 cm)
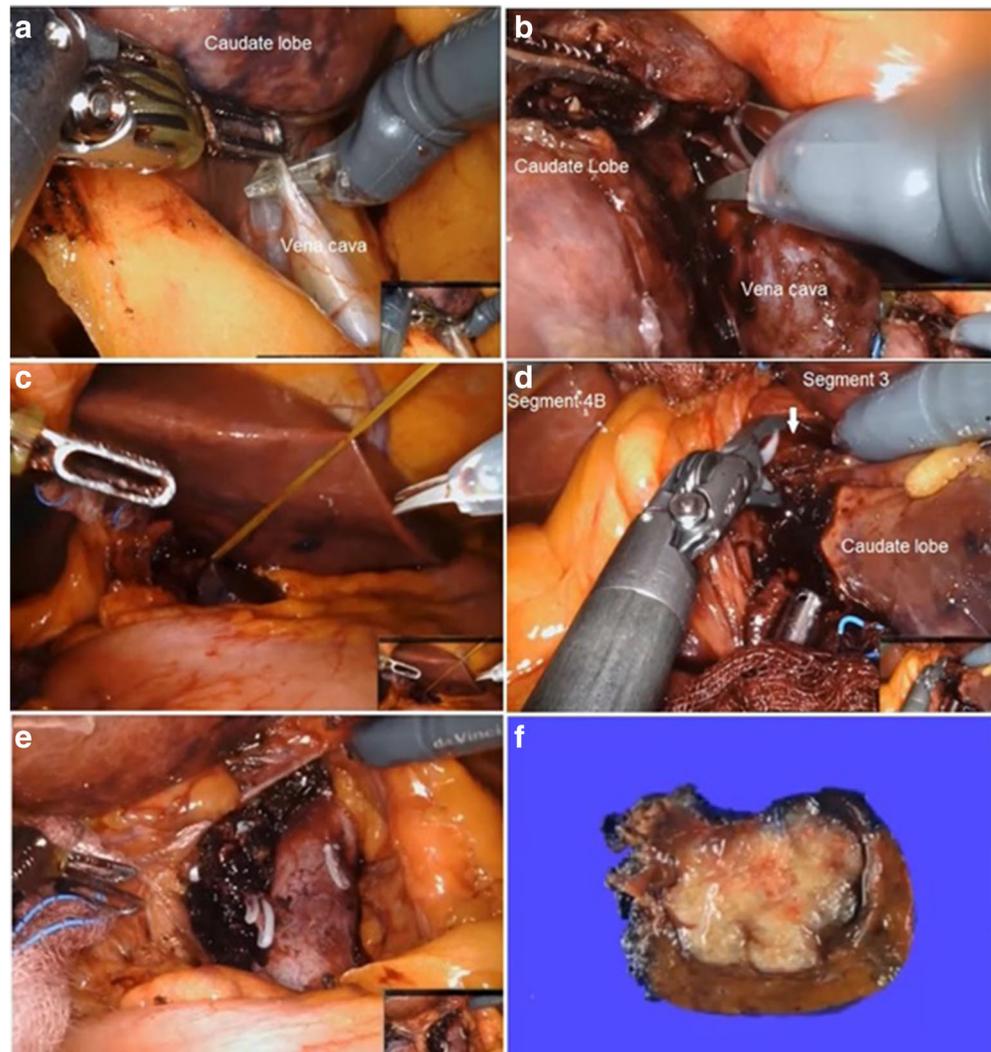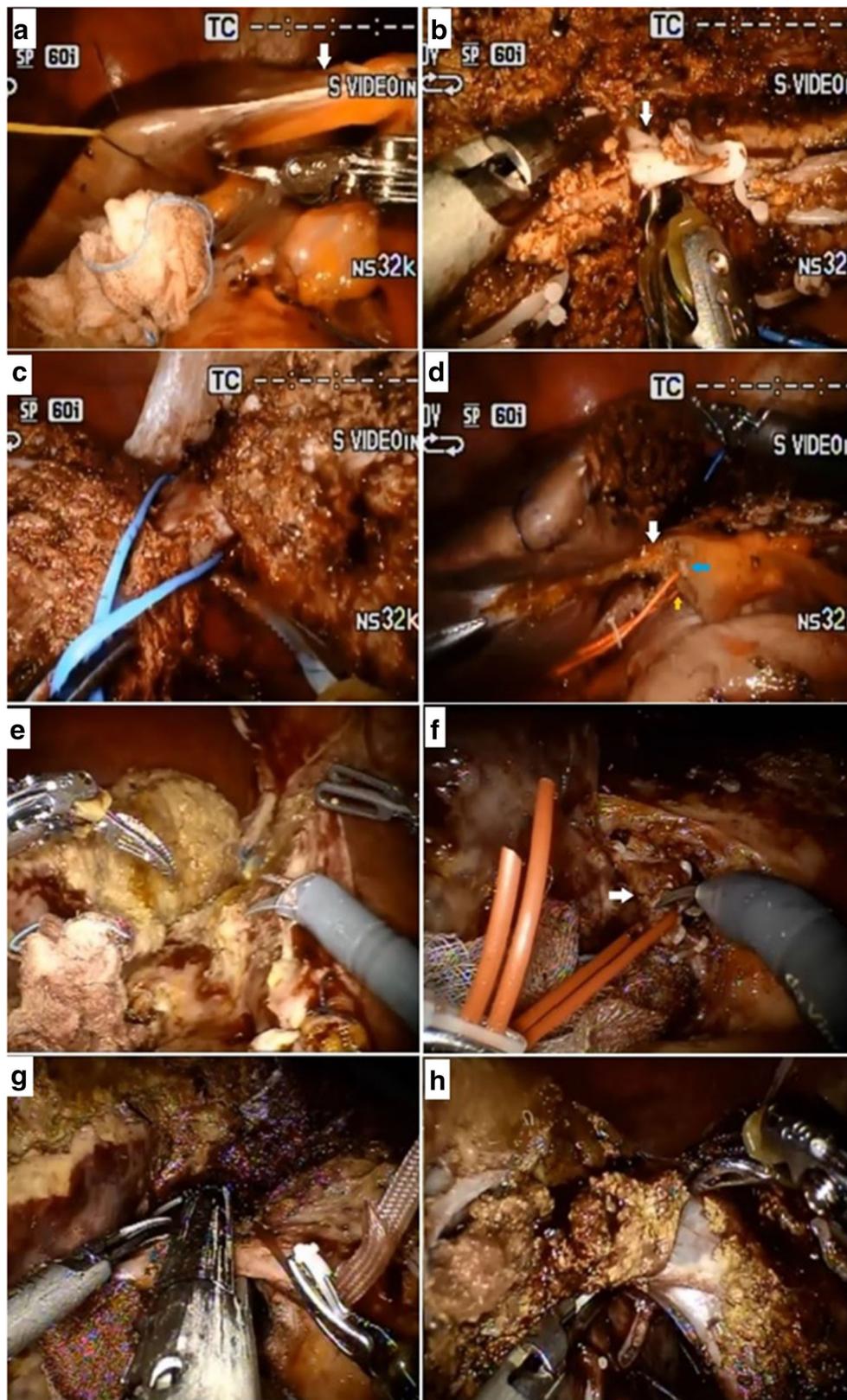
Fig. 9 Procedure for segmentectomy (segment 3) and wedge resection (segment 7). **a** Dissection started on the left, lateral to the umbilical fissure, and the segment 3 branch of the left pedicle was identified and ligated. **b** The demarcation line was followed after transection of the segment 3 pedicle. Tributaries of the left hepatic vein draining segment 3 were identified and ligated (**c**). An adequate margin was created around the tumor during wedge resection in segment 7 (**d**). The rubber band technique was used for stable traction and exposure. Hepatic veins and hepatic pedicles were carefully ligated and transected (**f**). Biopsy specimen showing adequate margins after segmentectomy (1.2 cm) (**g**) and wedge resection (0.3 cm) (**h**)
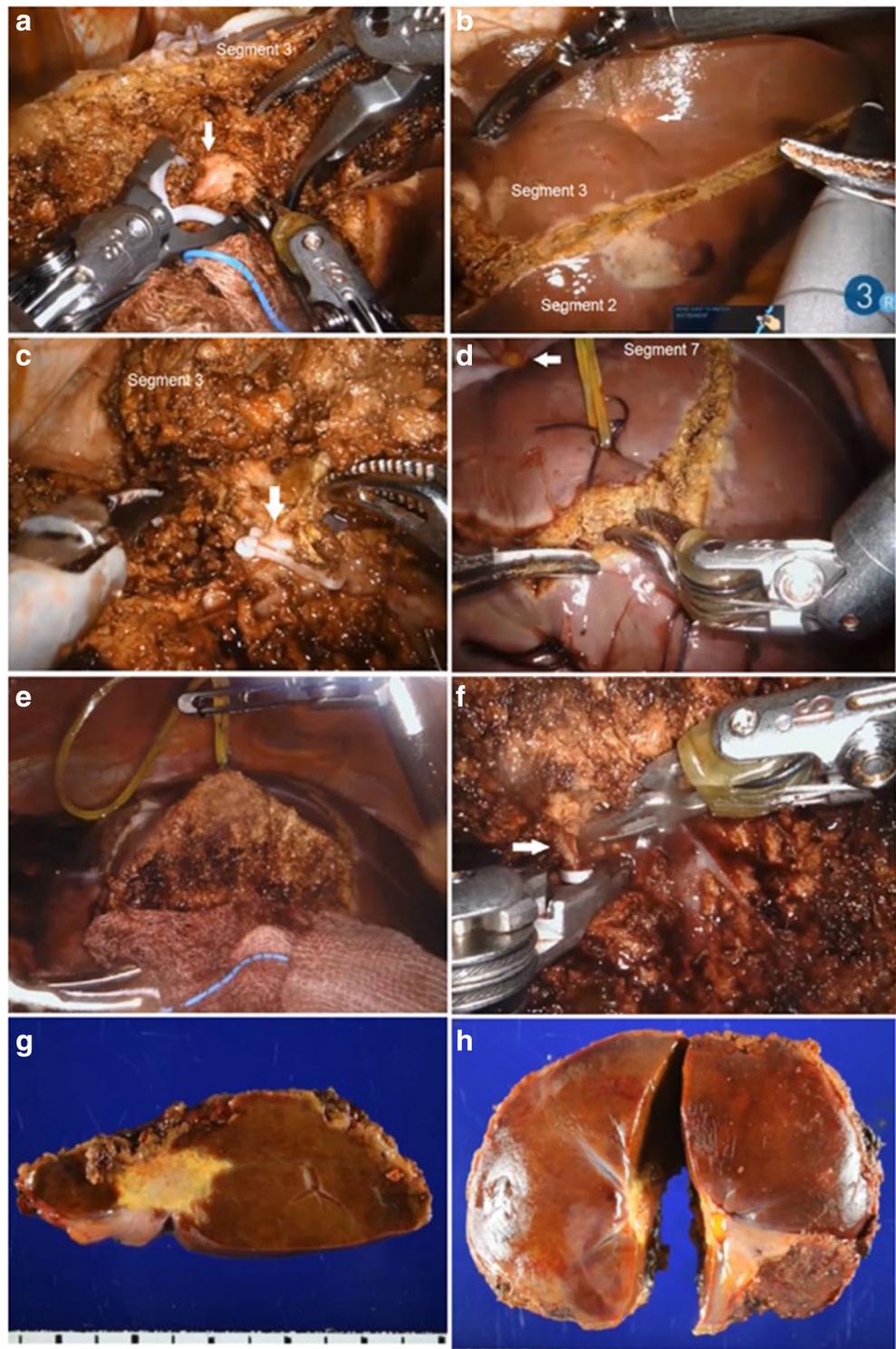
formed in a patient with a 2-cm liver metastasis in segment 1 (Fig. 8). For patients with multiple liver metastases, the liver resection procedures comprised two right hepatectomies, one left hepatectomy, one left lateral sectionectomy, one associated liver partition and portal vein ligation for staged hepatectomy (ALPPS), one segmentectomy of S3 and wedge resection of segment 7, and one wedge resection involving segments 4/5, 6, 7, and 8. Figure 9 illustrates the procedure for segmentectomy of S3 and wedge resection of S7 using the same trocar placements as those used during LAR.

Interestingly, one patient with liver metastases involving segments 1, 3, 4/5, 7, and 8 successfully underwent two-

stage ALPPS. The first surgery comprised wedge resection of the segment 3 and caudate lobe tumors, right portal vein ligation and transection, and liver transection along the right lateral border of the middle hepatic vein. After 11 days, robotic right hepatectomy was performed. Figure 10 shows the details of the ALPPS procedure.

◀   **Fig. 10** Procedure for associated liver partition and portal vein ligation for staged hepatectomy (ALPPS). **a** Liver dissection began at the right lateral umbilical ligament. **b** Inflows for segment 4b (white arrow) and 4a were identified and ligated. The middle hepatic vein (**c**) was isolated and tagged. **d** The right portal vein was ligated and transected (**d**, blue arrow), while the right bile duct (**d**, white arrow) and right hepatic artery (**d**, yellow arrow) were isolated and tagged. **e** The second-stage operation was performed 11 days after the first procedure. Ligation and transection of the right hepatic artery (**f**, white arrow), right bile duct with hilar plate (**g**), and right hepatic vein (**h**) were performed to complete the operation

Perioperative outcomes

Table 3 presents the post-operative complications after surgery. Overall, perioperative complications occurred in five (41%) patients. Complications related to liver resection were two liver abscesses and one case of ascites. Complications related to colorectal surgery included one anastomotic leak and one superficial surgical site infection. Severe complication (Clavien-Dindo classification grade 3) occurred in two (16.7%) patients (one bowel anastomotic leak and one liver abscess).

An anastomotic leak (grade III) occurred in a patient who underwent robotic LAR and segment 6 wedge resection. The patient presented with abdominal pain and fever about 16 days after the operation and underwent transanal repair 2 days later. The patient who underwent ALPPS had experienced ascites and was treated with an oral diuretic for 7 days. Liver abscesses developed in one patient who underwent LAR and segment 8 wedge resection; this patient was treated with intravenous antibiotics. A patient who underwent LAR and right

Table 3 Post-operative outcomes of the 12 patients included in this study

Post-operative outcomes	N = 12
Overall morbidity, n (%)	5 (41%)
Clavien-Dindo classification of surgical complications	
Grade I	1
Grade II	2
Grade IIIA	1
Grade IIIB	1
Colorectal-related complications, n (%)	
Superficial surgical infection	1
Bowel anastomotic leakage*	1
Liver resection-related complications, n (%)	
Liver abscess	2
Ascites*	1
Time to first fluid intake, days (range)	2 (1–2)
Time to first flatus, days (range)	2.8 (1–5)
Length of hospital stay, days (range)	12 (5–28)
30-day mortality, n (%)	0 (0)

*Ascites occurred in one patient after right hemicolectomy and ALPPS

hepatectomy also developed liver abscesses and was treated with percutaneous drainage plus antibiotics.

There was no conversion to laparotomy in this case series. Most of the patients were able to sip water on the first day and tolerate a liquid diet on the second day after the operation. The average time from surgery to first flatus was about 2.83 days (range, 1–5 days), while the average length of hospital stay was 12 days (range, 5–28 days). No mortalities were reported within 30 days of completion of the procedure.

Discussion

There is a paradigm shift occurring toward minimally invasive surgery as the standard treatment option in almost all gastro-intestinal surgeries [22–24]. Its undeniable advantages, such as less pain, shorter hospital stay, fewer wound-related complications, and early return to work, makes it the most logical procedure of choice. For instance, the randomized trial by Braga et al. [25] evaluating the short-term outcomes of laparoscopic versus open colorectal surgery showed the superiority of the laparoscopic group to open surgery. There were fewer infectious complications, such as wound infection and abdominal abscess, and noninfectious complications, such as delayed gastric emptying and ileus in the laparoscopic surgery group. In addition, the OSLO-COMET randomized controlled trial demonstrated that laparoscopic liver resection for colorectal metastasis was associated with fewer post-operative complications and shorter hospital stay compared to the open surgery group [26]. However, despite these advantages, the complexity of these abdominal surgeries has hindered the adoption of laparoscopic approaches among the general population of surgeons.

A British multi-center randomized trial found that laparoscopic rectal surgery can lead to a high rate of conversion to open surgery due to the complexity of the technique [27]. As such, advanced laparoscopic skills are necessary to perform this procedure to reduce surgical morbidity and achieve an excellent oncologic outcome. Nevertheless, a more recently published phase II prospective, single-center, randomized controlled trial in Korea [12] concluded a similar post-operative outcome between robot-assisted and laparoscopic surgery for rectal cancer. Moreover, an international multi-center randomized trial (ROLARR trial) [11] concluded that robotic surgery does not significantly reduce the risk of conversion to open surgery compared to laparoscopic surgery in patients with rectal cancer. However, one of the limitations of these studies is that the surgeons were already experts in laparoscopic colorectal surgery but had considerably limited experience or varying experience with robotic procedures prior to the studies. In fact, in the learning effects analysis in the ROLARR trial, it was concluded that robotic surgery had an advantage over laparoscopic surgery in terms of the risk of

conversion to laparotomy when performed by a surgeon with more experience in robotic surgery [28]. As such, thorough accumulation of experience with proper implementation and standardization of surgical techniques for surgeons learning to perform robotic surgery are required for the advantages of robotic surgery to be appreciated [29, 30].

In this case series, however, we sought to describe the technical feasibility of synchronous resection for colorectal cancer with liver metastasis encompassing both major and minor liver resections. Recently, we have begun to explore the feasibility of using a robotic surgical system for liver resection in particular [31] and to standardize our surgical technique [20]. Similarly, the feasibility of robotic rectal surgery was evaluated previously at our institution, with results indicating the superiority of a laparoscopic approach in terms of conversion rate, complication rates, and length of hospitalization [32]. These findings are supported by previous studies [33, 34]. Based on the accumulating evidence, patients with colorectal carcinoma with liver metastasis may potentially be treated with one-stage robotic surgery. We proposed that a robotic surgical system could facilitate the technical maneuvers in the pelvic area, resulting in greater oncologic resection during dissection. Moreover, the magnified three-dimensional view and wristed instruments can improve dissection of the hepatic hilum and hepatocaval plane and may facilitate suturing for the management of bleeding during liver parenchymal transection. Additionally, this strategy can eliminate the need for two surgical procedures, reducing the cost and length of hospital stay.

To date, the literature demonstrating the feasibility of robotic one-stage colorectal and liver surgery in colorectal carcinoma with liver metastasis consists of only case series [17, 35]. To the best of our knowledge, this report is the largest case series performed to date. Dwyer et al. [16] described their experience with six patients who underwent an entirely robotic one-stage colorectal and liver resection. There was no reported conversion to open surgery. The mean operation time was 401 min (349–506 min) with mean estimated blood loss of 316 mL (150–1000 mL). Delayed wound healing after abdominoperineal resection was observed in one patient, while another had delayed rectal anastomotic failure. The mean disease-free survival was 9.5 months. In the present case series, 12 patients with synchronous colorectal and liver metastasis were successfully treated with one-stage robotic colorectal and liver resection with no conversion to laparotomy.

Certain technical challenges have limited the use of robotic surgical systems. First, specifically with regard to liver surgery, harmonic shears are currently the only instrument used for parenchymal transection. However, we believe that the Cavitron Ultrasonic Surgical Aspirator (CUSA), which is presently unavailable in the robotic surgical system, is a more efficient and safer instrument for liver parenchymal transection. Unlike CUSA, the harmonic scalpel could potentially create a blind spot during dissection, making the surgeon unaware of the structures that will be encountered along the transection plane. As such, it is important to emphasize that the surgeon should carefully make only "small bites" of the liver parenchyma with the harmonic scalpel to avoid complete transection of a larger vessel in the deeper layer of the liver. In this scenario, a completely transected vessel is generally difficult to remedy unlike a partially transected vessel where a surgical clip can be easily applied. Aside from this, the harmonic shears do not articulate to conform to the direction of the transected plane. However, with an innovative modification of the rubber band technique, we found that the desired position of the transection plane can be adjusted by loosening or tightening the rubber band. Second, the locations of some tumors were previously thought to be limiting factors of robotic surgical approaches [20]. In the present case series, tumors located deep within segment 7 or 8 and tumors close or adjacent to the hepatic vascular structures were approached using right hepatectomy if the appropriate remnant liver volume was available. However, lesions superficially located within segment 7 or 8 or in the caudate lobe may be addressed using wedge resection or caudate lobectomy, respectively. Moreover, bilobar lesions can be easily and safely resected using the robotic platform without any additional trocars (Fig. 9). In this case series, we successfully performed all types of liver resection, from wedge resection to major hepatectomy. Third, operation time is typically dependent on the complexity of the procedure performed. Our mean operation time was longer than in other similar case series [16, 17]. However, our case series involved major hepatic resections. Nonetheless, as surgeons acquire more experience and expertise, the operation time for robotic-assisted surgery might be reduced. More importantly, none of the patients in this case series required a blood transfusion during or after the surgery. Lastly, one of the limitations hindering the propagation of robotic surgery is the higher cost. As postulated by previous studies [32, 36], longer operation times, use of specialized instruments, higher cost of the system itself, and higher maintenance costs contribute to the overall higher cost compared to laparoscopic surgery. In our institution, a patient's economic status is one factor considered by the surgeons before offering robotic surgery as an alternative option. This was the primary reason why robotic simultaneous resection of colorectal liver metastasis was performed in 2.5% (12 out of 477) of all patients and 16.9% (12 out of 71) of patients who received minimally invasive colorectal and liver resection. Technically, 59 patients who received laparoscopic synchronous resection of colorectal liver metastasis can be candidates for robotic resection. However, we had to consider the cost-effectiveness of robotic surgery. As such, we recommended robotic surgery primarily to patients who had metastatic liver tumors, which are difficult to resect laparoscopically. In doing so, a significant portion of patients with laparoscopic colorectal resection

and open hepatectomy (those who had a larger metastatic tumor size, higher number of tumors, more bilobar involvement, and more locations of S1 or 7 or 8) would be good candidates if the patients agreed to robotic surgery and a high additional cost. Nevertheless, with emerging competition for the da Vinci Robotic System, there is a possibility that the cost will decrease in the near future.

In addition to intraoperative ultrasonography [37], real-time identification of superficially located tumors can be greatly facilitated by fluorescence-imaging technology using ICG, which may consequently enhance the performance of robotic surgery [38–40]. Given the availability of this robotic "firefly" system, we employed ICG-imaging technology during simultaneous liver colorectal and liver resection, particularly for patients with multiple liver metastases. These liver metastases subsequently decreased in size significantly after neoadjuvant chemotherapy.

Although robotic surgery is currently gaining popularity in various fields that require more complex surgical procedures [41–43], our case series emphasized the importance of surgeons' experienced in robotic surgery. Proper patient selection, training, and standardization of procedures is paramount. We believe that robotic simultaneous colorectal and liver resection is a complex procedures which requires expertise in robotic surgery. Moreover, the robotic instruments do however not change the biology of the individual patient and the risks of major surgeries in frail patients especially when simultaneous resections are attempted. Thus, this sophisticated procedures should be carefully interpreted and should only be performed in centers with expert surgeons.

Conclusion

In summary, this case series shows that simultaneous robotic surgery of colorectal neoplasm with synchronous liver metastasis can be performed with acceptable morbidity with careful patient selection, when performed in specialized centers with well-trained teams, even in cases requiring major liver resections. Nevertheless, these data need to be confirmed in larger prospective and randomized studies.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval Formal consent was not required for participation in this type of study.

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