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ORIGINAL ARTICLE

Short-Term Clinical Outcomes After Laparoscopic and Robotic Gastrectomy for Gastric Cancer: a Propensity Score Matching Analysis

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Abstract

Background The different advantages of laparoscopic gastrectomy (LG) and robotic gastrectomy (RG), two new minimally invasive surgical techniques for gastric cancer, remain controversial.

Purpose To compare the short-term clinical outcomes of LG and RG.

Methods A retrospective, single-center comparative study of 1044 patients (LG = 750, RG = 294) was conducted. Patients undergoing LG and RG were matched (2:1 ratio) according to sex, age, BMI, extent of gastric resection, and pathologic stage. The primary outcomes were morbidity and mortality and perioperative recovery parameters; major types of complications were also analyzed.

Results After matching, 798 patients (LG = 532, RG = 266) were included. Both the LG and RG groups showed similar overall complication rates (LG = 12.8% vs RG = 12.4%) and operative mortality (LG = 0.4% vs RG = 0.4%). Compared to those who underwent LG, patients undergoing RG had significantly longer operative times (236.92 ± 57.28 vs 217.77 ± 65.00 min, $p < 0.001$), higher total costs (US$16,241.42 vs US$12,497, $p < 0.001$), less operative blood loss (77.07 ± 64.37 vs 103.68 ± 86.92 ml, $p < 0.001$), higher numbers of retrieved lymph nodes (32.0 vs 29.9, $p < 0.001$), and higher rates of retrieving more than 16 lymph nodes (94.0 vs 85.5%; $p < 0.001$). No significant differences between groups were noted in terms of the rate of reoperation, time until a soft diet was consumed, or length of hospital stay. The major complication and readmission rates were similar in both groups.

Conclusion RG and LG produced similar short-term clinical outcomes, indicating that RG is a safe and beneficial surgical procedure.

Keywords Short-term clinical outcomes · Laparoscopic gastrectomy · Robotic gastrectomy · Gastric cancer

Short-term outcomes after laparoscopic and robotic gastrectomy for gastric cancer

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Background

Gastric cancer is the fifth most prevalent type of malignancy and the third leading cause of cancer-related deaths worldwide[1]; gastric cancer has high incidence and mortality rates in China.[2] Surgical resection remains the only curative treatment option for gastric cancer. Since laparoscopic gastrectomy (LG) was first introduced in 1994,[3] it has become widely accepted for the treatment of gastric cancer because of its advantages, including less invasiveness and pain, better cosmetic results, faster recovery, and shorter hospital stays over open gastrectomy.[4,5] However, technical difficulties and the steep learning curve associated with performing LG have hindered the wider application of the procedure in clinical practice.[6] LG has also shown significant advantages over open gastrectomy in terms of better short-term outcomes with comparable long-term results.[7,8]

To overcome these limitations, surgeons have adopted robotic surgical techniques for gastric cancer surgery, expecting that this will produce better operative performance and surgical outcomes. Comparative studies investigating LG and robotic gastrectomy (RG) have been reported,[9–13] but these were not randomized controlled trials. Therefore, whether RG is comparable or superior to LG remains controversial. Many studies have been reported in Japan and Korea, while few studies have been published in China.

Therefore, to evaluate the safety and feasibility of RG, we compared the surgical outcomes of patients undergoing RG with those undergoing LG during the same period. The aim of this study was to evaluate the surgical outcomes and safety of RG compared to LG.

Materials and Methods

Patients

This single-institution, retrospective study investigated 1196 patients with gastric tumors who underwent minimally invasive gastrectomy from October 2014 to December 2017 in the Affiliated Hospital of Qingdao University. Patients were excluded if they were received neoadjuvant chemotherapy or radiation therapy. One hundred and twenty-four patients were excluded because of gastric stump cancer ($n = 8$), palliative surgery ($n = 82$), non-adenocarcinoma ($n = 31$) or thoracoabdominal surgery ($n = 3$). After these exclusions, 1072 patients were finally enrolled in this study (Fig. 1). Of these patients, 28 (LG = 26, RG = 2) were excluded due to laparoscopic exploration. To reduce the selection bias, the propensity score matching module in SPSS 22.0 was used to match (2:1 ratio, LG to RG) the patients based on age, sex, BMI, resection extent of the stomach, depth of invasion, nodal involvement, and pathologic stage. Ultimately, 532 patients who underwent laparoscopic surgery and 266 patients who underwent RG were enrolled and analyzed after being matched.

The preoperative staging workup was performed by gastroduodenoscopy or endoscopic ultrasonography and computed tomography. Advanced gastric cancer (AGC) was defined as stage cT2-4aN0-3M0 at the preoperative evaluation, according to the AJCC Cancer Staging Manual, 7th Edition, with expected curative resection via gastrectomy with D2 lymphadenectomy. Patients with advanced gastric cancer were recommended to undergo open surgery. Minimally invasive surgery (LG or RG) was recommended only for early-stage gastric cancer patients. Patients chose the type of operation after receiving an adequate comprehensive explanation of the surgical procedures for all types of gastrectomy. All patients provided informed consent for surgery, including agreeing to the extra costs associated with robotic surgery.

Surgery

Both the resection extent (total, distal subtotal or proximal gastrectomy) and the lymph node dissection extent (D2 or D2+) were determined according to the treatment guidelines of the Japanese Gastric Cancer Association.[14] The da Vinci Surgical System (Intuitive Surgical Inc., Sunnyvale, CA) was used for all RGs. Stage classification was determined according to the 7th American Joint Committee on Cancer/Union for International Cancer Control (AJCC/UICC) staging system.[15] All the surgeons performing RG and LG had performed more

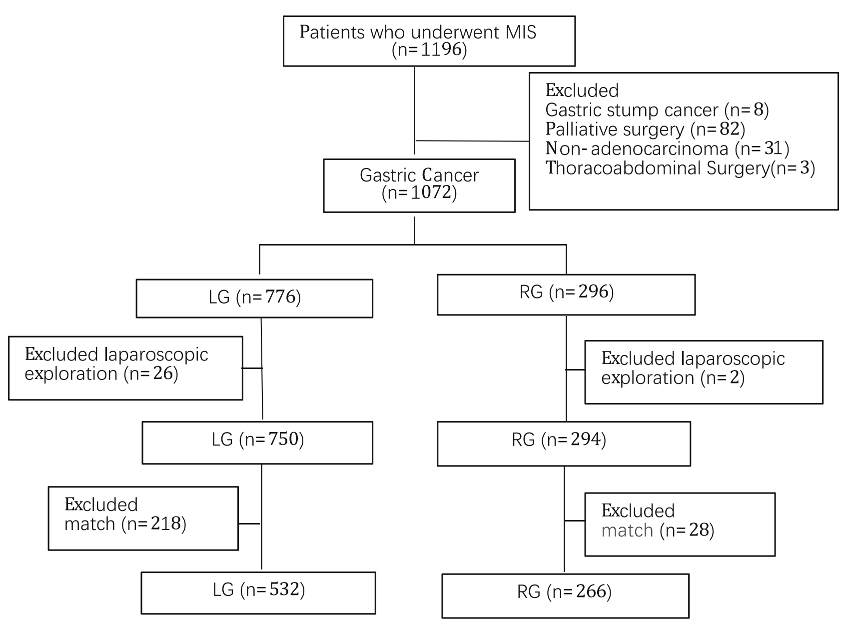

Fig. 1 Flow diagram of the study selection process. (MIS minimally invasive surgery, RG robotic gastrectomy, LG laparoscopic gastrectomy)

than 100 open gastrectomies and 50 LGs. Surgical procedures were performed in a similar manner in our institution. Extracorporeal anastomosis using a mini laparotomy was recommended in both robotic and laparoscopic surgery. The reconstruction type and method were selected on the basis of the surgeon's experience and preference.

Outcomes

The primary outcomes were postoperative morbidity and mortality. The secondary outcomes were the surgical outcomes including the operative time, estimated blood loss, total number of harvested lymph nodes, adequate number of lymph nodes harvested for staging (considered to be 16 nodes or more according to the latest TNM staging system),[16] rate of conversion to open gastrectomy, reoperation in-hospital, readmission (defined as admission within 30 days of discharge), length of postoperative hospital stay, and financial cost. Intraoperative complications (defined as bleeding due to named vessel injury or injury to visceral organs) and postoperative bleeding (defined as intra-abdominal bleeding, intraluminal bleeding or other condition requiring blood transfusions or surgical or radiologic intervention) were also analyzed.

The frequency and severity of complications were reviewed according to the Clavien-Dindo classification of surgical complications.[17] If a patient had more than one type of complication, the highest grade complication was recorded for analysis.

Statistical Analysis

PS Matching 3.04 in SPSS 22.0 and R Software for Windows 2.15.3 with a caliper = 0.2 were used to match the patients. IBM SPSS 22.0 was used to perform the statistical analysis. Comparisons between the two groups were performed by Student's t test for continuous variables and the chi-square test or Fisher's exact test for categorical variables. All statistical tests were two-sided, and p values less than 0.05 were considered significant.

Results

Patient Characteristics

Age, sex, BMI, grade of BMI, medical comorbidities, ASA classification, tumor size, tumor location, and TNM stage based on the 7th version of the pathologic classification guidelines of the UICC are summarized in Table 1. Except for in BMI, no significant differences were found between the two groups in any of the above variables. After matching, the baseline clinicopathologic characteristics of the patients were similar.

Surgical Outcomes after Matching

Table 2 provides the details of the surgical and postoperative outcomes. No differences were observed between the groups in terms of the year of surgery, resection extent, type of reconstruction, or lymphadenectomy extent. Both the mean numbers of retrieved lymph nodes and the rates of adequate retrieval of lymph nodes (≥ 16) were significantly higher in the RG group than in the LG group (31.98 ± 12.81 vs 29.87 ± 13.48; 93.4 vs 85.2%, both $p < 0.001$). The mean estimated blood loss differed significantly between the RG and LG groups (103.68 ± 86.92 vs 77.07 ± 64.37 ml, $p < 0.001$). The median operative time was significantly longer in the RG group than in the LG group (236.92 ± 57.28 vs 217.77 ± 65.00 min, $p < 0.001$).

With respect to the operative parameters, before matching, similar conversation rates were observed in both groups, but the results differed after matching. Three conversions to open surgery (1.1%) occurred in the RG group, two due to advanced tumor classification, and one due to a technical difficulty. However, 15 patients were converted to open surgery (2.8%) in the LG group; the causes were as follows: advanced tumor classification or very large tumor ($n = 6$), technical difficulty ($n = 3$), abdominal adhesions ($n = 2$), and uncontrolled bleeding ($n = 4$).

Combined resections were performed on 28 patients in the LG group and on 23 patients in the RG group (5.3 vs 8.6%, $p = 0.065$). The resected organs or tissues included the gallbladder (LG = 9 vs RG = 11), spleen and/or distal pancreas (LG = 2 vs RG = 1), partial transverse colon or mesentery (LG = 9 vs RG = 7), partial pancreas (LG = 3 vs RG = 0), partial liver (LG = 2 vs RG = 2), and other (LG = 3 vs RG = 2).

Intraoperative complications occurred in 3 patients (0.85%) in the RG group, with bleeding in 2 patients and spleen injury in 1 patient, and in 19 patients (3.6%) in the LG group, with vessel injury in 7 patients, spleen injury in 8 patients, transverse colon mesentery injury in 2 patients, and liver injury in 2 patients. The rates of intraoperative complications were significantly different between groups ($p = 0.047$) after matching.

The median duration of the postoperative hospital stay was similar between groups (LG = 10.35 ± 8.66 days vs RG = 9.53 ± 6.28 days, $p = 0.168$). The time of first flatus, number of days before consuming a soft diet, and duration of postoperative stay were similar between the LG and RG groups (all > 0.05). The hospital costs for the RG group were higher than those for the LG group (US$16,241.42 vs US$12,497, $p < 0.001$).

Postoperative Complications and Mortality after Matching

As shown in Table 3, 68 complications (12.8%) occurred in the LG group, and 33 complications (12.4%) occurred

Table 1 Baseline clinicopathologic characteristics of patients

Patient characteristics	Entire cohort			Matched cohort		
	LG $n = 750$	RG $n = 294$	$p^{\dagger}$	LG $n = 532$	RG $n = 266$	$p^{\dagger}$
Sex—no. (%)			0.228			0.537
Male	536 (71.5)	221 (75.2)		383 (72.0)	1197 (74.1)	
Female	214 (28.5)	73 (24.8)		149 (28.0)	69 (25.9)	
Age—year	59.10 ± 10.20	58.57 ± 10.51	0.452	58.92 ± 9.82	58.68 ± 10.54	0.749
BMI (kg/m^2)	24.00 ± 3.42	24.59 ± 3.33	0.012	24.25 ± 3.34	24.23 ± 3.06	0.941
Grade of BMI—no. (%)			0.005			0.645
< 22	219 (29.2)	66 (22.4)		145 (27.3)	65 (24.4)	
22–24.9	261 (34.8)	91 (31.0)		172 (32.3)	86 (32.3)	
≥ 25	270 (36.0)	137 (46.6)		215 (40.4)	115 (43.2)	
Comorbidity—no. (%)						
Diabetes mellitus	77 (10.3)	38 (12.9)	0.217	59 (11.1)	35 (13.2)	0.393
Emphysema or COPD	30 (4.0)	10 (3.4)	0.650	19 (3.6)	9 (3.4)	0.892
Hypertension	112 (14.9)	49 (16.7)	0.485	81 (15.2)	41 (15.4)	0.945
Coronary heart disease	51 (6.8)	17 (5.8)	0.549	42 (7.9)	14 (5.3)	0.170
Liver disease	20 (2.7)	11 (3.7)	0.357	11 (2.1)	10 (3.8)	0.159
History of abdominal surgery	35 (4.7)	18 (6.1)	0.335	29 (5.5)	16 (6.0)	0.745
ASA Classification—no. (%)			0.443			0.816
I	8 (1.1)	6 (2.0)		7 (1.3)	5 (1.9)	
II	515 (68.7)	203 (69.0)		373 (70.1)	184 (69.2)	
III	227 (30.3)	85 (28.9)		152 (28.6)	77 (28.9)	
Tumor size (mm)	42.65 ± 27.89	40.84 ± 22.85	0.323	41.35 ± 27.48	41.15 ± 23.27	0.918
Location			0.345			0.222
U	95 (12.7)	29 (9.9)		57 (10.7)	29 (10.9)	
M	146 (19.5)	65 (22.1)		97 (18.2)	62 (23.3)	
D	509 (67.9)	200 (68.0)		378 (71.1)	175 (65.8)	
Tumor stage			0.432			0.986
0	5 (0.7)	2 (0.7)		5 (0.9)	2 (0.8)	
I	197 (26.3)	77 (26.2)		149 (28.0)	70 (26.3)	
II	111 (14.8)	40 (13.6)		76 (14.3)	39 (14.7)	
III	325 (43.3)	117 (39.8)		215 (40.4)	111 (41.7)	
IV	112 (14.9)	58 (19.7)		87 (16.4)	44 (16.5)	
Nodal stage			0.983			0.973
0	317 (42.3)	127 (43.2)		235 (44.2)	118 (44.4)	
I	130 (17.3)	49 (16.7)		86 (16.2)	46 (17.3)	
II	114 (15.2)	46 (15.6)		80 (15.0)	38 (14.3)	
III	189 (25.2)	72 (24.5)		131 (24.6)	64 (24.1)	
AJCC pTNM stage			0.818			0.968
0	5 (0.7)	2 (0.7)		5 (0.9)	2 (0.8)	
I	245 (32.7)	90 (30.6)		176 (33.1)	86 (32.3)	
II	208 (27.7)	90 (30.6)		150 (28.2)	79 (29.7)	
III	292 (38.9)	112 (38.1)		201 (37.8)	99 (37.2)	
Histologic grade			0.646			0.617
G1	17 (2.3)	7 (2.4)		13 (2.4)	6 (2.3)	
G2	144 (19.2)	56 (19.0)		108 (20.3)	48 (18.0)	
G3	583 (77.7)	226 (76.9)		406 (76.3)	207 (77.8)	
GX	6 (0.8)	5 (1.7)		5 (1.0)	5 (1.9)	

BMI body mass index (kg/m^2), *ASA* American Society of Anesthesiologists, *COPD* chronic obstructive pulmonary disease, *AJCC* American Joint Committee on Cancer

† Chi-square test or Fisher's exact test

in the RG group; the incidences of postoperative complications were not significantly different between the two groups ($p = 0.880$). No differences were found regarding the Clavien-Dindo types of complications ($p = 0.111$). Regarding postoperative mortality, two (0.4%) and one (0.4%) in-hospital deaths were recorded in the LG and RG groups, respectively. The two patients in the LG group died of intra-abdominal bleeding and septic shock followed by anastomotic leakage, separately, while the patent in the RG group died due to intraluminal bleeding. The rates of readmission within 30 days of discharge (LG = 23, 4.3% vs RG = 14, 5.3%; $p = 0.552$) were also not significantly different between the two groups. Regarding patient deaths outside of the hospital, one patient in the LG group died of intraluminal bleeding, while no patients in the RG group died. Major complications

Table 2 Surgical and postoperative clinical outcomes

Characteristic	Entire cohort			Matched cohort		
	LG $n = 750$	RG $n = 294$	$p^{\dagger}$	LG $n = 532$	RG $n = 266$	$p^{\dagger}$
Year of surgery			0.132			0.093
2014	22 (2.9)	15 (5.1)		16 (3.0)	15 (5.6)	
2015	204 (27.2)	93 (31.3)		145 (27.3)	81 (30.5)	
2016	243 (32.4)	82 (27.9)		180 (33.8)	72 (27.1)	
2017	281 (37.5)	105 (35.7		191 (35.9)	98 (36.8)	
Resection extent			0.296			0.661
Proximal	12 (1.6)	2 (0.7)		5 (0.9)	2 (0.8)	
Distal	543 (72.4)	224 (76.2)		196 (73.7)	406 (76.3)	
Total	195 (26.0)	68 (23.1)		121 (22.7)	68 (25.6)	
Reconstruction			0.128			0.366
BI	8 (1.1)	2 (0.7)		7 (1.3)	2 (0.8)	
BII	10 (1.3)	0 (0)		6 (1.1)	0 (0)	
Roux-en-Y (GJ)	525 (70.0)	221 (75.2)		392 (73.7)	193 (72.6)	
Roux-en-Y (EJ)	194 (25.9)	69 (23.5)		122 (22.9)	69 (25.9)	
Other	13 (1.7)	2 (0.7)		5 (0.9)	2 (0.8)	
Lymphadenectomy			0.229			0.261
D2	740 (98.7)	287 (97.6)		527 (99.1)	261 (98.1)	
D2+	10 (1.3)	7 (2.4)		5 (0.9)	5 (1.9)	
Combined resection	42 (5.5)	25 (8.5)	0.070	28 (5.3)	23 (8.6)	0.065
Gallbladder	13 (1.7)	11 (3.7)		9 (1.7)	11 (4.1)	
Spleen and/or distal pancreas	5 (0.7)	1 (0.3)		2 (0.4)	1 (0.4)	
Partial transverse colon or mesentery	10 (1.3)	7 (2.4)		9 (1.7)	7 (2.6)	
Partial pancreas	3 (0.4)	1 (0.3)		3 (0.6)	0 (0)	
Partial liver	4 (0.5)	3 (1.0)		2 (0.4)	2 (0.8)	
Other	6 (0.8)	2 (0.7)		3 (0.6)	2 (0.8)	
Macroscopic Borrmann type			0.907			0.859
I	15 (2.0)	6 (2.0)		9 (1.7)	6 (2.3)	
II	164 (21.9)	58 (19.7)		119 (22.4)	52 (19.5)	
III	381 (50.8)	159 (54.1)		266 (50.0)	141 (53.0)	
IV	19 (2.5)	7 (2.4)		14 (2.6)	7 (2.6)	
Open conversion	24 (3.2)	3 (1.0)	0.046	15 (2.8)	3 (1.1)	0.129
Tumor-related	11 (1.5)	2 (0.7)		6 (1.1)	2 (0.8)	
Technical difficulty	4 (0.5)	1 (0.3)		3 (0.6)	1 (0.4)	
Adhesions	3 (0.4)	0 (0)		2 (0.4)	0 (0)	
Uncontrolled bleeding	6 (0.8)	0 (0)		4 (0.8)	0 (0)	
Intraoperative complication			0.031			0.047
Yes	26 (3.5)	3 (1.0)		19 (3.6)	3 (1.1)	
No	724 (96.5)	291 (99.0)		513 (96.4)	263 (98.9)	
Intraoperative blood transfusion†† (*n*, %)	45 (6.0)	11 (3.7)	0.145	29 (5.5)	10 (3.8)	0.296
Total no. of lymph nodes	29.71 ± 13.65	31.57 ± 12.59	0.044	29.87 ± 13.48	31.98 ± 12.81	0.035
No. of metastatic lymph nodes	4.76 ± 8.19	4.80 ± 7.86	0.941	4.76 ± 8.61	4.72 ± 7.90	0.957
Adequate lymph node retrieval (≥ 16)	637 (84.9)	277 (94.2)	< 0.001	455 (85.5)	250 (94.0)	< 0.001
Operative time (min)	219.43 ± 64.08	238.16 ± 57.64	< 0.001	217.77 ± 65.00	236.92 ± 57.28	< 0.001
Blood loss (ml)	105.67 ± 100.47	77.01 ± 62.50	< 0.001	103.68 ± 86.92	77.07 ± 64.37	< 0.001
Postoperative clinical outcomes						
Duration of fever (days)	2.59 ± 2.65	2.36 ± 2.04	0.169	2.61 ± 2.69	2.30 ± 1.98	0.096
Bowel function recovery (days)	3.37 ± 1.35	3.36 ± 1.40	0.970	3.41 ± 1.40	3.36 ± 1.43	0.631
Soft diet (days)	5.03 ± 3.46	4.85 ± 2.78	0.429	5.11 ± 3.87	4.85 ± 2.90	0.338
Postoperative hospital stay (days)	10.18 ± 7.86	9.54 ± 6.09	0.207	10.35 ± 8.66	9.53 ± 6.29	0.168
Total cost (dollars)	12,456.18 ± 3676.19	16,237.15 ± 4631.38	< 0.001	12,497.71 ± 3806.39	16,241.42 ± 4812.63	< 0.001

LG laparoscopic gastrectomy group, *RG* robotic gastrectomy group

† Chi-square test or Fisher's exact test

†† Intraoperative blood transfusion but no organ injury recorded

(Clavien-Dindo category 3 or higher) in both groups were similar (LG = 22, 4.1% vs RG = 7, 2.6%; $p = 0.285$). The rate of postoperative bleeding was not significantly different between the two groups (LG = 14, 2.6% vs RG = 10, 3.8%; $p = 0.379$).

Discussion

Although RG exhibited longer operation times and higher hospital costs than LG in this study, RG offers benefits such as less blood loss, a greater number of retrieved lymph nodes,

Table 3 Postoperative complications *n* (%)

Type of complications	Entire cohort			Matched cohort		
	LG $n = 750$	RG $n = 294$	$p^{\dagger}$	LG $n = 532$	RG $n = 266$	$p^{\dagger}$
Total no. of complications	105 (14.0)	37 (12.6)	0.549	68 (12.8)	33 (12.4)	0.880
Wound infection	5 (0.7)	0 (0)		4 (0.8)	0 (0)	
Intra-abdominal infection	7 (0.9)	2 (0.7)		6 (1.1)	1 (0.4)	
Intra-abdominal bleeding	10 (1.3)	3 (1.0)		8 (1.5)	3 (1.1)	
Intraluminal bleeding	9 (1.2)	7 (2.4)		5 (0.9)	6 (2.3)	
Duodenal stump leakage	5 (0.7)	0 (0)		5 (0.9)	0 (0)	
Intestinal obstruction	4 (0.5)	2 (0.7)		2 (0.4)	2 (0.8)	
Delayed gastric emptying	4 (0.5)	0 (0)		3 (0.6)	0 (0)	
Anastomotic leakage or fistula	17 (2.3)	6 (2.0)		10 (1.9)	6 (2.3)	
Pancreatic leakage	2 (0.3)	1 (0.3)		1 (0.2)	0 (0)	
Thrombotic diseases	3 (0.4)	1 (0.3)		2 (0.4)	1 (0.4)	
Pleural effusion or infection	29 (3.9)	9 (3.1)		18 (3.4)	9 (3.4)	
Heart failure	0 (0)	2 (0.7)		0 (0)	2 (0.8)	
Others	10 (1.3)	4 (1.4)		4 (0.8)	3 (1.1)	
In-hospital mortality	2 (0.3)	1 (0.3)		2 (0.4)	1 (0.4)	
Clavien-Dindo classification—no. (%)			0.104			0.111
II	80 (10.7)	31 (10.5)		46 (8.6)	27 (10.2)	
IIIa	13 (1.7)	1 (0.3)		11 (2.6)	1 (0.4)	
IIIb	9 (1.2)	1 (0.3)		8 (1.5)	1 (0.4)	
IV	1 (0.1)	3 (1.0)		1 (0.2)	3 (1.1)	
V	2 (0.3)	1 (0.3)	1.000	2 (0.4)	1 (0.4)	
Out-of-hospital mortality	1 (0.1)	0 (0)	1.000	1 (0.2)	0 (0)	1.000
Subgroup						
Major complication*	25 (3.3)	7 (2.4)	0.422	22 (4.1)	7 (2.6)	0.285
Reoperation	10 (1.3)	3 (1.0)	0.682	9 (1.7)	3 (1.1)	0.537
Bleeding-related	7 (0.9)	2 (0.7)		7 (1.3)	2 (0.8)	
Anastomotic leakage	2 (0.3)	1 (0.3)		1 (0.2)	1 (0.4)	
Intestinal obstruction	1 (0.1)	0 (0)		1 (0.2)	0 (0)	
Postoperative bleeding	19 (2.5)	11 (3.7)	0.293	14 (2.6)	10 (3.8)	0.379
Transfusion only	10 (1.3)	8 (2.7)		6 (1.1)	7 (2.6)	
Radiologic intervention and transfusion	1 (0.1)	0 (0)		1 (0.2)	0 (0)	
Surgical intervention and transfusion	7 (0.9)	2 (0.7)		7 (1.3)	2 (0.8)	
Readmission	36 (4.8)	16 (5.4)	0.668	23 (4.3)	14 (5.3)	0.552

LG laparoscopic gastrectomy group, *RG* robotic gastrectomy group

† Chi-square test or Fisher's exact test

*Clavien-Dindo category 3 or higher

and higher rates of retrieving more than 16 lymph nodes, while also having postoperative complications and mortality rates that are similar to those after LG. The two groups also had similar rates of open conversion, postoperative bleeding, reoperation, and readmission. All the results of this study were satisfactory in terms of both the in-hospital surgical outcomes and out-of-hospital outcomes. The major technical advantages of the robot-assisted approach included an increased number of surgeries with adequate lymph node dissections and decreased blood loss.

Morbidity and mortality are currently widely accepted as the most relevant parameters to assess surgical safety. Other aspects of surgical outcomes, such as (1) the mean number of harvested lymph nodes and the rate of harvesting more than 16 lymph nodes,[18,16] (2) blood loss, (3) conversion to open surgery, (4) readmission after discharge,[19] and (5) length of hospital stay and financial cost, should also be included to evaluate the results of surgical management.[20]

First, the number of lymph nodes is an important indicator in D2 lymph node dissections and has been proven to have survival benefits for advanced gastric cancer cases[21]; the most important factor is the adequate retrieval of lymph nodes because this is essential for optimal staging and prediction of patient survival.[16] In this study, higher rates of adequate lymph node retrieval (16 or more) were found in the RG group than in the LG group, mainly due to the advantages of RG over conventional laparoscopic surgery in terms of eliminating tremor, providing three-dimensional imaging, and offering improved dexterity with an internal articulated EndoWrist.[22,23] In previous reports, robotic surgery was shown to be comparable to or better than LG for the retrieval of lymph nodes.[11,24–28] These advantages of robotic systems are especially apparent in difficult operations requiring total gastrectomy or D2 dissection.[11,25,26] In patients who require a splenic hilum lymph node dissection, the risk of bleeding is quite high, and a splenectomy may be required if a vascular injury occurs during the lymph node dissection. With the aid of a robotic system, it is easier to dissect along the major vessels than when performing laparoscopic surgery.

Second, RG resulted in less blood loss than LG in this study. Blood loss is currently considered an important parameter to assess surgical safety and success. For some high-risk patients, such as those with cardiac disease or anemia or elderly patients, bleeding might be a critical and life-threatening event. In addition, some reports have indicated that perioperative transfusion might negatively impact oncologic outcomes[29] and influence the spillage of free cancer cells from lymph vascular channels[30]. Thus, by limiting blood loss, robotic systems may help facilitate higher quality surgery with more consistent outcomes. One report published in 2015 showed that the benefits of robotic surgery were more evident in patients with high BMIs.[31] Laparoscopic surgeries are impeded in patients with high BMIs.[32] Excess fat in high BMI patients impairs adequate exposure of the surgical field, and physiologic adhesions make it difficult to perform precise lymphadenectomy around major vessels. These difficulties may increase the risk of bleeding during lymphadenectomy; furthermore, the surgical field can be obscured by the blood loss, impairing dissection.

Third, conversion to open surgery should be regarded as another major parameter of surgical success. In colorectal surgery, open conversion from minimally invasive surgery has been reported as negatively influencing perioperative outcomes and disease-free survival.[19] In this study, no difference was found in the conversion rates between the two groups. The common causes of conversions are more advanced tumor stages and abdominal adhesions, which could almost be considered proactive conversions for oncologic safety; conversions due to uncontrollable bleeding were relatively rare.

Fourth, readmission is also associated with decreased overall median survival[33,34]; readmission is not only regarded as an important indicator of surgical safety but also a source of increased total cost and length of hospital stay, leading to deterioration in the relationship between doctors and patients. In fact, this study revealed similar rates of reoperation and readmission in both groups.

Fifth, the length of hospital stay and financial cost are important factors for both doctors and patients. Most studies have reported that the total cost for robotic surgery is much higher than that for laparoscopic surgery. However, future advances might reduce the cost of RG, especially when similar devices are developed by other companies. The cost may decrease automatically over time, as prices for the equipment and maintenance decrease with competition and when proprietary patents expire. Regarding the longer operation time, additional robot-specific procedures, such as preparation for docking and docking time, contribute to the relatively long operation times. However, docking times can gradually shorten upon an accumulation of greater experience. In fact, comparable operation times have been reported between RG and LG performed by experienced surgeons.[32]

In addition to intraoperative complications, common and severe complications were analyzed in our study. Reoperation could be caused by life-threatening events that frequently significantly increase the mortality rate and burden on the surgical unit.[35] Postoperative bleeding may be one of the most common causes leading to unplanned reoperation. In this report, nine patients in the LG group underwent reoperation, including seven patients due to postoperative bleeding, one due to intestinal obstruction, and one due to uncontrolled intra-abdominal infection after anastomotic leakage. In the RG group, three patients underwent unplanned reoperation, two due to uncontrolled postoperative bleeding, and one due to anastomotic leakage. As this study showed, more than half of the cases of postoperative bleeding could be treated with blood transfusion. However, more than one third of the patients required surgical intervention.

In addition, debates surrounding robotic surgery mainly focus on the hospital costs and patient benefits, while the health and well-being of surgeons may be ignored. Musculoskeletal pain is regarded as one of the most common occupational diseases and has attracted increased attention from surgeons. The prevalence rates of musculoskeletal disorder (MSD) were reported to be approximately 22–74% among surgeons performing minimally invasive surgery.[36] However, robotic approaches may provide ergonomic benefits for the surgeon and decrease the risk of MSD.[37,36,38] Continuous changes are being enacted to increase surgical care quality, and future interventions should be made to alleviate and prevent musculoskeletal pain among surgeons. Some reports have shown that RG requires a shorter learning period than LG.[39–42] The experience gained from performing RG may decrease the learning period for LG.[43] Due to the less steep learning curve for RG, even inexperienced surgeons can easily perform more complicated surgical procedures such as total gastrectomy or extended lymph node dissection, and surgeons might feel more comfortable performing RG.[44,45]

The present study had some limitations. First, this study was not a randomized clinical trial. Second, oncologic outcomes constitute an equally important area of interest. We cannot substantiate the long-term oncologic efficacy of robotic surgery in terms of recurrence and survival. Nevertheless, to the best of our knowledge, our report is one of the largest (non-meta-analysis) comparative studies to date to compare short-term outcomes between LG and RG. Additionally, the most patients in this study had advanced gastric cancer. This is a well-balanced comparison clinical trial with sufficient multidimensional power to evaluate the surgical safety of RG and LG for advanced gastric cancer.

In summary, RG is comparable to LG in terms of the postoperative length of hospital stay and short-term postoperative morbidity and mortality. RG is a safer procedure than LG for treating gastric cancer.

Authors' Contributions Ying Kong and Yanbing Zhou were involved in the concept, design, data acquisition, analysis and interpretation, and production of figures and tables and wrote the first draft and revised it critically in light of comments from other authors. Shougen Cao, Liankai Wang, Xiaodong Liu and Zequn Li were involved in the conception, interpretation, manuscript revision, and discussion. Cunlong Lu, Houxin Zhu and Shuai Shen were involved in data acquisition and literature review. All the authors approved the final version submitted. The authors would like to thank American Journal Experts for the help with the editing of this manuscript.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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