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# Feasibility and efficacy of minimally invasive limited resection for primary duodenal gastrointestinal stromal tumors: a retrospective cohort study

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## Abstract

**Background** The primary duodenal gastrointestinal stromal tumor (GIST) is a rare type of gastrointestinal tract tumor. Limited resection (LR) has been increasingly performed for duodenal GIST. However, only a few studies reported minimally invasive limited resection (MI-LR) for primary duodenal GIST.

**Methods** The clinical data of 33 patients with primary duodenal GIST from December 2014 to February 2024 were retrospectively analyzed including 23 who received MI-LR and 10 who received laparoscopic or robotic pancreaticoduodenectomy (LPD/RPD).

**Results** A total of 33 patients with primary duodenal GIST were enrolled and retrospectively reviewed. Patients received MI-LR exhibited less OT (280 vs. 388.5min,  $P=0.004$ ), EBL (100 vs. 450ml,  $P<0.001$ ), and lower morbidity of postoperative complications (52.2% vs. 100%,  $P=0.013$ ) than LPD/RPD. Patients received LPD/RPD burdened more aggressive tumors with larger size ( $P=0.047$ ), higher classification ( $P<0.001$ ), and more mitotic count/50 HPF ( $P=0.005$ ) compared with patients received MI-LR. The oncological outcomes were similar in MI-LR group and LPD/RPD group. All the patients underwent MI-LR with no conversion, including 12 cases of LLR and 11 cases of RLR. All of the clinicopathological data of the patients were similar in both groups. The median OT was 280(210-480) min and 257(180-450) min, and the median EBL was 100(20-1000) mL and 100(20-200) mL in the LLR and the RLR group separately. The postoperative complications mainly included DGE (LLR 4 cases, 33.4% and RLR 4 cases, 36.4%), intestinal fistula (LLR 2 cases, 16.7%, and RLR 0 case), gastrointestinal hemorrhage (LLR 0 case and RLR 1 case, 9.1%), and intra-abdominal infection (LLR 3 cases, 25.0% and RLR 1 case, 9.1%). The median postoperative length of hospitalization was 19.5(7-46) days in the LLR group and 19(9-38) days in the RLR group. No anastomotic stenosis, local recurrence or distant metastasis was observed during the follow-up period in the two groups.

**Conclusions** Minimally invasive limited resection is an optional treatment for primary duodenal GIST with satisfactory short-term and long-term oncological outcomes.

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**Keywords** Duodenal tumor, Gastrointestinal stromal tumor, Duodenectomy, Laparoscopic, Robotic

## Introduction

Gastrointestinal stromal tumors (GISTs) are the most common mesenchymal tumors of the gastrointestinal tract, of which 60% are located at the stomach and 30% are located at the small intestines [1]. The primary duodenal gastrointestinal stromal tumor is a rare type of GIST, which accounts for approximately 4-5% of all GISTs. The most common location of duodenal GIST is the second (D2) portion of the duodenum, compared to the first (D1), the third (D3), and the fourth (D4) portion of the duodenum [2].

Complete surgical resection is the mainstay of curative treatment for primary non-metastatic duodenal GISTs [3, 4]. Various procedures have been advocated for resectable duodenal GISTs, including limited resection (LR) and extended resection [5]. Extended resection mainly indicates pancreaticoduodenectomy (PD), while LR includes wedge resection, segmental duodenectomy or pancreas-sparing total duodenectomy. A recent European multicenter cohort study demonstrated that limited resection has similar oncological outcomes and a lower incidence of morbidity than PD for duodenal GIST [6]. However, the oncological outcomes of minimally invasive limited resection (MI-LR) for duodenal GISTs have not been investigated even after the minimally invasive approaches have been gradually adopted for duodenal surgery. MI-LR which includes laparoscopic limited resection (LLR) and robotic limited resection (RLR) are being increasingly performed in many centers with the advantage of preservation of organ function and rapid recovery. However, the experience and evidence regarding such minimally invasive therapeutic strategy is limited, especially the oncological outcomes, of which many are case reports [7].

In the present study, we performed MI-LR for 23 patients with primary duodenal GIST with satisfactory short-term and long-term oncological outcomes compared with minimally invasive pancreaticoduodenectomy.

## Methods

### Study design and patients

Patients diagnosed as duodenal GIST who underwent MI-LR, LPD or RPD at Fujian Medical University Union Hospital from December 2014 to February 2024 were considered eligible and included. Lesions originated from non-duodenal lesions or metastatic duodenal GIST were excluded. Several preoperative examinations were performed for a complete evaluation of the duodenal tumor,

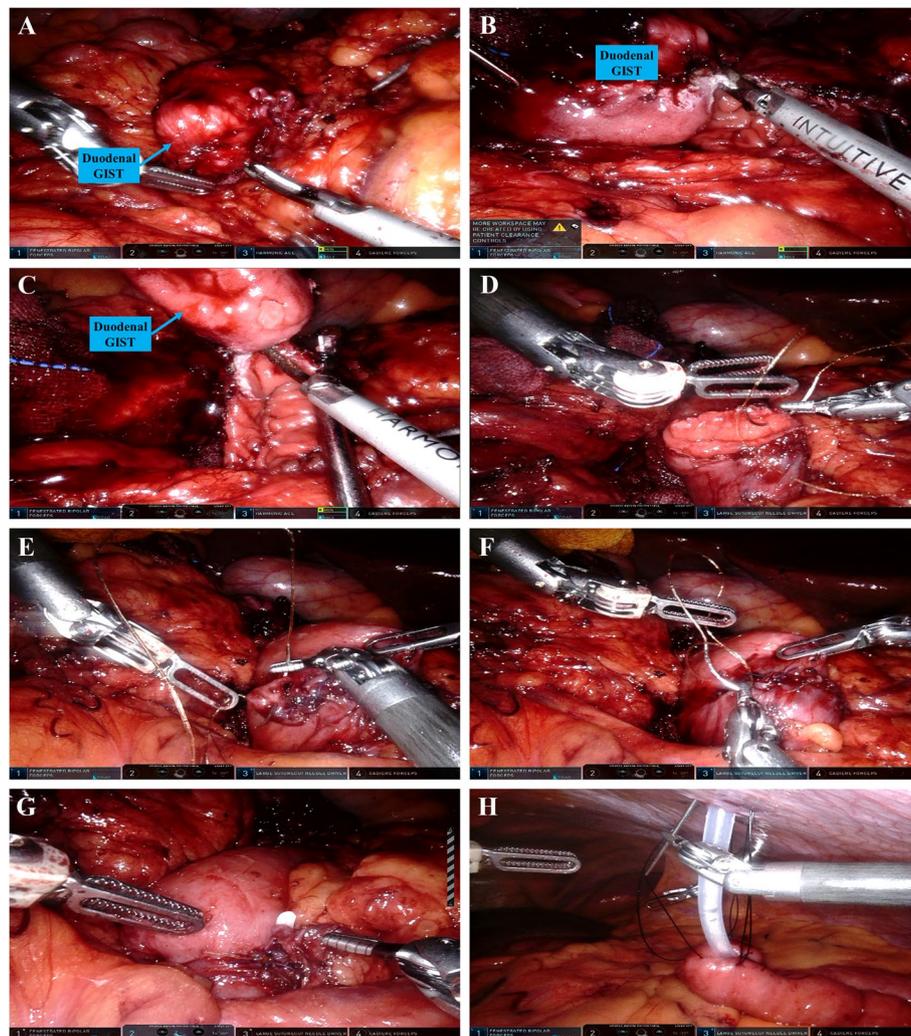
including endoscopy, serum tumor markers, upper gastrointestinal contrast, ultrasonography, contrast-enhanced computed tomography (CT), and magnetic resonance imaging (MRI). Endoscopic ultrasonography (EUS) was adopted if necessary. Surgical approaches like MI-LR, LPD or RPD were determined by multidisciplinary assessment. Neoadjuvant imatinib was not been administered considering its benefit of improving the rate of R0 resection or overall survival has not been proven [8].

The clinicopathological data of the patients were collected and prospectively recorded in a computer database. The characteristics of the data included age, gender, clinical presentation, tumor characteristics, surgical details, postoperative complication, length of stay (LOS), and follow-up details. The tumor characteristics included tumor location (D1, D2, D3, D4), tumor size, pathology (confirmed with histological and immunohistochemical analysis), mitotic count, CD117, CD34, Ki67, and risk classification. The risk classification was determined according to the consensus guidelines of the National Institutes of Health (NIH), based on tumor location, tumor size, and mitotic count [9]. The surgical details included resection status, procedures, operative time (OT), and estimated blood loss (EBL).

### Surgical approaches

The patient was placed in a supine position with two legs separated. For LLR, A 12-mm optical port was positioned below the umbilicus. A 5-mm and a 12-mm ports were placed at the right upper abdomen for the surgeon. Two 5-mm ports were placed at the left upper abdomen for the first assistant. The trocar placement of RLR was similar to that of LLR, as previously described [10]. For RLR, a total intra-abdominal exploration to exclude metastasis was adopted before docking of the robotic operative system.

After exploration, the gastrocolic ligament was incised and the hepatic flexure of the colon was mobilized downward to fully expose the duodenum. A Kocherization was performed to mobilize the duodenum. Wedge resection was performed for the tumor located at the anti-mesenteric edge of the duodenum, mostly at the D2 portion of the duodenum (Fig. 1). The primary defect area of the duodenum was closed by suture or staples. For proximal duodenectomy, D1 resection and distal gastrectomy were performed with or without resection of the upper part of D2 (Fig. 2). A side-to-side anastomosis between the stomach and



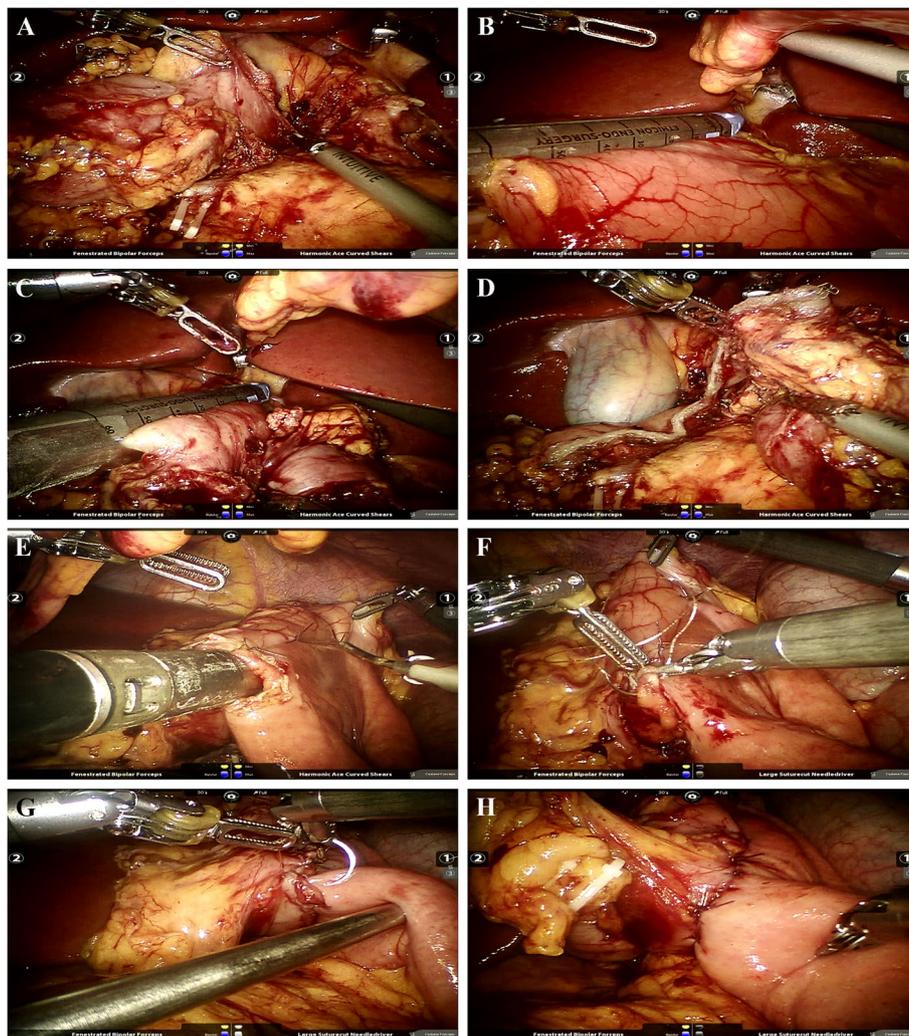
**Fig. 1** Robotic wedge resection for a GIST at the second portion of the duodenum. **A.** Exploration of the duodenal GIST; **B-C.** Wedge resection of the duodenal GIST; **D-E.** Closure of duodenal defect with continuous suture; **F.** Suture of the seromuscular layer of the duodenum for enhancement; **G.** View after the closure of duodenal defect; **H.** Nutritional jejunostomy

the jejunum was performed. For Distal duodenectomy, D3 and D4 resection was performed with or without resection of the lower part of D2. A side-to-side anastomosis between the D2 and the jejunum was performed (Fig. 3). A frozen section was used to confirm the resection margin and tumor pathology if not done preoperatively. For patients with high risks of an intestinal fistula or delayed gastric emptying (DGE), a nutritional jejunostomy was performed. A nasogastric tube was routinely placed before the operation with appropriately delayed removal to relieve the pressure of digestive juice for those patients with wedge resection or duodenojejunostomy.

#### Postoperative management and follow-up

The vital signs and drainage condition of the patients were monitored dynamically. Early ambulation was adopted on the first postoperative day (POD1) benefited from the minimally invasive approach. For patients received jejunostomy, 5%GNS was administered on POD1 for early enteric nutrition and total enteric nutrition was then adopted. An upper gastrointestinal contrast examination and CT scan were routinely arranged for the patients one week after the operation to determine postoperative complications.

The patients were followed up at the outpatient services every 3-6months with contrast-enhanced CT, MRI



**Fig. 2** Robotic proximal duodenectomy for a GIST at the first portion of the duodenum. **A.** Dissection of the first portion of the duodenum; **B.** Transection of the stomach; **C-D.** Transection of the duodenum; **E.** A side-to-side anastomosis between the stomach and the jejunum; **F-G.** Closure of the defect with continuous suture; **H.** View after gastrojejunostomy

or endoscopy in the first year after surgery, and at annually thereafter to recognize recurrence or metastasis. The disease-free survival (DFS) and overall survival (OS) were defined as the interval from the operative date to the date of disease relapse (local recurrence or distant metastasis), last follow-up, or death, whichever happened first.

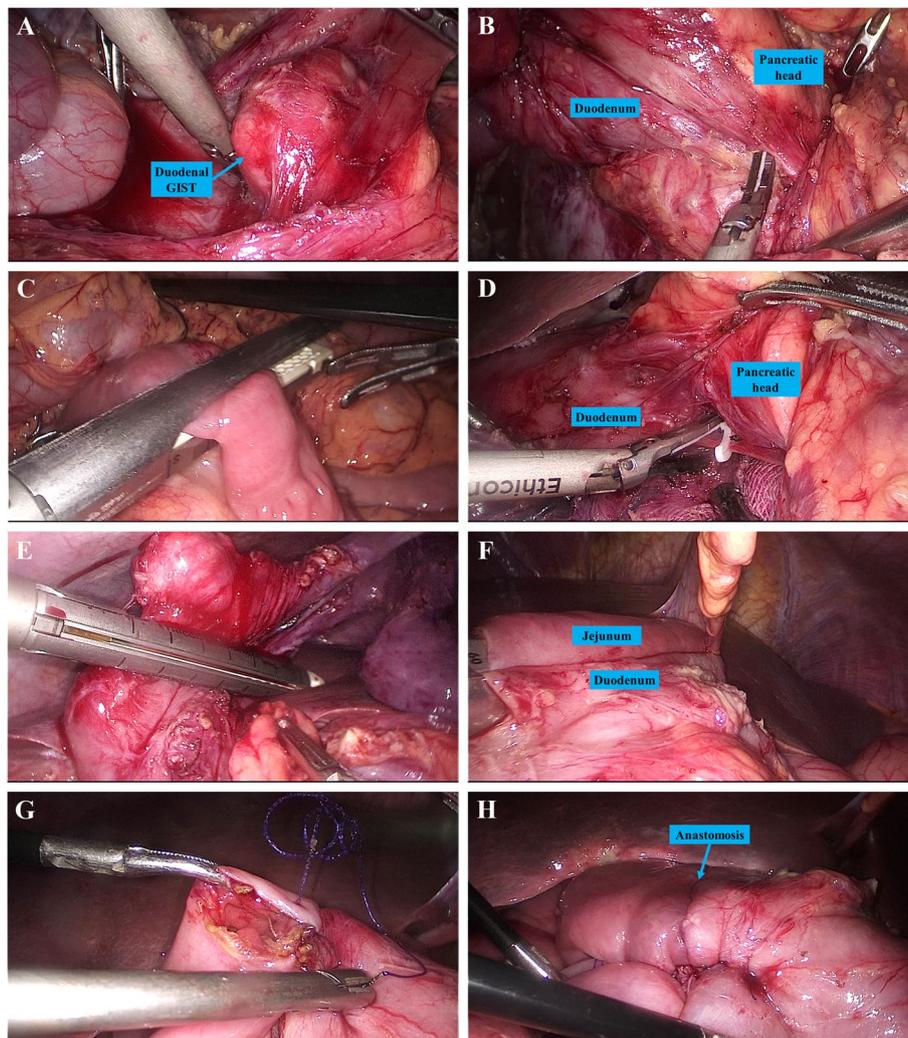
#### Statistical analysis

All data had undergone normality testing. Continuous data conforming to a normal distribution were presented as mean±standard deviation. Otherwise, the median with range was utilized. Categorical data were presented as frequencies and proportions. Should the continuous data adhere to a normal distribution, the t-test was adopted; otherwise, Mann-Whitney U test was employed. The

Chi-square test or Fisher exact test served the purpose of comparing intergroup discrepancies for categorical data. A probability (*P*) value less than 0.05 was set as statistical significance. The statistical analysis was performed using SPSS software version 22.0 (SPSS Inc., Chicago, IL, USA).

#### Results

A total of 33 patients with primary duodenal GIST were enrolled and retrospectively reviewed (Table 1). Twenty-three patients received MI-LR and ten received LPD/RPD. There were 16 male and 17 female patients. The mean age was 57±9.41 years. There were 22 symptomatic patients, 16 with gastrointestinal hemorrhage, and 6 with abdominal pain. Eleven patients with asymptomatic duodenal GIST were incidentally diagnosed. The locations



**Fig. 3** Laparoscopic distal duodenectomy for a GIST at the lower part of the second portion of the duodenum. **A.** Exploration of the duodenal GIST; **B.** Dissection of the duodenum; **C.** Transection of the proximal jejunum; **D.** Separation of the duodenum from the pancreatic head; **E.** Transection of the second portion of the duodenum proximal to the GIST; **F.** A side-to-side anastomosis between the duodenum and the jejunum; **G.** Closure of intestinal defect with continuous suture; **H.** View after duodenojejunostomy

of duodenal GIST were D1 ( $n=5$ ), D2 ( $n=21$ ), D3 ( $n=7$ ), D4 ( $n=0$ ). The median largest tumor diameter of duodenal GIST was 4cm (2 -15cm). According to the NIH classification, 20 patients were classified into the low-risk group, 7 patients were into the intermediate-risk group, and 6 patients into the high-risk group. There were 28 spindle cell differentiation tumors and 5 mixed-type differentiation with spindle and epithelioid cells. CD117 was positive in all the GISTs, while CD34 was positive in 26 patients. The mitotic count was  $\leq 5/50$  HPF in 27 tumors and  $>5/50$  HPF in 6 tumors. Patients received MI-LR exhibited less OT (280 vs. 388.5min,  $P=0.004$ ), less EBL (100 vs. 450ml,  $P<0.001$ ), and lower morbidity of postoperative complications (52.2% vs. 100%,  $P=0.013$ )

than LPD/RPD. Compared with patients who underwent MI-LR, patients who underwent LPD/RPD burdened more aggressive tumors with larger size ( $P=0.047$ ), higher classification ( $P<0.001$ ) and more mitotic count/50 HPF ( $P=0.005$ ). All the patients are alive during a median follow-up of 33(1-110) months. No anastomotic stenosis, local recurrence or distant metastasis was observed during the follow-up period in both groups.

All the patients underwent MI-LR with no conversion, including 12 cases of LLR and 11 cases of RLR (Table 2). All of the clinicopathological data of the patients were similar in the LLR and RLR groups, including gender, age, presentation, tumor location, tumor diameter, histologic type, mitotic count/50HPF, CD117, CD34, risk NIH

**Table 1** The clinicopathological data of the patients who underwent LPD/RPD and MI-LR for primary duodenal GIST

Variate	Total (n=33)	LPD/RPD (n=10)	MI-LR (n=23)	P value
Gender				0.465
Male	16(48.5%)	6(60.0%)	10(43.5%)	
Female	17(51.5%)	4(40.0%)	13(56.5%)	
Age	57±9.41	55.7±10.37	57.57±9.15	0.609
Presentation				0.094
GI hemorrhage	16(48.5%)	4(40.0%)	12(52.2%)	
Abdominal pain	6(18.2%)	4(40.0%)	2(8.7%)	
Incidental finding	11(33.3%)	2(20.0%)	9(39.1%)	
Tumor diameter	4(2-15)	5.25(3.5-15)	4(2-8)	0.047
Tumor location				0.101
1 <sup>st</sup> part of duodenum	5(15.2%)	0(0.0%)	5(21.7%)	
2 <sup>nd</sup> part of duodenum	21(63.6%)	9(90.0%)	12(52.2%)	
3 <sup>rd</sup> part of duodenum	7(21.2%)	1(10.0%)	6(26.1%)	
4 <sup>th</sup> part of duodenum	0(0.0%)	0(0.0%)	0(0.0%)	
Histologic type				0.291
Spindle cell	28(84.8%)	10(100.0%)	18(78.3%)	
Mixed type	5(15.2%)	0(0.0%)	5(21.7%)	
Mitotic count/50 HPF				0.005
≤5/50 HPF	27(81.8%)	5(50.0%)	22(95.7%)	
>5/50 HPF	6(18.2%)	5(50.0%)	1(4.3%)	
CD117				-
Positive	33(100.0%)	10(100.0%)	23(100.0%)	
Negative	0(0.0%)	0(0.0%)	0(0.0%)	
CD34				0.646
Positive	26(78.8%)	7(70.0%)	19(82.6%)	
Negative	7(21.2%)	3(30.0%)	4(17.4%)	
Risk NIH classification				<0.001
Very low risk	0(0.0%)	0(0.0%)	0(0.0%)	
Low risk	20(60.6%)	1(10.0%)	19(82.6%)	
Intermediate risk	7(21.2%)	4(40.0%)	3(13.0%)	
High risk	6(18.2%)	5(50.0%)	1(4.3%)	
R-Status				-
R0	33(100.0%)	10(100.0%)	23(100.0%)	
R1	0(0.0%)	0(0.0%)	0(0.0%)	
Tumor rupture				-
No	33(100.0%)	10(100.0%)	23(100.0%)	
Yes	0(0.0%)	0(0.0%)	0(0.0%)	
OT (min)	290(180-584)	388.5(276-584)	280(180-480)	0.004
EBL (mL)	100(20-2300)	450(50-2300)	100(20-1000)	<0.001
Transfusion	11(33.3%)	6(60.0%)	5(21.7%)	0.049
Postoperative complications	22(66.7%)	10(100.0%)	12(52.2%)	0.013
DGE	11(33.3%)	3(30.0%)	8(34.8%)	1
Intestinal fistula	2(6.1%)	0(0.0%)	2(8.7%)	1
Anastomotic leakage	3(9.1%)	3(30.0%)	0(0.0%)	0.022
GI hemorrhage	1(3.0%)	0(0.0%)	1(4.3%)	1
Intra-abdominal infection	12(36.4%)	8(80.0%)	4(17.4%)	0.001
LOS (day)	21(7-88)	28.5(12-88)	19(7-46)	0.094
Long-term outcome				
Local recurrence	0(0.0%)	0(0.0%)	0(0.0%)	-
Distant metastasis	0(0.0%)	0(0.0%)	0(0.0%)	-
Follow-up (month)	33(1-110)	25(1-63)	39(4-110)	0.115

MI-LR minimally invasive limited resection, LPD laparoscopic pancreaticoduodenectomy, RPD robotic pancreaticoduodenectomy, GIST gastrointestinal stromal tumor, GI gastrointestinal, HPF high-power field

**Table 2** The clinicopathological data of the patients who underwent LLR and RLR for primary duodenal GIST

Variate	MI-LR (n=23)	LLR (n=12)	RLR (n=11)	P value (LLR vs. RLR)
Gender				0.68
Male	10(43.5%)	6(50.0%)	4(36.4%)	
Female	13(56.5%)	6(50.0%)	7(63.6%)	
Age	57.57±9.15	55.5±11.74	59.82±4.71	0.268
Presentation				0.3
GI hemorrhage	12(52.2%)	7(58.3%)	5(45.5%)	
Abdominal pain	2(8.7%)	0(0.0%)	2(18.2%)	
Incidental finding	9(39.1%)	5(41.7%)	4(36.4%)	
Tumor diameter	4(2-8)	4.25(2.5-8)	4(2-7)	0.615
Tumor location				0.152
1 <sup>st</sup> part of duodenum	5(21.7%)	4(33.3%)	1(9.1%)	
2 <sup>nd</sup> part of duodenum	12(52.2%)	4(33.3%)	8(72.7%)	
3 <sup>rd</sup> part of duodenum	6(26.1%)	4(33.3%)	2(18.2%)	
4 <sup>th</sup> part of duodenum	0(0.0%)	0(0.0%)	0(0.0%)	
Histologic type				0.317
Spindle cell	18(78.3%)	8(66.7%)	10(90.9%)	
Mixed type	5(21.7%)	4(33.3%)	1(9.1%)	
Mitotic count/50 HPF				1
≤5/50 HPF	22(95.7%)	11(91.7%)	11(100.0%)	
>5/50 HPF	1(4.3%)	1(8.3%)	0(0.0%)	
CD117				-
Positive	23(100.0%)	12(100.0%)	11(100.0%)	
Negative	0(0.0%)	0(0.0%)	0(0.0%)	
CD34				0.317
Positive	19(82.6%)	11(91.7%)	8(72.7%)	
Negative	4(17.4%)	1(8.3%)	3(27.3%)	
Risk NIH classification				0.51
Very low risk	0(0.0%)	0(0.0%)	0(0.0%)	
Low risk	19(82.6%)	10(83.3%)	9(81.8%)	
Intermediate risk	3(13.0%)	1(8.3%)	2(18.2%)	
High risk	1(4.3%)	1(8.3%)	0(0.0%)	

MI-LR minimally invasive limited resection, LLR laparoscopic limited resection, RLR robotic limited resection, GIST gastrointestinal stromal tumor, GI gastrointestinal, HPF high-power field

classification. Details of perioperative data and long-term outcome for patients received MI-LR was showed in Table 3. In the LLR group, there were two patients underwent wedge resection with jejunostomy, six proximal duodenectomies with distal gastrectomy and gastrojejunostomy, four distal duodenectomies with duodenojejunostomy and nutritional jejunostomy. In the RLR group,

there were six wedge resections with nutritional jejunostomy, one wedge resection with distal gastrectomy and gastrojejunostomy, two proximal duodenectomy with distal gastrectomy and gastrojejunostomy, two distal duodenectomy with duodenojejunostomy and nutritional jejunostomy. R0 resection was achieved and no tumor rupture occurred during the operation for all the patients.

The median OT was 280 (210-480) min and 257 (180-450) min, and the median EBL was 100 (20-1000) mL and 100 (20-200) mL in the LLR and the RLR group separately. The postoperative complications mainly included DGE (LLR 4 cases, 33.3% and RLR 4 cases, 36.4%), intestinal fistula (LLR 2 cases, 16.7%, and RLR 0 case),gastrointestinal hemorrhage (LLR 0 case and RLR 1 case, 9.1%), and intra-abdominal infection (LLR 3 cases, 25.0% and RLR 1 case, 9.1%). The median postoperative length of hospitalization was 19.5(7-46) days in the LLR group and 19(9-38) days in the RLR group. The RLR group had a shorter median follow-up duration (18 vs. 52.5 months,  $P=0.001$ ) because robotic approach has recently become the priority choice for duodenal GIST compared to laparoscopic approach in our center.

### Discussion

Resection is the curative treatment for primary duodenal GISTs with or without adjuvant imatinib (IM), including endoscopic resection (ER) and surgical resection. Compared to surgical resection, ER is less invasive and has a similar OS [11, 12]. Nevertheless, considering the high incidence of the positive resection margin and perforation, ER is recommended for duodenal GIST smaller than 2cm [13]. In the present study, ER was not considered since the smallest diameter of duodenal GISTs was 2cm.

Surgical resection for duodenal GISTs could be divided into extended resection and limited resection [14]. Due to the complex anatomic structures in this area, including the duodenum, the head of pancreas, the duodenal papilla, the common bile duct and the main pancreatic duct, PD is a widely accepted method for duodenal GIST [15]. Though the mortality has been significantly reduced in recent decades, PD is still associated with a high incidence of postoperative complications and decreased long-term quality of life. Therefore, LR including wedge resection, segmental duodenectomy, or pancreas sparing total duodenectomy has been increasingly utilized. Segmental duodenectomy consists of proximal duodenectomy and distal duodenectomy, with the duodenal papilla as the borderline. Compared to PD, LR has a lower incidence of complications [14, 16]. Of note, it is reported that LR exhibited the similar long-term outcomes with PD [5]. Moreover, the biological behaviors

**Table 3** Perioperative data and long-term outcome of patients with primary duodenal GIST who underwent LLR and RLR

Variate	MI-LR (n=23)	LLR (n=12)	RLR (n=11)	P value
Procedure				
Wedge resection	9(39.1%)	2(16.7%)	7(63.6%)	0.036
Proximal duodenectomy	8(34.8%)	6(50.0%)	2(18.2%)	0.193
Distal duodenectomy	6(26.1%)	4(33.3%)	2(18.2%)	0.635
Digestive reconstruction				
Gastrojejunostomy	9(39.1%)	6(50.0%)	3(27.3%)	0.4
Duodenojejunostomy	6(26.1%)	4(33.3%)	2(18.2%)	0.64
Nutritional jejunostomy	14(60.9%)	6(50.0%)	8(72.7%)	0.4
R-Status				-
R0	23(100.0%)	12(100.0%)	11(100.0%)	
R1	0(0.0%)	0(0.0%)	0(0.0%)	
Tumor rupture				-
No	23(100.0%)	12(100.0%)	11(100.0%)	
Yes	0(0.0%)	0(0.0%)	0(0.0%)	
OT (min)	280(180-480)	280(210-480)	257(180-450)	0.773
EBL (mL)	100(20-1000)	100(20-1000)	100(20-200)	0.603
Transfusion	5(21.7%)	4(33.3%)	1(9.1%)	0.317
Postoperative complications	12(52.2%)	8(66.7%)	4(36.4%)	0.22
DGE	8(34.8%)	4(33.3%)	4(36.4%)	1
Intestinal fistula	2(8.7%)	2(16.7%)	0(0.0%)	0.478
Anastomotic leakage	0(0.0%)	0(0.0%)	0(0.0%)	-
GI hemorrhage	1(4.3%)	0(0.0%)	1(9.1%)	0.478
Intra-abdominal infection	4(17.4%)	3(25.0%)	1(9.1%)	0.59
LOS (day)	19(7-46)	19.5(7-46)	19(9-38)	0.916
Adjuvant Imatinib	2(8.7%)	2(16.7%)	0(0.0%)	0.478
Long-term outcome				
Local recurrence	0(0.0%)	0(0.0%)	0(0.0%)	-
Distant metastasis	0(0.0%)	0(0.0%)	0(0.0%)	-
Follow-up (month)	39(4-110)	52.5(13-110)	18(4-62)	0.001

MI-LR minimally invasive limited resection, LLR laparoscopic limited resection, RLR robotic limited resection, GIST gastrointestinal stromal tumor, OT operative time, EBL estimated blood loss, DGE delayed gastric emptying, GI gastrointestinal, LOS length of stay

of duodenal GIST appears to be relatively indolent with a low incidence of lymph node metastasis (3.7%) and distant metastasis (7.5%) [12]. And the characteristic of expansive growth would not be a barrier when dissecting duodenum from adjacent organs. In this light, LR emerges as a favorable surgical option for GIST located at the D1, D3, D4, and on the lateral wall of D2 [17–20]. However, PD should be firstly considered for tumors located at the medial wall of D2, due to the proximity to the pancreatic head or ampullar of Vater [2, 19, 21].

With the rapid development of minimally invasive techniques, skillful general surgeons have increasingly performed MI-LR, including LLR and RLR. However, there is limited literature regarding duodenal GIST. Despite the feasibility and safety of MI-LR has been demonstrated by several case series or case reports, the long-term oncological outcomes deserve further evaluated.

MI-LR exhibited decreased OT and POS compared with open LR in a retrospective study enrolled 53 patients with D2 or D3 duodenal GIST [22]. Zhou et al. [23] reported a case series of RLR for 17 patients with duodenal GIST with acceptable outcomes. Whereas most of the other studies were case reports or with a small sample size [7, 24]. Besides, the long-term oncological outcomes remain unclear. Some surgeons even concerned that LLR may elevate the risk of anastomotic leakage, stenosis or tumor rupture which subsequently impact on oncological outcomes [25]. Therefore, laparoscopic approach is limited to GIST smaller than 2cm [8]. In the present study, MI-LR was performed in 23 patients and no tumor rupture, anastomotic leakage, and stenosis were observed which indicated that the risk above could be erased by skillful surgeons. No local recurrence or distant metastasis was observed in all 23 patients which

indicated that the long-term oncological outcomes were comparable with LPD/RPD. However, it is noteworthy that the indication of LPD/RPD and MI-LR have not been formally established yet. Optimal minimally invasive surgery strategy for duodenal GIST appears to be individually tailored than non-duodenal GIST. For the oncological feasibility and efficacy, we consider that MI-LR is more suitable for duodenal GIST than LPD/RPD if the tumors do not invade pancreatic head or ampullar of Vater. According to the previous studies, minimally invasive wedge resection was considered suitable for GIST located at any part of the anti-mesenteric border of the duodenum with small size [26, 27]. However, we believed that the diameter of tumor base should be the decisive condition for selecting minimally invasive wedge resection or segmental resection instead of tumor size. In other words, the technical challenge of achieving primary closure in the transverse direction would be significantly reduced if the defects in the duodenal wall are smaller than 5cm. Otherwise, minimally invasive segmental duodenectomy should be considered to avoid stenosis of the duodenum. Distal duodenectomy with duodenojejunostomy could be utilized for GIST at infra-papilla and proximal duodenectomy with gastrojejunostomy for super-papilla. In conclude, the indications of MI-LR should be determined based on the diameter of tumor base, tumor site, and the extent of invasion into pancreatic head or ampullar of Vater.

The robotic operative system can theoretically overcome some of the technical limitations of laparoscopy [28]. It provides tridimensional magnified visualization with high resolution, extended range of motion and tremor filtration, which is related to precise dissection and convenient suture. A recent study showed that robotic PD decreased the incidence of major complications for patients with periampullary cancer than open PD [29]. Hirata Y et al. conducted robotic partial duodenectomy for a patient with duodenal GIST and found no complications or readmission within 90 days [30]. Vicente et al. found satisfied oncological outcomes of patients with duodenal GIST received robotic duodenal enucleations. But the sample size was too small to avoid accidental event with only 3 patients [31]. In the present study, seven patients underwent robotic wedge resection with satisfied clinical and oncological outcomes. Tumor rupture has been recognized as a factor that increases the risk of recurrence [32]. The constraints associated with forceps manipulation during laparoscopic resection can occasionally heighten the risk of tumor rupture. Robotic surgery systems present significant advantages in the treatment of duodenal GIST. With the multi-angle joints and flexible, stable grasping capabilities, the risk of tumor rupture can be

minimized effectively. In instances of wedge resection, repairing the defects of the duodenal wall typically requires hand-sewn suturing. The intricacy of the duodenal-pancreatic region poses a considerable challenge to achieving primary closure. Robotic surgical systems offer a solution by furnishing unparalleled precision and maneuverability.

DGE is one of the most common postoperative complications in MI-LR (34.8%). Extended dissection of the duodenum during kocherization might be an important factor associated with DGE. A side-to-side gastrojejunostomy was performed for one patient who underwent wedge resection and no DGE was noticed. Gastrojejunostomy might be an alternative method to prevent DGE for wedge resection. In the study, nutritional jejunostomy was routinely performed for distal duodenectomy and wedge resection without gastrojejunostomy for treating DGE. It can provide total enteric nutrition and shorten the recovery course.

Imatinib plays a critical role in treating GISTs [33]. A retrospective study enrolling 1000 patients with GIST indicated that imatinib significantly prolonged the OS compared to the pre-imatinib area [34]. In the National comprehensive cancer network (NCCN) guidelines, imatinib is recommended for patients with intermediate or high risks of recurrence [35]. Therefore, the effective adjuvant TKI therapy greatly supports the MI-LR for duodenal GIST. So, one patient with high risk of recurrence and one with intermediate risk received adjuvant imatinib therapy after MI-LR in the present study.

This retrospective study has some limitations. Firstly, the sample size of the present study was small because of the rare occurrence of duodenal GIST and strict patient selection criteria. Furthermore, the limited number of cases undergoing conventional open LR in our center hindered a meaningful comparison with MI-LR. Therefore, a multiple-center trial that recruits more patients with duodenal GIST will be necessary in the future to further evaluate the long-term outcomes of MI-LR.

## Conclusion

Minimally invasive limited resection is an optional treatment for primary duodenal GIST with satisfactory short-term and long-term oncological outcomes.

## Abbreviations

GIST	Gastrointestinal stromal tumor
LR	Limited resection
MI-LR	Minimally invasive limited resection
LLR	Laparoscopic limited resection
RLR	Robotic limited resection
PD	Pancreaticoduodenectomy
LPD	Laparoscopic pancreaticoduodenectomy

RPD	Robotic pancreaticoduodenectomy
HPF	High-power field
DGE	Delayed gastric emptying
IM	Imatinib
ER	Endoscopic resection
GI	Gastrointestinal
OT	Operative time
EBL	Estimated blood loss
LOS	Length of stay
EUS	Endoscopic ultrasonography
CT	Contrast-enhanced computed tomography
MRI	Magnetic resonance imaging
NIH	National Institutes of Health
POD1	First postoperative day
DFS	Disease-free survival
OS	Overall survival

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### Authors' contributions

(I) Study conception and design: Fengchun Lu and Huguang Huang; (II) Acquisition of data: Miao Liu, Ronggui Lin, Xianchao Lin; (III) Analysis and interpretation of data: Congfei Wang, Yuanyuan Yang and Haizong Fang; (IV) Drafting of manuscript: Longhang Wu and Ronggui Lin; (V) Critical revision of manuscript: Longhang Wu and Ronggui Lin; (VI) Final approval of manuscript: all authors. All authors reviewed the manuscript.

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### Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

### Declarations

#### Ethics approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Helsinki. The need for approval was waived by the Ethical Committee of Fujian Medical University Union Hospital for this retrospective study. Informed consent was obtained from all subjects involved in the study.

#### Competing interests

The authors declare no competing interests.

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