ORIGINAL ARTICLE

Learning Curve in Robot-Assisted Laparoscopic Liver Resection

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Abstract
Background The objective of this study was to evaluate the learning curve effect on the safety and feasibility of robot-assisted liver resection (RALR).
Methods In 140 consecutive cases, all data about demographic, surgical procedure, postoperative course were collected prospectively and analyzed. Risk-adjusted cumulative sum model was used for determining the learning curve based on the need for conversion.
Results Among all 140 patients, no patients suffered from any organ dysfunction postoperatively and the operative mortality was 0%. The CUSUM analysis showed that at the 30th consecutive patient, the open conversion rate reached to the average value, and it further improved thereafter. In the last 70 patients, only 3 patients (4.3%) required conversion and 7 patients (10%) needed blood transfusion. Only 1 patient (1.3%) out of 79 patients with HCC had a positive resection margin. Univariate analyses showed the following risk factors associated with significantly higher risks of conversion ($P < 0.05$): tumor number > 1, lesions in segments 1/4a/7/8, right posterior sectionectomy, and lesions which were beyond the indications of the Louisville statement. Multivariate logistic analysis revealed that both tumor number > 1 (OR: 2.10, $P < 0.05$) and right posterior sectionectomy (OR: 11.19, $P < 0.01$) were risk factors of conversion.
Conclusions The robotic approach for hepatectomy is safe and feasible. A learning curve effect was demonstrated in this study after the 30th consecutive patient. The long-term oncological outcomes of robotic hepatectomy still need further investigation.

Keywords Robot · Learning curve · Hepatectomy · Laparoscopic

Introduction

Over the last two decades, laparoscopic liver resection has evolved to become the approach of choice for both benign and malignant tumors.[1–4] The advantages of the laparoscopic approach include, but not limited to, decrease in blood loss, postoperative pain, morbidity, hospital stay, and early postoperative oral intake, as well as improved cosmesis.[1–3] In recent years,

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laparoscopic hepatectomy has become safe and feasible in the hands of experienced surgeons.[5] Drawbacks in laparoscopic instruments, such as intrinsic human tremor, and restricted movements with only 4 degrees of freedom and two-dimensional view, limit its utility in complex liver resections.[6–9] A review on the studies published from 1991 to 2014 showed that minor liver resections still comprise the vast majority of laparoscopic procedures in clinical practice.[5] Thus, a surgical robotic system with Endowrist® instruments and three-dimensional vision was introduced in liver surgery, with the aim of overcoming the limitations of traditional laparoscopic surgery.

Since the inception of robot-assisted liver resection (RALR) in 2002,[10] this innovative approach has gained wide acceptance as evidenced by a staggering number of RALRs achieved to date on 537 patients,[11] a number that continues to increase globally. Various types of RALR have been performed for different pathologies in many centers worldwide.[11,12] In general, for laparoscopic or robotic procedures,[5,12] there is a "learning curve." This learning curve has been reported in laparoscopic liver resection.[13] Although

there are also a few literatures[14,15] focused on learning curve of robotic liver resection, the exact volume of patients we need to overcome the learning curve is still not elucidated.

Our center has performed robotic liver resections since February 2015. Up to April 2017, we have carried out RALR on 140 patients. This study aimed to report on our single-center experience on the learning curve of RALR.

Materials and Methods

Between February 2015 and April 2017, all liver resections which were performed in the Tongji Hospital, Wuhan, China, utilizing the robotic approach were included into this study. The decision on treatment was made by a team of multidisciplinary liver tumor experts at a weekly held conference. All patients underwent chest radiography, ultrasonography of the abdomen, contrast computed tomography (CT), or magnetic resonance imaging (MRI). Laboratory blood tests including hepatitis B surface antigen, HBV-DNA, antibodies to hepatitis C, serum alpha fetoprotein (AFP), carcinoembryonic antigen (CEA), carbohydrate antigen 19.9 (CA19.9), serum albumin, serum total bilirubin, aspartate aminotransferase, alanine aminotransferase, and prothrombin time were carried out, and the Child-Pugh score and Indocyanine green retention rate at 15 min (ICG-R15) were calculated. Further investigations were carried out, if necessary, to exclude extrahepatic metastasis. All procedures were performed by two surgeons (Bixiang Zhang and Peng Zhu) in equal ratio. At the beginning of the learning curve, both surgeons had no experience in robotic operations, but were skilled in open and laparoscopic liver surgery. Before performing robotic liver surgery, Doctor Zhang had finished training in robotic module via simulation.

Patient Selection

The suitability to use the RALR approach was determined based on the lesion location, assessment of the clinical status of the patient, and type of the planned operation. The selection criteria for the robotic approach were as follows: no major vascular or bile duct invasion by tumor, Child-Pugh class A, American Society of Anesthesiologists score of 2 or less, and ICG-R15 of less than 15%. As abdominal adhesions would increase the difficulties of the operation and prolong the operation time, those patients who had previous upper abdominal operations were also excluded. All the procedures were performed after informed consents were obtained from the patients.

Surgical Procedure

The patient was placed in a supine position for left lateral sectionectomy, left hepatectomy, right hepatectomy, and segment 1, 2, 3, 4, 5, 8 resections. The left decubitus position was used for right posterior sectionectomy and segment 6, 7 resections. Pneumoperitoneum was induced using a Veress needle and maintained at 12–14 mmHg. A 12-mm camera port, a 12-mm operative port, and two or three working 8-mm robotic ports were utilized. They were positioned along a semicircular arc facing the tumor or the planned liver transection plane. The da Vinci® Surgical System (dVSS, Intuitive Surgical Inc., Sunnyvale, CA) was used for all the robot-assisted procedures. The robotic surgical system's patient cart was docked at the patient's head. The surgical team comprised at least two surgeons. The operating surgeon was seated at the robotic console, while the assisting surgeon, who was positioned on the left or right side of the patient, was responsible for exchanging robotic instruments and for carrying out conventional laparoscopic tasks. Intraoperative ultrasound (IOUS) was routinely performed to detect the number, size, and location of lesions and to detect any lesion which was not found on preoperative imaging. The relationship between the lesion and intrahepatic vascular structures was noted. A surgical tape was regularly placed around the hepatic pedicle and intermittent Pringle maneuver was used if necessary. If the tumor was situated close to the hepatic vein or inferior vena cava, infrahepatic inferior vena cava clamping was also used to control any bleeding coming from the hepatic veins as we have previously described in open surgery.[16] Parenchymal liver transection was performed with a Harmonic scalpel or Maryland forceps. The central venous pressure was maintained at 4 to 5 cm H_2O during liver transection. Any vessel of more than 3 mm in size which crossed the transection plane was clipped, ligated, or sutured. The resected specimen was placed into a plastic bag and was extracted through an extended umbilical incision. Postoperatively, the patient was only sent to the intensive care unit if necessary.

Definitions

The types of liver resection were classified using the Brisbane 2000 terminology.[17] Major hepatectomy was defined as resection of three or more Couinaud segments, while minor hepatectomy was defined as resection of two segments or less.[5,18] Conversion to open surgery was defined as completion of the procedure via laparotomy. The indication for red blood cell transfusion was either blood loss exceeding 1000 ml or a hemoglobin level below 5.6 mmol/l during or within 48 h of surgery.[16] The operative mortality was defined as death within 90 days of surgery. Liver dysfunction was defined as both a prothrombin rate < 50% and a serum bilirubin level > 50 μmol/L on postoperative day 5.[19] Radical resection was considered when all tumors were resected with a microscopically free surgical margin. The postoperative morbidity was assessed according to the Clavien-Dindo classification.[20]

Statistical Analysis

Patients who underwent any additional surgical procedures to liver resection were not included into this study. The clinical data of the included patients were recorded in a prospectively designed data sheet, and they were analyzed retrospectively. The SPSS 19.0 was used to compare continuous variables between the groups. The unpaired t test or the Mann-Whitney U test was used as appropriate. Categorical variables were compared by the χ^2 test or the Fisher exact test, as appropriate. For assessing any trends to evaluate variables in the different patient groups, the χ^2 test was used. A P value of less than 0.05 was considered significant for all the tests.

The learning curve analysis was based on the conversion rate to open surgery.[13] A univariate analysis of the predictive factors of conversion was performed. Comparison of the conversion rates into the three consecutive groups of patients was adjusted by the multivariate logistic analysis. The Cumulative Sum (CUSUM)[21] technique was applied for a visual representation of the learning curve, which was used for all the 140 consecutive patients based on the conversion to open surgery. A visual representation of the level of performance was then given to show any departure from the defined level. A successful robotic liver resection was weighted less for a patient with a low expected probability of conversion and was weighted more for a high expected probability.

Results

Patient Demographics and Comparison of Patient Groups

The background demographic characteristics and outcomes of 140 patients are summarized in Table 1. Among all these patients, almost half of them suffered from varying degrees of liver cirrhosis. A total of 41.4% patients needed Pringle maneuver, and the median time of pedicle clamping was 25 min. Based on the Louisville statement, 56 patients (40%) were within the indication for laparoscopic hepatectomy. Post-operatively, no patients suffered from any organ dysfunction. The operative mortality was 0%. The CUSUM analysis showed that at the 30th consecutive patient, the open conversion rate reached to the average value, and it further improved thereafter. At the 70th consecutive patient, the curve moved into a plateau phase. To further analyze the outcomes of these 140 consecutive patients, these patients were divided into three groups (group A: the first 30 patients, the exploration stage; group B: the 31–70 patients, the developmental stage; group C: the remaining 70 patients, the plateau stage).

Table 1 General characteristic and outcomes of patients

Sex (male/female)	91/49
Age (years)	49 (4–74)
BMI (kg/m^2)	23.2 (10.3–32.4)
HBsAg (±)	74/66
HCV-Ab (±)	1/139
ICG-R15 (%)	3.7 (0.7–37.3)
Tumor size (cm)	4.4 (1–15.0)
ASA score (1/2/3/4)	97/43/0/0
Portal hypertension (±)	10/130
Postoperative diagnosis	
HCC/benign/metastasis/ICC/others	79/44/8/9
Operative time (min)	193 (60–560)
Cirrhosis (no/mild/moderate/severe)	72/35/20/13
Blood loss (ml)	300 (10–2000)
Pedicle clamping (yes/no)	58/82
Time of pedicle clamping (min)	25 (5–97)
Resection type	
LLS/AR other than LLS/NAR	36/58/46
LLS/MIH other than LLS/MAH	36/87/17
Within or beyond the Louisville statement indication	56/84
Conversion (yes/no)	25/115
Blood transfusions (yes/no)	24/116
VBT (ml)	2.3 (0.5–6.0)
Morbidity (1/2/3/4/5)	1/27/9/0/0
Hospital stay (days)	6 (3–48)

Continuous variables are reported as median (range)

BMI body mass index, *ICG* indocyanine green retention test, *ASA score* American Society of Anesthesiologists Score, *HCC* hepatocellular carcinoma, *ICC* intrahepatic cholangiocarcinoma, *LLS* left lateral sectionectomy, *AR* anatomical resection, *NAR* non-anatomical resection, *MIH* minor hepatectomy, *MAH* major hepatectomy, *VBT* volume of blood transfused

Preoperative Characteristics and Intraoperative Data

The preoperative parameters showed that there were no significant differences in age, sex, BMI, ASA score, previous abdominal surgery, basic liver disease, diagnosis, number, and diameter of lesions among the three groups. The intraoperative data are summarized in Table 2. There was a significantly higher proportion of patients with cirrhosis in group B and group C. There were no significant differences in the rates of minor or major hepatectomy, pedicle clamping, and clamping time among the three groups. There was an obvious trend in less operative time in group C. Only three patients (4.3%) required conversion to open approach in group C (hemorrhage in two patients and oncological reasons in one). This conversion rate was significantly less when compared to groups A and B. The amount of blood loss was similar between group A and group B, but it was significantly less in group C. Only seven patients (10%) in group C required blood transfusion.

Table 2 Intraoperative data and postoperative outcomes

Parameters	Group A n = 30	Group B n = 40	P A vs. B	Group C n = 70	P B vs. C	A vs. C
Intraoperative data						
Right posterior/1/4a/7/8	9/0/0/1/1	8/0/0/0/3	0.357	8/4/0/2/4	0.193	0.189
Cirrhosis	9 (30%)	23 (57.5%)	0.030	36 (51.4%)	0.558	0.053
Minor hepatectomy	26 (86.7%)	36 (90%)	0.664	61 (87.1%)	0.655	0.948
LLS	10 (33%)	11 (27.5%)	0.610	15 (21.4%)	0.492	0.218
Other minor hepatectomy	16 (53.3%)	25 (62.5%)	0.472	46 (65.7%)	0.836	0.267
Major hepatectomy	4 (13.3%)	4 (10%)	0.664	9 (12.9%)	0.655	0.948
Left hepatectomy	2	4	–	6	–	–
Right hepatectomy	1	0	–	3	–	–
LLS + RPS	1	0	–	0	–	–
Operative time (min)	240 (90–560)	185 (110–390)	0.001	178 (60–420)	0.403	0.000
Pedicle clamping	12 (40%)	17 (42.5%)	0.834	29 (41.4%)	0.913	0.894
Clamping time (min)	34 (5–69)	25 (10–46)	0.280	15 (5–97)	0.149	0.146
Intraoperative outcomes						
Conversion	15 (50%)	7 (17.5%)	0.005	3 (4.3%)	0.035	0.000
Hemorrhage	7	4	–	1	–	–
No progression	5	0	–	0	–	–
Oncological reasons	3	3	–	2	–	–
Blood loss (ml)	400 (50–2000)	425 (50–2000)	0.879	100 (10–1200)	0.001	0.001
Blood transfusions	10 (33%)	7 (17.5%)	0.163	7 (10%)	0.372	0.008
VBT	2.5 (0.5–5.0)	3.0 (1.0–3.0)	0.962	2.0 (1.5–6.0)	0.620	0.962
Postoperative outcomes						
Mortality	0	0	–	0	–	–
Morbidity	10 (33%)	9 (22.5%)	0.417	18 (25.7%)	0.819	0.472
Total minor complications (grade I + II)	9 (30%)	7 (17.5%)	0.218	12 (17.1%)	0.962	0.148
Total major complications (grade III–V)	1 (3.3%)	2 (5%)	0.733	6 (8.6%)	0.488	0.347
Hospital stay	8 (4–48)	6 (3–38)	0.004	5 (3–21)	0.143	0.000
Reoperation	0	0	–	0	–	–

Continuous variables are reported as median (range)

LLS left lateral sectionectomy, *RPS* right posterior sectionectomy, *N/P* negative/positive, *VBT* volume of blood transfused

Postoperative Outcomes

The operative mortality was 0% and no patients required reoperation (Table 2). The overall morbidity rates were 26.4% (37/140), which included 20% (28/140) for minor complications and 6.4% (9/140) for major complications. When compared to groups A and B, no obvious differences were found in the morbidity rates in group C. In addition, there were no significant differences in the minor or major complication rates. A significant shorter hospital stay was observed in group C when compared to group A.

Outcomes in Patients with Hepatocellular Carcinoma

Seventy-nine patients in this study underwent robot-assisted hepatectomy for HCC, which included 69 minor hepatectomies and 10 major hepatectomies. In Table 3, these HCC patients were divided into three groups according to the learning curve effect. There was a significant decrease in the conversion rate, operation time, and hospital stay in group C when compared to group A. Only 1 patient (1.3%) out of 79 patients with HCC had a positive resection margin. However, six patients suffered from tumor rupture during the operation. All these patients were converted to open surgery. There were no differences in minor or major complication rates among the three groups of patients.

Conversion to Open Surgery: Risk Factors and Learning Curve

Univariate analyses (Table 4) revealed the following risk factors associated with significantly higher risks of conversion

Table 3 Results in patients with HCC ($n = 79$)

Parameters	Group A $n = 15$	Group B $n = 24$	P A vs. B	Group C $n = 40$	P B vs. C	A vs. C
Major hepatectomy	1 (6.7%)	3 (13%)	0.559	6 (15%)	0.781	0.409
Conversion	7 (58%)	5 (21%)	0.153	3 (7.5%)	0.139	0.002
Pedicle clamping	6 (40%)	9 (38%)	0.876	17 (43%)	0.693	0.867
Clamping time (min)	30 (5–49)	30 (10–46)	0.255	15 (5–74)	0.722	0.223
Operative time (min)	222 (150–560)	185 (110–390)	0.047	180 (100–420)	0.322	0.008
Blood loss (ml)	400 (50–2000)	400(100–2000)	0.882	150 (20–1000)	0.001	0.057
Blood transfusion	4 (27%)	5 (21%)	0.711	3 (7.5%)	0.139	0.079
VBT (U)	3.0 (1.5–4.5)	3.0 (1.0–3.0)	0.370	2.0 (1.5–6.0)	0.786	0.910
Resection margin (N/P)	15/0	23/1	0.423	40/0	0.193	1.000
Medical rupture	3 (20%)	3 (13%)	0.658	0	0.049	0.017
Postoperative outcomes						
Mortality	0	0		0		
Morbidity	7 (47%)	5 (21%)	0.153	12 (30%)	0.562	0.341
Total minor complications (grade I + II)	6 (40%)	4 (16.7%)	0.104	8 (20%)	0.741	0.129
Total major complications (grade III–V)	1 (6.7%)	1 (8.4%)	0.731	4 (10%)	0.400	0.702
Hospital stay	9 (4–48)	6 (3–38)	0.013	5 (3–14)	0.421	0.001

Continuous variables are reported as median (range); VBT means volume of blood transfused

($P < 0.05$): tumor number > 1, lesions in segments 1/4a/7/8, right posterior sectionectomy, and lesions which were beyond the indications of the Louisville statement.[18] Multivariate logistic analysis showed that both tumor number > 1 and right posterior sectionectomy were risk factors of conversion. The adjusted odds ratios for tumor number > 1 and right posterior sectionectomy were 2.10 ($P < 0.05$) and 11.19, respectively ($P < 0.01$). The cumulative conversion graphs for the various procedures are shown in Figs. 1, 2, and 3. An extremely low conversion rate was observed in left lateral sectionectomy (LLS) or patients within the indications of the Louisville statement. The CUSUM analysis of the entire series showed that at the 30th consecutive patient, the conversion rate reached to the average value and it then further improved thereafter (Fig. 4).

Discussion

Since the inception of the robotic technique for liver surgery in 2002,[10] RALR has been accepted by an increasing number of surgeons and hospitals worldwide.[11,12,22,23] To the best of our knowledge, no specific analyses have been reported on the conversion rate of robotic liver resection. Based on the Morioka consensus statement,[5] to learn minimally invasive liver surgery is easier with the robotic approach.

The robotic approach is a further development of laparoscopic liver resection. According to the Morioka consensus statement,[5] the indications for robotic liver resections are similar to those of laparoscopic liver resections. Based on the

Louisville consensus statement,[18] the indications are for solitary lesions, 5 cm or less, and located in liver segments 2–6. Patients who are beyond the above indications are not considered to be appropriate candidates for laparoscopic liver resection in most centers. On the other hand, a number of systematic reviews[11,12,24] have indicated that the location of lesions resected using the robotic approach has been extended to every segment of the liver, and only those tumors which have invaded major vascular structures or patients who are pneumoperitoneum intolerant are contraindications to robotic liver resection. In our study, the patient selection was not constrained by the Louisville statement indications. Only 56 patients (40%) were within the indications, and the remaining 84 patients (60%) were beyond the indications. The ratio of lesions located in segments 1/4a/7/8 was 28.6% (40 patients), and the number of patients with 5 cm or larger tumor was 61 (43.6%). Our incidence of morbidity (26.4%) was similar to those reported by others[5] (8%–46.7%), and no mortality was observed in our series of patients. These data showed that robotic liver surgery was safe and feasible, and the indications for robotic surgery could be extended.

As previously reported,[13] the conversion to open surgery rate could be used as a criterion to assess the quality of laparoscopic surgery. This is also a suitable criteria in robotic liver surgery. The reported conversion to laparotomy rates for robotic hepatectomy in series with more than 25 patients ranged from 3.7 to 20%.[5] The most common reason[11] for conversion is uncontrollable bleeding (46.7%), followed by unclear tumor margin (33.3%). Other reasons of conversion include severe

Table 4 Predictive factors of conversion: univariate analysis

Parameters	Conversion		P	OR	95% CI
	number	%			
Age			0.526		
0–55	20/104	19.2		–	–
56–70	5/31	16.1		0.81	0.28–2.37
>70	0/5	0		1.06	1.01–1.12
Cirrhosis			0.950		
Yes	12/68	17.6		0.98	0.42–2.29
No	13/72	18.1		–	–
MLC			0.034		
Yes	4/8	50		5.29	1.23–22.81
No	21/132	15.9		–	–
Number of lesion			0.029		
1	17/118	14.4		–	–
>1	8/22	36.4		3.40	1.24–9.31
Location of lesion			0.005		
S1/4a/7/8	15/40	37.5		5.40	2.16–13.48
S2–6	10/100	10.0		–	–
Tumor size (cm)			0.860		
0–4.9	14/79	17.7		–	
5.0–9.9	9/46	19.6		1.13	0.45–2.86
≥10.0	2/15	13.3		0.71	0.15–3.53
Type of hepatectomy			0.981		
Major hepatectomy	3/17	17.6		–	
Minor hepatectomy	22/123	17.9		1.02	0.27–3.84
RPS			0.001		
Yes	13/25	52.0		9.30	3.47–24.94
No	12/115	10.4		–	–
Guideline indication			0.007		
Within the indication	4/56	7.1		–	
Beyond the indication	21/84	25.0		4.33	1.40–13.42

Continuous variables are reported as median (range)

MLC metastatic liver cancer, *S* segment, *RPS* indicates right posterior sectionectomy

S2–6 do not include S4a; guideline indication means the indication of Louisville statement

adhesions (10%), difficult progression (6.7%), and difficult liver mobilization (3.3%). In our series, the initial conversion rate was 17.5%, but it gradually dropped to 3 patients in the last 70 patients. For these last three patients who were converted, one patient developed uncontrollable bleeding due to laceration of the right hepatic vein. The other two patients needed laparotomy due to oncological reasons. The first patient who was planned to undergo right posterior sectionectomy was found to have an additional nodule in segment 8 on intraoperative ultrasonography. The other patient was found to have tumor invasion to the diaphragm. The adjusted odd ratios of the conversion rate demonstrated a

significant improvement in the most recent period in our series, which showed that the "learning curve effect" existed in skill acquisition in robot-assisted hepatectomy.

Since 1994, the CUSUM technique has been adopted by the medical profession to analyze surgical performance.[25] Along with laparoscopic hepatectomy[13] and colorectal surgery,[26] the conversion rate was chosen in this study to perform learning curve analyses using the CUSUM method. For each patient, the probability of conversion to open surgery determines the magnitude by which the graph ascends or descends. For every non-converted patient, the graph ascends by an amount equal to the estimated probability of conversion. For every converted patient, the graph descends by an amount equal to the estimated probability of non-conversion, which means that if a robotic case is converted in a patient with a high risk of conversion, the surgeon's performance chart is not unduly penalized. Only when a converted case with a low risk occurs, the graph will obviously descend. In our study, the CUSUM analysis showed that the conversion rate reached to the average value at the 30th consecutive patient and it was further improved thereafter. This learning curve is significantly shorter when compared to laparoscopic hepatectomy (60 patients).[13] This result confirms the viewpoint as expressed in the Morioka consensus statement[5]: learning minimally invasive liver surgery is easier with the robotic approach. There are several explanations for such a result: first, the advantages of using the dVSS include the wristed instruments, tremor filtration, and stereoscopic steady vision which indeed could help us to overcome the inherent limitations of the conventional laparoscopic surgery. Second, both the operating surgeon and the assisting surgeon had been well trained and had accumulated enough experience through more than 100 laparoscopic hepatectomies. We believe that it is important for a surgeon to acquire expert laparoscopic skills before using the robotic approach. Third, the third robotic arm and the ease in suturing are also advantages of the robotic approach when compared to the traditional laparoscopic method. If there is uncontrolled bleeding, especially after failure of hemostasis using coagulation or clipped technique, the third robotic arm can be used to hold a small gauze to press on the bleeding site to achieve temporary hemostasis while the other two arms can be used to carry out suturing. Sometimes the third arm can also be used to achieve better exposure of the deep liver parenchyma to facilitate parenchymal transection and vessel dissection. Fourth, the robotic approach allows more flexible application of various kinds of hepatic vascular exclusion methods, resulting in more effective control of bleeding during parenchymal transection. Lastly, IOUS can help to identify tumors and its relationship to intrahepatic vascular structures, to guide liver transection at the correct plane, and to determine the width of tumor resection margin.

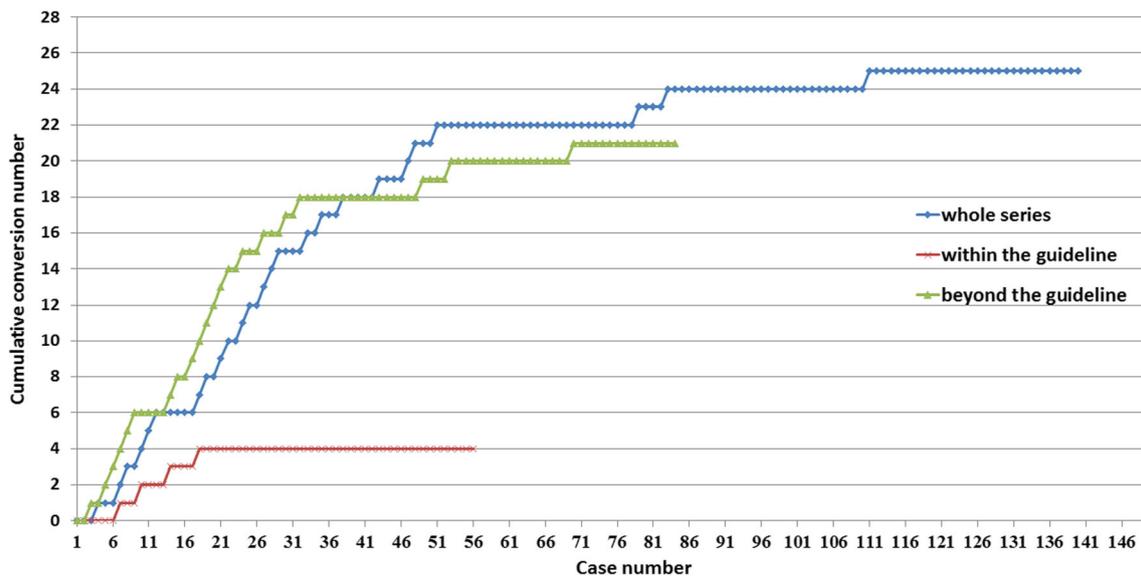Based on our experience in robotic liver resection, a beginner is recommended to start robotic surgery on left

Fig. 1 Cumulative conversions in the whole series of patients, 56 patients within the guideline, and 84 patients beyond the guideline for hepatectomies

lateral sectionectomy or on patients who are within the indications of the Louisville statement. Multiple tumors or right posterior sectionectomy should be avoided in the initial stage for the following reasons: first, once the robotic surgical system's patient cart was docked, the patient position cannot be changed during the rest of the hepatectomy procedure. This is different from the pure laparoscopic approach. The principle of trocar distribution is tumor-centered, and it is difficult to be used on some parts of the liver in difficult operations. Second, all the wristed instruments are not specifically designed for hepatectomy. The harmonic scalpel is

usually used for liver transection. However, it is not wristed and it is designed for a straight-line transection. Even though equipped in a different arm, it still cannot be comfortably applied to some parts of the liver in difficult operations. Third, the right posterior sectionectomy is well considered to be technically difficult in laparoscopic liver resections. It is recognized as a "major" resection in the Louisville[18] and Morioka[5] consensus conferences. Thus, it is inappropriate to include these as the initial cases. Our experience showed that the left flank position (60°) facilitated liver mobilization for lesions in segments 6 and 7, and a better
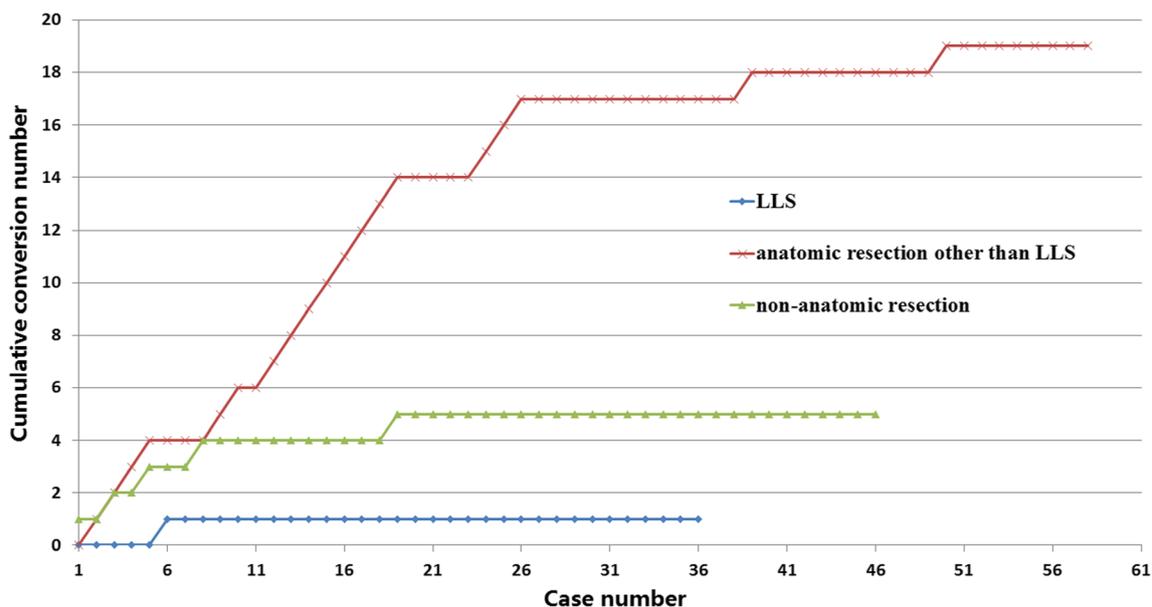

Fig. 2 Cumulative conversions in 36 left lateral sectionectomies (LLS), 58 anatomical resections other than LLS, 46 non-anatomical resections
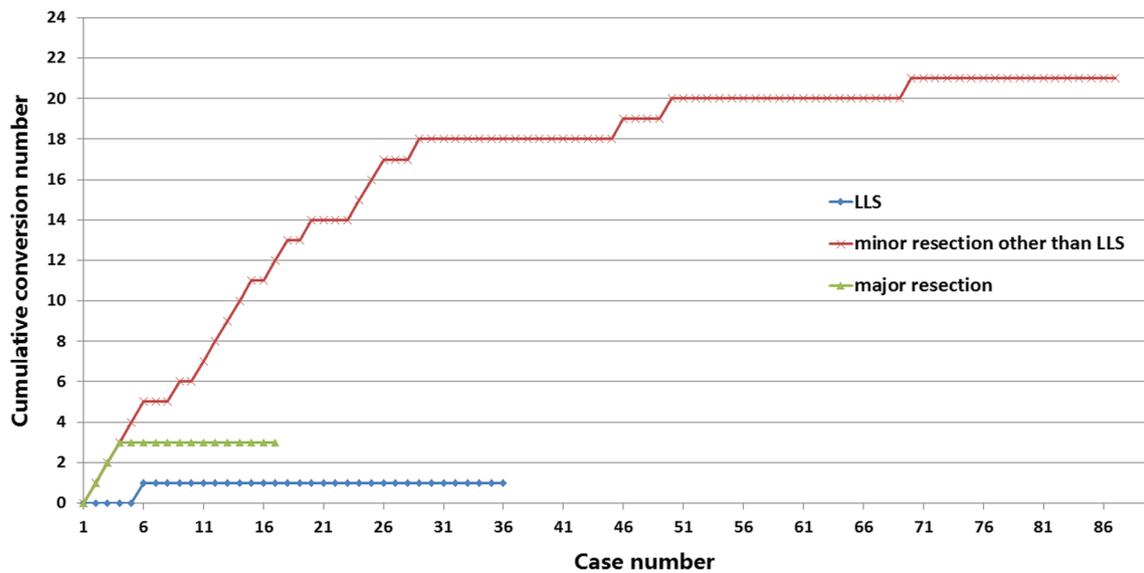
Fig. 3 Cumulative conversions in 36 left lateral sectionectomies (LLS), 87 minor hepatectomies other than LLS, 17 major hepatectomies

exposure could be achieved during parenchyma transection utilizing gravity to pull onto the liver.

Although the introduction of minimally invasive techniques has dramatically transformed surgery in the past 25 years, it has not gained wide acceptance and it remains a subject of controversy among liver surgeons in the treatment of HCC. With more and more studies,[27–31] the controversy becomes less and less. A number of non-randomized comparative studies[27–29] suggested that the laparoscopic approach gave equivalent survival outcomes and better perioperative outcomes when compared to open approach in selected patients with HCC. To the best of our knowledge, there has only been one paper[32] which reported on the long-term outcomes of HCC patients after robotic liver resection. There were

no significant differences in oncological outcomes between the robotic approach and the pure laparoscopic approach in R0 resection rate (96 vs. 91.4%), 5-year overall survival rate (65 vs. 48%), and disease-free survival rate (42 vs. 38%). In our series, six patients suffered from tumor rupture and needed conversion to the open approach to avoid tumor dissemination. The histopathological result confirmed that only one patient had a positive resection margin (R0 resection, 98.7%). The result is comparable to those reported by others.[32,33] Better perioperative outcomes, including shorter operative time and hospital stay, less blood loss, and lower conversion rate, were observed in our HCC patients during the plateau stage, which demonstrated the feasibility and safety of robotic liver resection for HCC
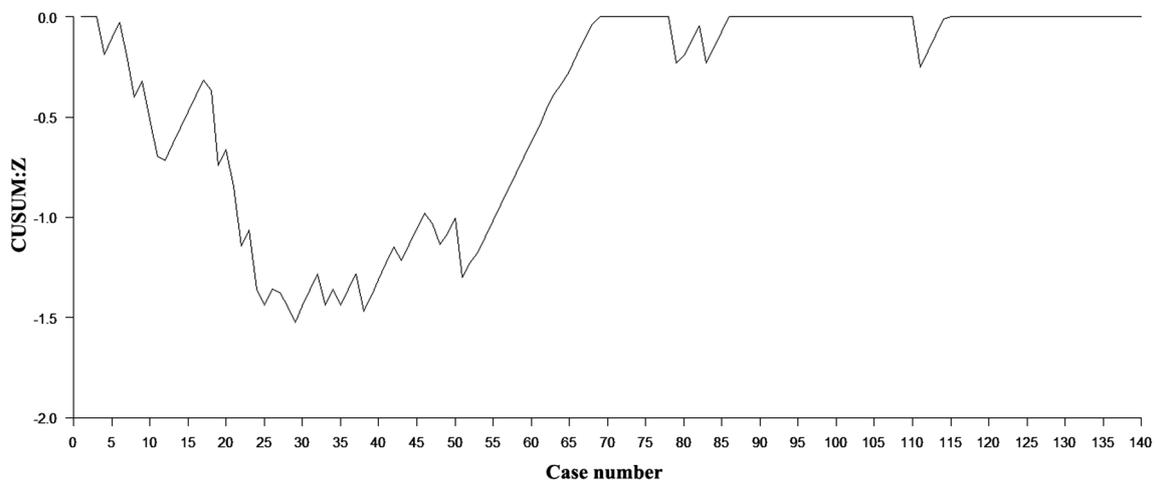

Fig. 4 Risk-adjusted CUSUM chart of all 140 consecutive robot-assisted liver resections

patients. However, the long-term oncological outcomes of this approach are still uncertain and need further investigation.

Finally, interesting data derive from learning curve specific statistics in this study, which confirm that robotic liver resection could allow shorter learning curve compared to laparoscopic liver surgery. However, patients should be accurately selected and only LLS or other minor hepatectomy should be considered, which could contribute to better learning and increase the confidence of the surgeons. To be honest, on account of sample size, if the amount of hepatectomy is less than 20 cases per year in a center, it is considered that there is a lack of sufficient volume to complete the learning process for both laparoscopic and robotic hepatectomy. Another issue related to robotic hepatectomy is cost-effectiveness evaluation. In our center, the major expenditures of robotic approach are start-up fee of dVSS and instrument fee due to limitation of usage counter, which might restrict its widespread application.

In conclusion, the robotic approach for hepatectomy is safe and feasible. The indications should be properly extended. A learning curve effect was demonstrated in this study after the 30th consecutive patient. The long-term oncological outcomes of robotic hepatectomy still need further investigation.

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Wei Liao, Ze-yang Ding, Lin Chen, Wan-guang Zhang: Participate in the operation, acquisition, and analysis of data.

Bi-xiang Zhang: conception and design, perform the operation.

Xiao-ping Chen: conception and design, analysis, and interpretation of data.

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