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Comparison of robotic gastrectomy and laparoscopic gastrectomy for gastric cancer: a propensity score-matched analysis

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Abstract

Background The benefits of robotic gastrectomy (RG) over laparoscopic gastrectomy (LG) remain controversial. This single-center, propensity score-matched study aimed to compare the outcomes of RG with those of LG for treating gastric cancer.
Methods We searched the prospective gastric cancer database of our institute for patients with gastric cancer who underwent RG or LG between January 2014 and December 2019, excluding patients with remnant stomach cancer and those who underwent concurrent surgery for comorbid malignancies. One-to-one propensity score matching was performed to reduce bias from confounding patient-related variables, and short- and long-term outcomes were compared between the groups.
Results We identified 1189 patients who underwent LG ($n = 979$) or RG ($n = 210$). After propensity score matching, we selected 210 pairs of patients who underwent LG (distal gastrectomy, 138; total or proximal gastrectomy, 72) or RG (distal gastrectomy, 143; total or proximal gastrectomy, 67). RG was associated with a significantly shorter operative time (RG = 201 min vs. LG = 231 min, $p = 0.0051$), less blood loss (RG = 13 mL vs. LG = 42 mL, $p < 0.0001$), lower postoperative morbidity (RG = 1.0% vs. LG = 4.8%, $p = 0.0066$), and a shorter postoperative hospital stay ($p = 0.0002$) than LG. Drain amylase levels on postoperative Days 1 and 3 in the RG group were significantly lower than those in the LG group ($p < 0.0001$).
Conclusions RG is a safe and feasible treatment for gastric cancer, with a shorter operative time, less blood loss, and lower postoperative morbidity than LG. The application of robotics in minimally invasive gastric cancer surgery may offer an alternative to conventional surgery. Multicenter, prospective, randomized controlled trials comparing RG with conventional LG are needed to establish the feasibility and efficacy of minimally invasive gastric cancer surgery.

Keywords Gastric cancer · Laparoscopic gastrectomy · Minimally invasive surgery · Robotic gastrectomy

Gastric cancer remains the fifth most common cancer and the third leading cause of cancer-related death worldwide [1]. Minimally invasive surgery, including laparoscopic and robotic gastrectomy, has provided an alternative approach to treating gastric cancer. The introduction of laparoscopic surgery significantly improved gastric cancer surgery in terms of less blood loss, faster recovery, less pain, and shorter postoperative hospitalization than open surgery [2–9], with comparable morbidity and long-term outcomes [10–12]. However, laparoscopic surgery has significant drawbacks, such as limited range of motion, restricted instrument axis, amplification of hand tremors due to long-handled devices, and inconvenient surgical position. Due to these limitations, the operative time of laparoscopic gastrectomy is reported to be significantly longer than that of open gastrectomy [5, 8, 9]. Furthermore, some studies have shown that laparoscopic surgery has a high rate of postoperative complications, such as anastomotic leakage and pancreatic fistula, mainly due to the abovementioned limitations and intraoperative pancreatic injuries caused by laparoscopic forceps [13–15].

Robotic surgery has been developed to overcome the innate limitations of traditional laparoscopic surgery. This surgical instrument offers new features, including complete tremor filtering, a three-dimensional stereoscopic high-definition view with magnification, instruments with seven degrees of freedom, a shorter learning curve, and improved

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surgical dexterity when fine manipulation is required [16–18]. This promising and innovative surgical approach is increasingly being used to reduce the aforementioned intra-abdominal complications during the treatment of gastric cancer, and its safety has been confirmed in several prospective trials [19, 20]. However, robotic gastrectomy is not superior in terms of reducing the operative time and postoperative morbidity [19, 20]. Moreover, a multi-institutional prospective study reported that robotic gastrectomy had the disadvantages of longer operative time and higher cost compared to laparoscopic gastrectomy [20].

The benefits of robotic gastrectomy over conventional laparoscopic gastrectomy remain controversial. Therefore, we developed various modifications, including the suprapancreatic lymph node dissection with anchored pancreas using an organ retractor (SPIDER) technique, as a non-touch pancreas method, and the Maryland bipolar soft-coagulation (MBS) technique, which facilitates suprapancreatic lymphadenectomy while reducing thermal damage to major organs and aiming to standardize robotic gastrectomy. We aimed to compare the outcomes of robotic gastrectomy with conventional laparoscopic gastrectomy to show the feasibility, efficacy, and safety of robotic gastrectomy for the treatment of gastric cancer.

Materials and methods

Study design

This was a single-center comparative study of robotic laparoscopic gastrectomy versus conventional laparoscopic gastrectomy in patients with clinical stage I–IV gastric cancer, using data collected from our prospective gastric cancer database. The superiority of robotic gastrectomy over laparoscopic gastrectomy with regards to postoperative morbidity was hypothesized. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The study design was approved by the Institutional Review Board of Osaka International Cancer Institute (Protocol ID: 18033-4). Written informed consent was obtained from all patients, who were preoperatively informed of the surgical and oncological risks.

We searched the prospective gastric cancer database of Osaka International Cancer Institute for patients with gastric cancer who underwent gastrectomy between January 2014 and December 2019. Indications for laparoscopic gastrectomy included a clinical diagnosis of gastric cancer (stages I–IV). The first robotic gastrectomy for gastric cancer was performed in our institute in March 2014. Since April 2018, robotic surgery for gastric cancer has been covered by National Health Insurance in Japan. Indications for robotic gastrectomy included clinical stages I and II from 2014 to 2017. Since April 2018, indications have expanded to include all stages of gastric cancer. The eligibility criteria of this study were (1) age > 20 years, (2) histologically proven gastric cancer or esophagogastric junction adenocarcinoma, (3) underwent laparoscopic or robotic gastrectomy, and (4) no comorbid malignancies. Patients with remnant stomach cancer and those who underwent concurrent surgery for comorbid malignancies and duodenal resection for duodenal invasion or concurrent duodenal tumors were excluded. Patients with a history of abdominal surgery and R1 resection for positive peritoneal lavage cytology who had no gross peritoneal dissemination were included, because we routinely perform gastrectomy for P0CY1 stage IV gastric cancer. Patients with bulky lymph nodes or distant metastasis, such as paraaortic lymph node metastases, liver metastases, or peritoneal dissemination, were treated with chemotherapy followed by surgery. Patients who received neoadjuvant chemotherapy and those who had undergone conversion surgery after chemotherapy for unresectable gastric cancer were included (Fig. 1). Preoperative assessment comprised gastroduodenoscopy, abdominal ultrasonography, and computed tomography. Finally, cases were grouped into a laparoscopic group (LG) and a robotic group (RG).

Data collection

Data were collected prospectively and recorded in a computer database at Osaka International Cancer Institute. Age; sex; tumor location; clinical and pathological findings; gastrectomy type; reconstruction method; extent of lymph node dissection; operative outcomes, including operative time and blood loss; morbidity; mortality; and conversion to open surgery were recorded. Open conversion was defined as an extension of the primary incision for reasons other than specimen extraction, oncological indications, or reconstruction procedures. Indications for conversion were recorded. Morbidity was stratified as recommended by Dindo et al. [21]. The Japanese classification of gastric carcinoma (third English edition) was used for Tumor–Node–Metastasis staging [22].

Surgical procedures and quality control

In Japan, the endoscopic surgical skill qualification system was developed by the Japanese Society of Endoscopic Surgeons in 2004 as a tool to reliably and reproducibly evaluate the surgical skills of trainees. In this system, two judges evaluate unedited videotapes using a double-blind method with strict criteria regarding which laparoscopic surgeons should become supervisors. Robotic gastrectomies were

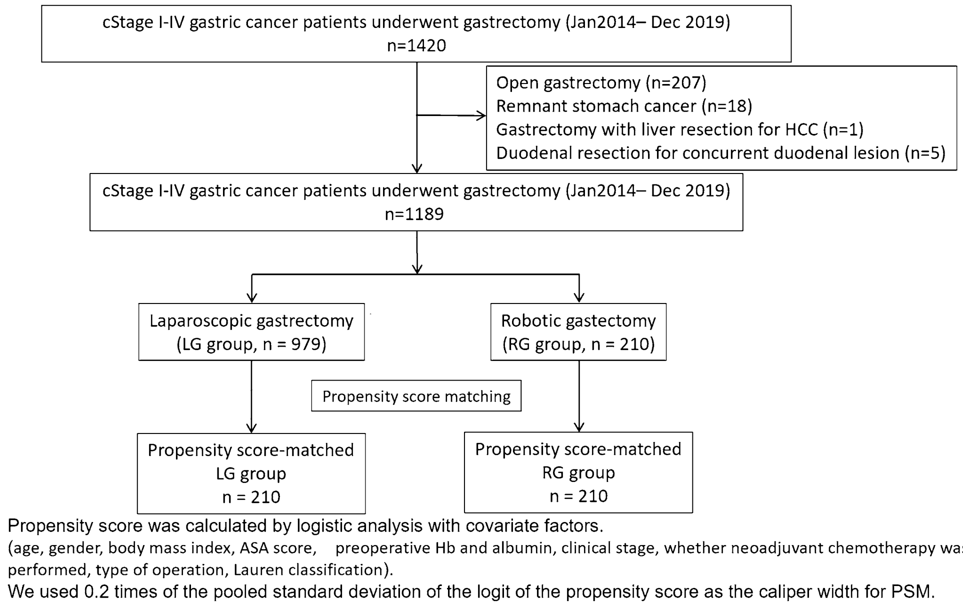

Fig. 1 Patient flow chart. Propensity scores were calculated by logistic regression analysis with age, sex, body mass index, American society of anesthesiologists score, preoperative hemoglobin and albumin, clinical stage, neoadjuvant chemotherapy, type of operation, and Lauren classification as covariates. *HCC* hepatocellular carcinoma, *LG* laparoscopic gastrectomy, *RG* robotic gastrectomy

performed by one of two endoscopic surgical skill qualified, da Vinci trained surgeons (T.O. and Y.F.) (each with experience of > 200 laparoscopic gastrectomies for gastric cancer) using the da Vinci Si or Xi robotic system (Intuitive Surgical Inc., Sunnyvale, CA, USA). T.O. and Y.F. implemented or supervised all laparoscopic gastrectomies in this study. In our institution, laparoscopic surgery has been standardized, and our surgical procedure for laparoscopic gastrectomy has been reported previously [23, 24]. Briefly, the patient is positioned on an operating room table in the supine position with legs apart. Laparotomy is performed via a 2.5–3.0-cm vertical umbilical incision. After application of the wound-sealing device (Lap protector), the camera trocar is covered with the EZ access device. The pneumoperitoneum is then established by carbon dioxide insufflation at a pressure of 8–12 mmHg, according to the patient's body shape. Robotic and laparoscopic gastrectomy use five ports (one camera port in the umbilicus, two ports in the right abdomen, and two ports in the left abdomen). In both groups, suprapancreatic lymphadenectomy was carefully performed without touching the pancreas with forceps and energy devices to avoid pancreatic injury. Laparoscopic coagulating scissors were used for gastric mobilization and lymphadenectomy in both RG and LG. In RG, suprapancreatic lymphadenectomy was performed using Maryland bipolar forceps, which were connected to the bipolar soft-coagulation mode of the VIO system (Erbe, Tubingen, Germany) or ERBE VIO dv 1.0 (Intuitive Surgical Inc., Sunnyvale, CA, USA). D1 + or D2 lymphadenectomy was performed according to the 2014 Japanese gastric cancer treatment guidelines [25]. Gastrectomy was performed under preoperative marking guidance [26]. Reconstruction was performed using the intracorporeal anastomotic technique as previously reported [27, 28].

SPIDER technique

We developed the SPIDER technique in March 2019 to facilitate suprapancreatic lymph node dissection. Since then, the combination of the SPIDER and MBS techniques have been applied to the robotic approach.

In the SPIDER technique, an internal organ retractor (B. Braun Melsungen AG, Melsungen, Germany) with a thread attached to a straight needle (2–0 Prolene, Ethicon Endosurgery Inc., Cincinnati, OH, USA) is used to stabilize the pancreas as follows: the transverse colon/mesocolon attached to the pancreas is held by the internal organ retractor (Fig. 2a). The straight needle is pierced into the lower left abdominal wall and the thread is pulled out of the abdominal cavity (Fig. 2b). After stabilizing the pancreas, by anchoring it dorsally (Fig. 2c), suprapancreatic lymphadenectomy can be easily performed without touching the pancreas if robotic articulated forceps are used (Fig. 2d–f).

MBS technique

We developed an improved technique for robotic surgery, namely the MBS technique. Suprapancreatic lymph nodes were carefully dissected using Maryland bipolar forceps, which were connected to the bipolar soft-coagulation mode of the VIO system. The bipolar soft-coagulation mode limited the maximum level to 200 V, so no sparking occurred between the electrodes. This technique can reliably seal blood and lymph vessels at low temperatures, thus, reducing thermal damage to organs, such as the pancreas and great vessels (Fig. 2e, f). This technique also allows us to perform suprapancreatic lymphadenectomy safely with minimal bleeding.

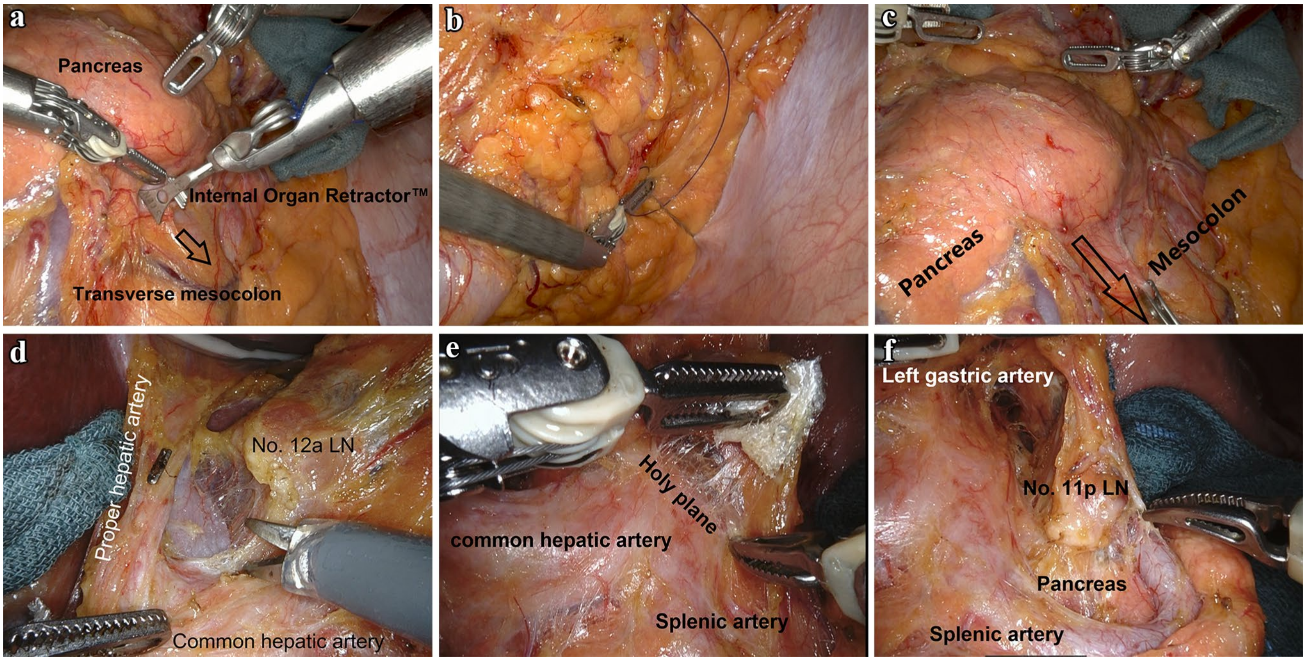

Fig. 2 Suprapancreatic lymphadenectomy using the SPIDER/MBS technique. **a** The mesocolon of the dorsal side of the pancreas was held by the internal organ retractor. **b** The needle penetrated the lower left abdominal wall and the thread was pulled to anchor the pancreas to the retroperitoneum (**c**). **d** No. 8a, 12a lymph node dissection. **e** Dissection of the "holy plane." **f** No. 11p lymph node dissection

Postoperative care

The perioperative management protocol was the same for all patients in both groups and followed the clinical pathway of our hospital. Patients received basic analgesia with continuous infusion of fentanyl for 48 h, postoperatively. Additional analgesics, such as nonsteroidal anti-inflammatory drugs, were administered upon patient request. None of the patients received epidural analgesia. After the first passage of flatus, soft food was resumed.

Propensity score matching analysis

We used propensity score matching (PSM) to limit confounders and overcome possible patient selection bias due to the retrospective study design. A regression model was created based on potential variables (age, sex, body mass index, American Society of Anesthesiologists physical status, preoperative hemoglobin and serum albumin levels, clinical stage, preoperative chemotherapy use, operation type, extent of lymphadenectomy, and Lauren classification) associated with the selection of treatment. A 1:1 nearest neighbor matching algorithm with an optimal caliper width of 0.2 without replacement was applied to match the propensity scores.

Statistical analysis

Patient data were analyzed on an intention-to-treat basis. All statistical analyses were conducted using JMP software (version 14) (SAS Institute Inc., Cary, NC, USA). Demographic and clinicopathological characteristics are summarized descriptively. Quantitative data are expressed as mean ± standard error or median (interquartile range). Student's t tests or Mann–Whitney U tests and Pearson's χ^2 tests were used to compare continuous and categorical variables, respectively. Multivariable binary logistic regression analysis was performed to identify independent risk factors for complications, and odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Overall survival was estimated using the Kaplan–Meier method and compared using the log-rank test. Cox proportional hazards regression models were used to calculate hazard ratios and 95% CIs for patients who underwent RG, after adjusting for age, sex, pathological stage, neoadjuvant chemotherapy, and R0/R1 resection. All tests were two-tailed, and p values < 0.05 were considered significant.

Results

Patient baseline characteristics

Table 1 shows the patient characteristics of the entire ($n=1189$) and propensity-matched ($n=420$) cohorts. The RG group comprised more male patients than the LG group (72.4% vs. 64.0%, respectively; $p<0.05$). Patients in the RG group also had more advanced gastric cancer in terms of depth of tumor invasion, lymph node metastasis, and clinical or pathological stage than those in the LG group. Furthermore, D2 lymphadenectomy tended to be more common in the RG group than in the LG group (79.0% vs. 55.9%, respectively; $p<0.0001$).

After PSM, there were no statistically significant differences between the two groups in terms of patient characteristics, including age, sex, body mass index, American Society of Anesthesiologists physical status, type of tumor, esophagogastric junction (EGJ) cancer, type of reconstruction, and clinical Tumor–Node–Metastasis stage (Table 1). The distributions of pathological T stage, nodal status, and tumor stage according to the Japanese classification of gastric carcinoma (third English edition) were similar [22]. The distribution of skilled surgeons differed between the two groups in all cohorts, but the difference did not persist after PSM.

Surgical outcomes

Table 2 shows the perioperative results. The operation time was significantly shorter in the RG group than in the LG group [RG = 208 (148–286) min vs. LG = 231 (191–223) min, $p=0.0051$] in the propensity-matched cohort. Moreover, less blood loss was observed in the RG group than in the LG group (RG = 13 mL vs. LG = 42 mL, $p<0.0001$). Postoperative hospital stay was shorter in the RG group than in the LG group [RG = 7 (6–8) days vs. LG = 8 (7–10) days, $p=0.0002$].

Postoperative morbidity and mortality

According to the Clavien–Dindo classification, all-grade complications were significantly lower in the RG group than in the LG group (RG = 4.8% vs. LG = 12.9%, $p=0.0034$) (Table 2). Fewer complications of grade III or higher were observed in the RG group than in the LG group (0.95% vs. 4.76%, respectively; $p=0.0066$).

The incidence of intra-abdominal infection due to pancreatic fistula or anastomotic leakage was lower in the RG group than in the LG group (RG = 0.48% vs. LG = 5.24%, $p=0.0034$). There were no cases of grade III or higher intra-abdominal infections in the RG group, such as intra-abdominal abscess, anastomotic leakage, pancreatitis, and pancreatic fistula. There were no significant between-group differences in postoperative inflammatory reactions. There was no 30-day mortality in the RG group.

After PSM, 34 (8.1%) patients had Siewert type I/II EGJ cancer, including 16 (7.6%) in the LG group and 18 (8.6%) in the RG group. Anastomotic leakage occurred in two (12.5%) patients with EGJ cancer in the LG group and none in the RG group, although the difference was not significant.

Drain amylase levels in the propensity-matched cohort

Table 3 shows postoperative amylase levels in the drain discharge. Regarding pancreatic injury, drain amylase levels on postoperative Days 1 and 3 in the RG group were significantly lower than those in the LG group. Severe pancreatic damage within the first postoperative day was defined as drain amylase levels > 2000 U/L, and was more common in the LG group than in the RG group.

Risk factors for postoperative complications

To evaluate the risk factors for overall postoperative complications after laparoscopic and robotic gastrectomy, univariate and multivariate logistic regression analyses were employed (Table 4). In univariate analysis, sex and EGJ cancer were significant risk factors for postoperative complications, while age and laparoscopic approach tended to be risk factors for postoperative complications. Laparoscopic gastrectomy (OR, 3.14, 95% CI 1.46–6.74; $p=0.034$) and EGJ cancer (OR, 2.84, 95% CI 1.17–6.87; $p=0.0207$) were significant risk factors for postoperative complications in multivariate analysis.

Long-term outcomes

Figure 3 shows the cumulative survival curves for patients undergoing laparoscopic and robotic gastrectomy after PSM. The 5-year overall survival rate did not differ significantly different between the LG and RG groups [86.6% (95% CI: 79.8%–91.4%) vs. 91.0% (95% CI: 85.3%–94.6%], respectively; log-rank $p=0.87$). In the Cox proportional hazards regression model, which was adjusted for five potential confounding factors, including age, sex, pathological stage, neoadjuvant chemotherapy, and R0/R1 resection, the hazard ratio of death in the RG group was 0.961 (95% CI 0.528–1.634).

Discussion

This single-center PSM study evaluated the impact of the robotic approach for the treatment of gastric cancer, by comparing the surgical outcomes of robotic gastrectomy with

Table 1 Characteristics of all and propensity score-matched patients

	All			Propensity score-matched		
	LG (*n* = 979)	RG (*n* = 210)	*p* value	LG (*n* = 210)	RG (*n* = 210)	*p* value
Age, years, mean ± SE	66.4 ± 0.4	66.0 ± 0.8	0.629	65.5 ± 0.8	66.0 ± 0.8	0.671
Sex, male/female, (*n*)	627/352	152/58	0.021	153/57	152/58	0.913
BMI, kg/m2, mean ± SE	22.5 ± 0.1	22.8 ± 0.2	0.292	22.7 ± 0.2	22.8 ± 0.2	0.906
Hb	13.2 ± 0.06	13.4 ± 0.1	0.174	13.3 ± 0.1	13.4 ± 0.1	0.771
Alb	4.1 ± 0.01	4.2 ± 0.03	0.075	4.2 ± 0.03	4.2 ± 0.03	0.838
ASA physical status, *n*			0.976			0.754
1	117	24		23	24	
2	775	167		172	167	
3	87	19		15	19	
Primary lesion, *n*			0.465			0.560
Upper	313	49		54	49	
Middle	434	102		91	102	
Lower	232	59		65	59	
EGJ cancer, *n*			0.634			0.524
No	878	186		190	186	
Yes	101	24		20	24	
Siewert type I/II/III	3/69/29	4/14/6		0/17/3	4/14/6	
Maximum tumor size (mm)						
Mean ± SD	44.8 ± 1.0	48.7 ± 2.2	0.105	49.5 ± 2.3	48.6 ± 2.3	0.790
Neoadjuvant chemotherapy			0.189			1.000
Yes	48	15		15	15	
No	931	195		195	195	
Type of operation, (*n*)			0.981			0.757
Distal gastrectomy	660	143		138	143	
Proximal gastrectomy	142	30		29	30	
Total gastrectomy	177	37		43	37	
Extent of lymphadenectomy			< 0.0001			0.716
D1	432	44		41	44	
D2	547	166		169	166	
Skilled surgeon			< 0.0001			0.411
Y.F	203	18		23	18	
T.O	776	192		187	192	
Clinical T status, (*n*)			< 0.0001			0.668
T1 (T1a/T1b)	627 (111/516)	91 (23/68)		90 (20/70)	91 (23/68)	
T2	146	33		30	33	
T3	124	49		56	49	
T4a	76	37		32	37	
T4b	6	0		2	0	
Clinical N status, (*n*)			< 0.0001			0.756
cN0	793	139		142	139	
cN + (N1/N2/N3)	185 (128/50/8)	71 (53/15/3)		68 (43/21/4)	71 (53/15/3)	
Clinical stage, (*n*)			< 0.0001			0.975
I	713	110		110	110	
IIA/IIB	133 (60/77)	50 (13/27)		40 (10/30)	50 (13/27)	
III	105	52		50	52	
IVA/IVB	2/2	1/7		1/9	1/7	
Pathological T status, (*n*)			0.0002			0.908
pT1	595 (235/360)	97 (38/59)		94 (36/57)	97 (38/59)	

Table 1 (continued)

	All			Propensity score-matched		
	LG ($n=979$)	RG ($n=210$)	p value	LG ($n=210$)	RG ($n=210$)	p value
pT2	121	26		26	26	
pT3	149	39		47	39	
pT4 (T4a/T4b)	114 (107/7)	48 (44/4)		44 (42/4)	48 (44/4)	
Pathological N status, (*n*)			0.249	108	123	0.606
pN0	662	123		108	123	
pN1	130	27		34	27	
pN2	99	27		34	27	
pN3 (N3a/N3b)	88 (50/38)	33 (18/15)		34 (20/14)	33 (18/15)	
Pathological stage, (*n*)			0.002			0.247
I (IA/IB)	635 (513/122)	103 (84/19)		99 (75/24)	103 (84/19)	
II (IIA/IIB)	166 (100/66)	53 (27/26)		39 (24/15)	53 (27/26)	
III (IIIA/IIIB/IIIC)	140 (54/38/38)	37 (12/11/14)		56 (24/13/19)	37 (12/11/14)	
IV	48	17		15	17	
Lymphatic invasion						
−/+	695/284	144/66	0.485	129/81	144/66	0.125
Vascular invasion						
−/+	661/318	112/98	< 0.0001	115/95	112/98	0.769
Curability						
R0/R1	933/46	197/13	0.366	199/11	197/13	0.674
Lauren classification (*n*)			0.704			0.903
Intestinal	537	110		110	110	
Diffuse	429	98		97	98	
Indeterminate	13	2		2	2	

Tumor–Node–Metastasis staging was performed according to the Japanese classification of gastric carcinoma (third English edition) [22]

Alb albumin, *ASA* American Society of Anesthesiologists, *BMI* body mass index, *EGJ* esophagogastric junction, *Hb* hemoglobin, *LG* laparoscopic gastrectomy, *RG* robotic gastrectomy, *SD* standard deviation, *SE* standard error

those of conventional laparoscopic gastrectomy. The primary aim of this study was to demonstrate the efficacy of robotic gastrectomy in reducing postoperative complications. The results clearly showed that robotic gastrectomy had a significantly lower incidence of postoperative complications than laparoscopic gastrectomy. Furthermore, our results showed that robotic gastrectomy was associated with a shorter operative time, less blood loss, and a shorter postoperative hospital stay than laparoscopic gastrectomy, with acceptable long-term oncologic outcomes. Thus, robotic gastrectomy can be an effective alternative for the treatment of gastric cancer.

In a randomized controlled trial of robotic vs. laparoscopic gastrectomy [19], and in a multicenter prospective comparative study by Kim et al. [20], robotic gastrectomy resulted in a longer operative time, comparable morbidity, and higher medical costs than those of laparoscopic gastrectomy. Therefore, it was concluded that robotic gastrectomy was safe and feasible, but not superior to laparoscopic gastrectomy. The authors suggested that laparoscopic surgery can be made sufficiently safe and feasible by standardizing the procedure. Consequently, there is no room for improvement by using a robotic approach. A recent randomized controlled trial [29] showed that robotic distal gastrectomy was associated with lower morbidity, faster recovery, a milder inflammatory response, and improved lymph node resection compared to laparoscopic distal gastrectomy. However, several meta-analyses indicated that robotic gastrectomy was comparable to laparoscopic gastrectomy in terms of surgical outcomes, but at higher medical cost and longer operative time [30, 31]. This study showed that robotic gastrectomy had excellent surgical outcomes, including a shorter operative time [RG: 208 (148–286) min vs. LG: 231 (191–223) min, $p=0.0051$], less blood loss, lower postoperative morbidity (RG: 4.8% vs. LG: 12.9%, $p=0.0034$), and fewer intra-abdominal infection-related complications (RG = 0.48%) or severe complications (Clavien–Dindo grade III or higher) (RG = 0.95%) compared to laparoscopic gastrectomy. Furthermore, there was no mortality or severe intra-abdominal complications in robotic gastrectomy. These results were comparable to or better than those of prospective trials (postoperative complication rate, 9.6–14.2%; intra-abdominal infection rate, 2.6–3.3%; serious complication

Table 2 Surgical outcomes of all and propensity score-matched patients

	All			Propensity score-matched		
	LG (*n* = 979)	RG (*n* = 210)	*p* value	LG (*n* = 210)	RG (*n* = 210)	*p* value
Operative time, min[a]	223 [181–273]	208 [148–286]	0.0383	231 [191–223]	208 [148–286]	0.0051
Estimated blood loss, mL, mean ± SD	33.2 ± 2.7	13.4 ± 5.8	< 0.001	42.1 ± 4.7	13.4 ± 4.7	< 0.001
Number of lymph nodes retrieved, (*n*)	44.3 ± 0.6	44.5 ± 1.2	0.8961	45.8 ± 1.1	44.5 ± 1.1	0.419
Complication, *n* (%)	86 (8.78)	10 (4.76)	0.052	27 (12.86)	1 (4.76)	0.0034
Grade I						
Wound infection	4	0		1	0	
Pancreatic fistula	4	0		1	0	
Ileus	1	0		0	0	
Bleeding	1	1		0	1	
Grade II or higher	76 (7.9)	9 (4.29)	0.759	25 (11.90)	9 (4.29)	0.0042
Grade II	48	7		15	7	
Wound infection	3	2		1	2	
Intra-abdominal fluid accumulation	1	1		0	1	
Anastomotic leakage	5	1		2	1	
Anastomotic structure	2	0		2	0	
Pancreatic fistula	9	0		4	0	
Ileus	1	0		1	0	
Delayed gastric emptying	9	1		0	2	
Pulmonary infection	9	0		3	0	
Bleeding	1	0		1	0	
Others	4	2		2	2	
Grade III or higher	28 (2.86)	2 (0.95)	0.110	10 (4.76)	2 (0.95)	0.0066
Wound infection	2	0		0	0	
Anastomotic leakage	10	0		4	0	
Pancreatic fistula	1	0		1	0	
Intra-abdominal fluid accumulation	4	0		3	0	
Ileus	4	0		4	0	
Pulmonary infection	3	0		1	0	
Bleeding	6	0		2	0	
Pleural effusion	0	1		0	1	
Cerebral infarction	0	1		0	1	
Intra-abdominal infection						
Grade II or higher	27 (1.76)	1 (0.48)	0.0479	11 (5.24)	1(0.48)	0.0034
Postoperative hospital stay, days[a]	8 [7–10]	7 [6–8]	< 0.0001	8 [7–10]	7 [6–8]	0.0002
Postoperative mortality, (*n*)	1	0		1	0	–
White blood cell count, $\times 10^3/\mu L$[a]						
POD1	9.3 [7.8–11.4]	8.9 [7.2–11.4]	0.1657	9.4 [7.8–11.7]	8.9 [7.2–11.4]	0.1233
POD3	7.6 [6.3–9.5]	7.6 [6.3–9.4]	0.980	7.5 [6.5–10.5]	7.6 [6.3–9.4]	0.3229
C-reactive protein, mg/dL[a]						
POD1	3.7 [2.3–5.9]	5.0 [3.4–6.9]	< 0.0001	3.9 [2.4–6.1]	5.0 [3.4–6.9]	0.0008
POD3	9.9 [5.5–14.5]	10.1 [6.0–16.1]	0.406	11.2 [7.0–16.7]	10.1 [6.0–16.1]	0.2391

LG laparoscopic gastrectomy, *POD* postoperative day, *RG* robotic gastrectomy, *SD* standard deviation

[a]Data are shown as median [interquartile range]

rate [Clavien–Dindo grade III or higher], 1.0–8.9%) [20, 32–37].

Robotic gastrectomy has been reported in a randomized control trial [29] to be associated with a reduced inflammatory response and a lower incidence of complications than laparoscopic gastrectomy. The inflammatory response, however, remains controversial, as it has also been reported that robotic gastrectomy is associated with the same

Table 3 Postoperative inflammatory reaction and drain amylase levels in the propensity-matched cohort

	LG ($n=210$)	RG ($n=210$)	p value
Drain amylase, U/L			
POD1	438 [225–860]	297 [166–522]	< 0.0001
POD3	159 [103–302]	119 [72–204]	< 0.0001
Drain amylase at POD1, n (%)			
≥ 500 U/L	87 (42)	53 (26)	0.0008
≥ 1000 U/L	40 (19)	14 (7)	0.0002
≥ 2000 U/L	16 (8)	2 (1)	0.0009

LG laparoscopic gastrectomy, *POD* postoperative day, *RG* robotic gastrectomy

[a]Data are shown as median [interquartile range]

inflammatory response as laparoscopic gastrectomy, despite less damage to the pancreas [38]. In this study, the relatively low incidence of intra-abdominal infections (5.24% in the LG group vs. 0.48% in the RG group) suggests that there was no significant difference in the inflammatory response between the two groups. Further large-scale randomized controlled trials are warranted.

In patients with EGJ cancer, the incidence of anastomotic leakage is reported to be relatively high (11.9%), due to difficulties in performing reconstruction procedures in the inferior mediastinum [39]. In this study, anastomotic leakage occurred in two (12.5%) patients with EGJ cancer in the LG group, which was comparable to the previous study. Conversely, there were no reports of anastomotic leakage in the RG group. A robotic approach may facilitate transhiatal reconstruction and reduce anastomotic leakage in patients with EGJ cancer.

Complications of intra-abdominal infection, such as pancreatitis, pancreatic fistula, and intra-abdominal fluid accumulation, have been reported to be associated with intraoperative pancreatic injury, due to thermal damage from energy devices and pancreatic compression [14, 33, 34, 40, 41]. Robotic gastrectomy can reduce pancreatic damage [29, 32, 42]. Laparoscopic gastrectomy was an independent risk factor for postoperative complications in multivariate analysis (OR 2.01, 95% CI 1.02–3.96; $p=0.042$). In this study, drain amylase levels on postoperative Days 1 and 3 were lower in the RG group than in the LG group, and no pancreatitis or pancreatic fistula was observed in the RG group. Robotic gastrectomy using our non-touch pancreas method, which combines the SPIDER and MBS techniques, may be effective in reducing pancreatic damage.

In a multicenter prospective study, robotic gastrectomy had a longer operative time than laparoscopic gastrectomy (221 min vs. 178 min, respectively; $p<0.001$) [20]. Similarly, other retrospective studies and meta-analyses have reported longer operative times (221–381 min) for robotic gastrectomy than for laparoscopic gastrectomy (171–360 min) [31–34]. The reason for the longer operative time in robotic surgery is that while the effective time, comprising gastric mobilization and lymphadenectomy, remains the same, the "junk" time, comprising setup, docking, and instrument exchange, is longer than in laparoscopic gastrectomy [43]. These additional robot-specific procedures can be shortened with training. In fact, surgical times for robotic and laparoscopic procedures performed by experienced surgeons have been reported to be comparable [44]. In this study, the operative time was significantly shorter in robotic gastrectomy than in laparoscopic gastrectomy. We developed a modified technique to streamline the robotic gastrectomy procedure. First, we reduced the robotic-specific procedure time. By standardizing the setup of the robot, the docking time was reduced to approximately 1 min (data not shown), and the equipment replacement time was also reduced. Second, we improved the surgical method by using the MBS technique, which prevents the forceps from touching the pancreas and reduces thermal damage to the organ during suprapancreatic lymph node resection. This ensures a fast and safe operation, minimizes bleeding with reliable hemostasis, and reduces both the frequency of instrument changes and the operative time. Finally, anchoring the pancreas to the retroperitoneum using the SPIDER technique effectively reduces the operative time, because a stable surgical field can be obtained without traction of the pancreas with forceps. The median operative time for robotic distal gastrectomy was 140 [122–167] min (data not shown).

This study has several limitations that should be considered when interpreting the data. First, although patient characteristics were well-matched by PSM, confounding factors may have remained, because of the different historical backgrounds, surgeons, and technical aspects, including the SPIDER technique, of the two groups. Second, because of the short follow-up period, we were unable to clearly assess the long-term outcomes. We plan to evaluate the long-term outcomes of this cohort once the follow-up period reaches 5 years. Finally, because of the retrospective nature of this study and small sample size, further evaluation of long-term outcomes and randomized controlled trials are needed to establish the feasibility of a robotic approach.

In conclusion, the results of this study indicate that robotic gastrectomy is a safe and feasible treatment option for gastric cancer, with better short-term surgical outcomes, including a shorter operative time, less blood loss, and lower postoperative morbidity, than laparoscopic gastrectomy. The application of robotics for minimally invasive gastric cancer surgery could be a potential alternative to conventional surgery. Multicenter, prospective, randomized controlled trials

Table 4 Risk factors for overall postoperative complications

		Univariate analysis			Multivariate analysis		
	n	OR	95% CI	*p* value	OR	95% CI	*p* value
Sex							
Male	779	1.74	1.07–2.83	0.025	0.38	0.15–1.04	0.060
Female	410						
Age							
$\geq$70 years	522	1.43	0.94–2.17	0.093	1.09	0.54–2.21	0.812
$<$70 years	667						
BMI							
$\geq$25 kg/m^2	233	1.14	0.66–1.97	0.620	–	–	–
$<$25 kg/m^2	956						
ASA							
2/3	1048	0.93	0.50–1.76	0.840	–	–	–
1	141						
PNI							
$<$45	31	1.72	0.58–5.01	0.320	–	–	–
$\geq$45	1158						
Preoperative chemotherapy							
Yes	63	1.46	0.64–3.3	0.370	–	–	–
No	1126						
Surgical approach							
LG	979	1.93	0.98–3.77	0.056	3.14	1.46–6.74	0.003
RG	210						
Surgical procedure							
TG	214	1.40	0.85–2.30	0.190	–	–	–
Non-TG	975						
Lymphadenectomy							
D2	476	0.81	0.53–1.23	0.320	–	–	–
D1	713						
EGJ cancer, (*n*)							
Yes	125	2.66	1.13–6.25	0.025	2.84	1.17–6.87	0.021
No	1064						
Skilled surgeon							
Y.F	213	1.14	0.68–1.93	0.620	–	–	–
T.O	976						
First surgeon							
Non-qualified	410	0.90	0.58–1.40	0.640	–	–	–
Qualified	779						

ASA American society of anesthesiologists, *BMI* body mass index, *CI* confidence interval, *EGJ* esophagogastric junction, *LG* laparoscopic gastrectomy, *OR* odds ratio, *POD* postoperative day, *PNI* prognostic nutritional index, *RG* robotic gastrectomy, *TG* total gastrectomy

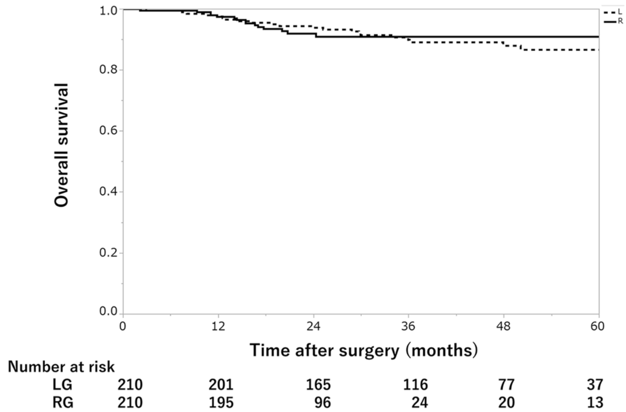

Fig. 3 Cumulative survival curves for patients undergoing laparoscopic and robotic gastrectomy after propensity score matching. The 5-year overall survival rate did not differ significantly between the LG and RG groups (86.6% vs. 91.0%, respectively; log-rank $p = 0.87$). *LG* laparoscopic gastrectomy, *RG* robotic gastrectomy

comparing robotic gastrectomy with conventional laparoscopic gastrectomy are still needed to establish the feasibility and efficacy of this minimally invasive approach.

Declarations

Disclosures Drs. Takeshi Omori, Kazuyoshi Yamamoto, Hisashi Hara, Naoki Shinno, Masaaki Yamamoto, Kouhei Fujita, Takashi Kanemura, Tomohira Takeoka, Hirofui Akita, Hiroshi Wada, Masayoshi Yasui, Chu Matsuda, Junichi Nishimura, Yoshiyuki Fujiwara, Hiroshi Miyata, Masayuki Ohue, and Masato Sakon have no conflicts of interest or financial ties to disclose.

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