Surgical outcomes and learning curve analysis of robotic gastrectomy for gastric cancer: Multidimensional analysis compared with three-dimensional high-definition laparoscopic gastrectomy

JIYANG LI[1,2*], HONGQING XI[1*], XIN GUO[1,2], YUNHE GAO[1,2], TIANYU XIE[1,2], ZHI QIAO[1] and LIN CHEN[1,2]

[1]Department of General Surgery; [2]General Surgery Institute, Chinese PLA General Hospital, Beijing 100853, P.R. China

Received January 14, 2019; Accepted June 4, 2019

DOI: 10.3892/ijo.2019.4851

Abstract. The present ambispective cohort study was performed to compare the short-term surgical outcomes, including financial cost and surgeons' acceptance, of robotic versus three-dimensional high-definition (3D-HD) laparoscopic gastrectomy for patients with gastric cancer (GC). Between 2011 and 2017, 517 patients with GC were enrolled for treatment with either robotic gastrectomy [408 patients, including 73 treated by one of the authors (LC)] or 3D-HD laparoscopic gastrectomy (109 patients, including 71 treated by LC). The cumulative summation method was developed to analyze the learning curves of robotic and 3D-HD laparoscopic gastrectomy performed by LC. In the analysis of all 517 patients, there were no significant differences in the clinicopathological characteristics between the two treatment groups, with the exception of smoking status (P<0.001). The robotic group had a shorter operative time (OT; 209 vs. 228 min, P=0.004), fewer postoperative days (PODs) to first flatus (3 vs. 4 days, P=0.025), more PODs to removal of the drainage and nasogastric tubes (12 vs. 9 days, P=0.001; 6 vs. 4 days, P=0.001, respectively), and more postoperative complications (21.3 vs. 9.2%, P=0.003). Comparison of these short-term outcomes of robotic and 3D-HD laparoscopic gastrectomy performed by LC (144 patients) revealed that only the number of retrieved lymph nodes (27 in the robotic group vs. 33 in the 3D-HD group; P=0.038) and PODs to removal of the nasogastric tube (5 days in the robotic group vs. 3 days in the 3D-HD group; P<0.001) were significantly different. The OT stabilized after around 21 robotic gastrectomy procedures and 19 3D-HD laparoscopic gastrectomy procedures. The cost-effectiveness analysis revealed that robotic gastrectomy had a significantly higher total cost than 3D-HD laparoscopic gastrectomy (124,907 vs. 94,395 RMB, P<0.001). With comparable surgical outcomes, lower financial cost and higher surgeons' acceptance, 3D-HD laparoscopic gastrectomy is highly recommended as a minimally invasive surgical method for patients with GC prior to the popularization of robotic surgery.

Correspondence to: Professor Lin Chen or Professor Zhi Qiao, Department of General Surgery, Chinese PLA General Hospital, 28 Fuxing Road, Haidian, Beijing 100853, P.R. China
E-mail: chenlin_301bj@163.com
Email: drqiaozhi@126.com

[*]Contributed equally

Key words: gastrectomy, gastric cancer, three-dimensional laparoscopy, robotic surgery, learning curve, cumulative summation analysis

Introduction

For decades, laparoscopic gastrectomy has been widely applied for the treatment of gastric cancer (GC) (1). Its long-term oncological safety and short-term operative advantages over open gastrectomy have been confirmed (2). With the development of minimally invasive surgery as a standard technique, improvements in instruments, such as robotic surgical systems and three-dimensional high-definition (3D-HD) laparoscopic devices (3), have arisen to overcome the limitations of traditional laparoscopy. The da Vinci Robotic Surgical system (Intuitive Surgical, Inc.) can filter surgeons' physiological hand tremors, offer degrees of articulated movement, and provide a 3D magnified view of the operating field and an ergonomic surgical environment for surgeons (4-7). However, the use of robotic technology may produce quite drastic changes in the surgical environment. Notably, surgeons must adapt to a loss of haptic feedback because they only operate from the console table, which is located far from the patient. In the last few years, 3D-HD laparoscopy has provided surgeons with stereoscopic vision for accurate spatial positioning as well as haptic feedback (8). 3D-HD laparoscopy restores natural 3D vision and depth perception to laparoscopic procedures, making it easier to identify tissue planes.

Robotic systems and 3D-HD laparoscopic devices, which facilitate precise dissection in a confined surgical field with impressive dexterity, have recently become important tools in gastrectomy (3,6,7,9-17). The development of novel surgical methods or tools is associated with a period of acquisition to attain surgical proficiency. This period allows surgeons to become increasingly familiar with the fine details of the technique, allowing them to use it successfully and efficiently even in extremely complex cases. This is known as the 'surgical learning curve' and is usually defined by the number of cases required for proficiency. Cumulative summation (CUSUM) analysis, which is a method of statistical process control, can be used to determine the learning curve based on objective surgical outcomes.

To the best of our knowledge, no supporting evidence regarding the safety, efficacy or surgeons' acceptance of robotic vs. 3D-HD laparoscopic gastrectomy for patients with GC has yet been established. Therefore, we conducted a single-center cohort study to compare short-term surgical outcomes, including financial cost and learning curves, of robotic vs. 3D-HD laparoscopic gastrectomy for patients with GC.

Materials and methods

Patients. This single-center cohort study was performed to investigate a prospectively maintained database (Gastric Cancer Database of the Chinese People's Liberation Army General Hospital) for selection of patients with GC who underwent either robotic gastrectomy [408 patients, including 73 treated by one of the present authors (LC)] or 3D-HD laparoscopic gastrectomy (109 patients, including 71 treated by LC) between August 2011 and June 2017. The following data were collected from the database: Baseline demographic characteristics (age, sex and body mass index), preoperative variables [American Society of Anesthesiologists score (18), history of diabetes, history of smoking, history of abdominal surgery and preoperative chemotherapy], intraoperative variables [extent of excision, estimated blood loss, skin-to-skin OT and number of retrieved lymph nodes], postoperative variables [duration of hospitalization, postoperative days (PODs) until flatus, PODs until removal of drainage and nasogastric tubes, postoperative complications, readmission and mortality], and pathological variables (tumor location, tumor size, Borrmann type (19), degree of differentiation, T stage, N stage, M stage and type of margin) (20).

Skin-to-skin OT was defined as the time from the initial incision using a Veress needle to suturing of the surgical wounds. Postoperative complications were defined as any complications that occurred within 30 days after the operation. Postoperative mortality was defined as any postoperative deaths within 30 days of the operation or during the hospitalization period. The severity of complications was classified according to the Clavien-Dindo classification (21).

The inclusion criteria were as follows: i) Gastric adenocarcinoma confirmed by pathological examination; and ii) no distant metastases according to imaging modalities (abdominal ultrasonography combined with magnetic resonance imaging and/or computed tomography) or surgical exploration. Patients were excluded if they were i) mentally incompetent, ii) illiterate, iii) pregnant, or iv) diagnosed with untreated second primary malignancies prior to surgery. Obesity was not considered to be a contraindication for robotic surgery. The patients chose the surgical method after receiving a thorough explanation of the risks and possible alternatives, including the extra costs for robotic surgery, by their surgeons. A flow chart of patient enrollment is shown in Fig. S1. All enrolled patients provided written informed consent. This study was approved by the institutional review board of the Chinese People's Liberation Army General Hospital.

Treatments. All included patients underwent curative gastrectomy with D2 lymphadenectomy. Subtotal gastrectomy was indicated for distal GC, and total gastrectomy was preferred for proximal GC or tumors involving more than one section of the entire stomach. All gastrectomies were performed with adequate margins (≥2 cm for cancer in the gastric antrum or cardia, ≥4 cm for cancer in the corpus) using the Billroth I, Billroth II or Roux-en-Y techniques for extracorporeal digestive tract reconstruction. All patients were managed postoperatively using the same standardized care protocol: Encouragement of ambulation on the first postoperative day, and allowance of water or a liquid diet following confirmation of intestinal peristalsis or the first flatus. Patients were discharged from the hospital if they met predefined discharge criteria, including the ability to fully ambulate without assistance, tolerable pain with no analgesics, and the ability to consume semi-liquid diets without significant gastrointestinal symptoms. All patients were observed for 30 days following surgery, and short-term surgical outcomes (including postoperative complications and the length of postoperative hospital stay) and clinicopathological characteristics were assessed.

Surgical standards and surgeons' experience. Robotic or 3D-HD laparoscopic gastrectomy was defined as successful if it met the following criteria: i) No conversion to open surgery for any reason, ii) an adequate number of lymph nodes (>15) harvested, iii) negative resection margin, iv) no mortality within 30 days after the operation or during the hospitalization period, and v) no outpatient complications requiring readmission (22). Any of these events was considered a surgical failure.

All surgeons who participated in this study had experience performing ≥50 laparoscopic gastrectomies (range, 50-500 gastrectomies) prior to the study. Surgeons were excluded if they had retrieved <15 lymph nodes in >10% of their minimally invasive surgeries.

Learning curve assessment (CUSUM analysis). Learning curves were obtained by plotting outcomes against the number of cases using a quantitative evaluation technique (CUSUM analysis). CUSUM involves the accumulation of differences between individual data and the average of a target value (23). CUSUM analysis was performed recursively as follows. Firstly, all cases were organized in chronological order according to the date of surgery; the recursive process was then started. $CUSUM_{OT}$ for the first case was defined as the difference between the OT of the first case and the mean OT for all cases (μOT). $CUSUM_{OT}$ for the second case was defined as addition of the former $CUSUM_{OT}$ to the difference between the OT of the second case and the μOT. The same procedure was repeated for all patients, with the exception of the last patient, for whom the $CUSUM_{OT}$ was calculated as zero (24). Risk-adjusted CUSUM analysis was unnecessary because no intraoperative mortality occurred (25). Polynomial regression was conducted to provide the coefficient of determination, R^2. The CUSUM plot was constructed using QI Macros for Microsoft Excel 2012.1 (Microsoft Corporation).

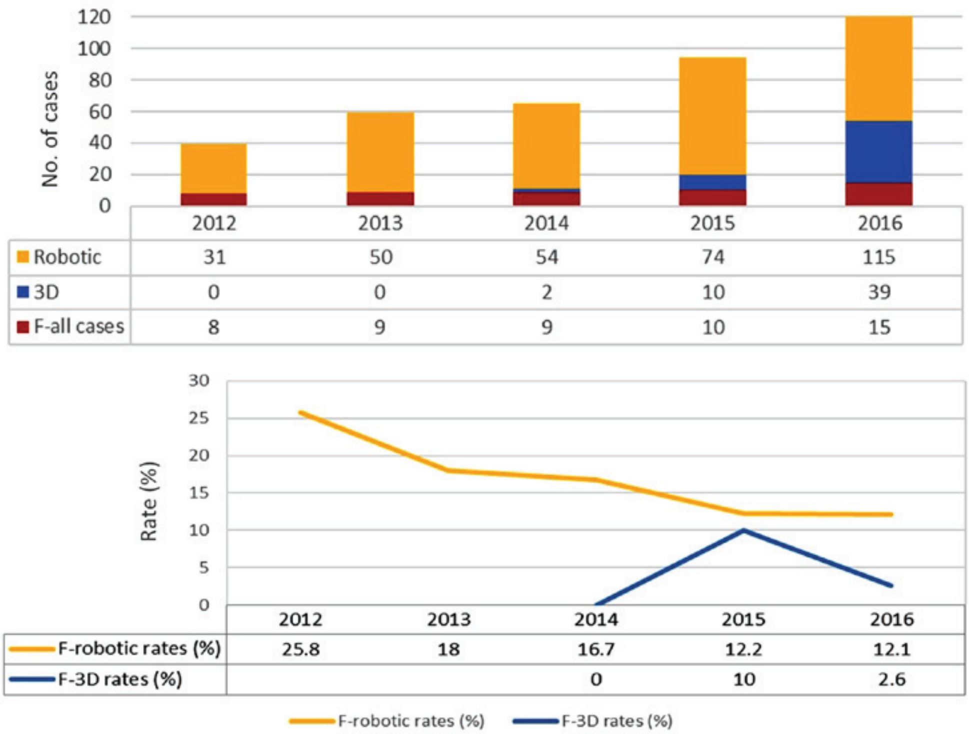

Figure 1. Summary of robotic and 3D-HD laparoscopic gastrectomy in the middle 5 years of the study period (2012-2016). The surgical failure rates of robotic gastrectomy were 25.8% (8/31), 18.0% (9/50), 16.7% (9/54), 12.2% (9/74) and 12.1% (14/115) in 2012, 2013, 2014, 2015 and 2016, respectively. The surgical failure rates of 3D-HD laparoscopic gastrectomy were 0.0% (0/2), 10.0% (1/10) and 2.6% (1/39) in 2014, 2015 and 2016, respectively. 3D-HD, three-dimensional high-definition; F, surgical failure rate.

Statistical analysis. All results for continuous variables are expressed as the mean ± standard deviation or the median (minimum value, maximum value), and frequencies and proportions are reported as percentages. Categorical variables were compared using the χ^2 test or Fisher's exact test (for one or more cells with an expected value of <5). Continuous variables were compared using Student's t-test or the Wilcoxon rank-sum test (if the Kolmogorov-Smirnov test of normality was significant, P>0.05). Three groups were compared using one-way analysis of variance. P<0.05 (two-sided) was considered to indicate a statistically significant difference. All analyses were performed using SPSS software (version 19.0; IBM Corporation).

Results

Patients. In total, 517 patients with GC were analyzed to compare the short-term surgical outcomes between robotic gastrectomy (408 patients) and 3D-HD laparoscopic gastrectomy (109 patients). Table I summarizes the baseline characteristics of all 517 patients. There were no differences in baseline characteristics between the robotic and 3D-HD laparoscopic groups, with the exception of smoking status (P<0.001). The robotic group had more smoking patients than the 3D-HD laparoscopic group (42.2 vs. 21.1%, respectively). Patients with a history of abdominal surgery were not excluded from this cohort study as long as no serious abdominal adhesions that could have affected rotation of the surgical instruments were present. The previous abdominal operations included 59 appendectomies, eight cesarean sections and six resections for uterine myoma through a low midline incision. Among all of the 517 patients, 144 patients (73 robotic and 71 3D-HD laparoscopic) were treated by LC. In the baseline analysis, all characteristics were balanced between the two groups as shown in Table I.

Surgical success analysis. All operations were performed without intraoperative mortality. To further analyze the quality of these operations, we evaluated their success according to criteria that are recognized as surgical standards for both open and minimally invasive gastrectomy. Because this study was performed between August 2011 and June 2017, the data in the middle 5 whole years (2012-2016) were analyzed (Fig. 1). The surgical failure rates of robotic gastrectomy were 25.8% (8/31), 18.0% (9/50), 16.7% (9/54), 12.2% (9/74) and 12.1% (14/115) in 2012, 2013, 2014, 2015 and 2016, respectively. The surgical failure rates of 3D-HD laparoscopic gastrectomy were 0.0% (0/2), 10.0% (1/10), and 2.6% (1/39) in 2014, 2015 and 2016, respectively. The overall surgical failure rates were 15.4% (63/408) and 7.3% (8/109) respectively, in the robotic group and 3D-HD laparoscopic group, respectively, with a significant difference (P=0.028).

According to the five aforementioned standards, this study further analyzed the reasons for surgical failure. Because no intraoperative mortality occurred, the major causes of surgical failure were summarized as conversion to open surgery (5.9%, 3/51), <16 harvested lymph nodes (100.0%, 51/51), a positive resection margin (5.9%, 3/51) and complications requiring readmission (5.9%, 3/51) (data not shown).

Surgical safety analysis: comparison of short-term surgical outcomes between robotic and 3D-HD laparoscopic

Table I. Baseline characteristics of patients with gastric cancer.

	All patients			Patients treated by LC		
Characteristic	Robotic, n=408 (%)	3D-HD laparoscopic, n=109 (%)	P-value	Robotic, n=73 (%)	3D-HD laparoscopic, n=71 (%)	P-value
Age (years)	59.4±11.1	60.2±11.8	0.515	58.8±11.3	57.6±11.4	0.535
Sex			0.151			0.066
Male	294 (72.1)	86 (78.9)		47 (64.4)	56 (78.9)	
Female	114 (27.9)	23 (21.1)		26 (35.6)	15 (21.1)	
BMI (kg/m^2)	24.1±3.3	24.0±3.0	0.783	23.4±3.4	24.3±2.8	0.064
ASA score			0.153			0.586
I	13 (3.2)	2 (1.8)		2 (2.7)	1 (1.4)	
II	359 (88.0)	93 (85.3)		65 (89.0)	63 (88.7)	
III	36 (8.8)	14 (12.9)		6 (8.3)	7 (9.9)	
Diabetes	52 (12.7)	10 (9.2)	0.308	5 (6.8)	5 (7.0)	0.964
Smoking status	172 (42.2)	23 (21.1)	<0.001	25 (34.2)	15 (21.1)	0.079
History[a]	58 (14.2)	15 (13.8)	0.904	8 (11.0)	11 (15.5)	0.422
Preoperative chemotherapy	18 (4.4)	8 (7.3)	0.214	2 (2.7)	5 (7.0)	0.272
Tumor location			0.057			0.116
Upper	85 (20.8)	25 (22.9)		10 (13.7)	17 (23.9)	
Middle	80 (19.6)	31 (28.4)		14 (19.2)	18 (25.4)	
Lower	197 (48.3)	48 (44.0)		42 (47.5)	34 (47.9)	
Diffuse	46 (11.3)	5 (4.6)		7 (9.6)	2 (2.8)	
Size (cm)	4.3±2.9	4.6±2.5	0.416	4.0±2.4	4.4±2.5	0.323
Borrmann type			0.227			0.790
Mass	21 (5.1)	10 (9.2)		3 (4.1)	4 (5.6)	
Ulcerative	221 (54.2)	62 (56.9)		41 (56.2)	34 (47.9)	
Infiltrative ulcerative	148 (36.3)	35 (32.1)		27 (37.0)	31 (43.7)	
Diffuse infiltrative	18 (4.4)	2 (1.8)		2 (2.7)	2 (2.8)	
Differentiation			0.598			0.075
Well	23 (5.6)	4 (3.7)		6 (8.2)	0	
Moderate	64 (15.7)	18 (16.5)		8 (11.0)	9 (12.7)	
Poor or signet-ring	321 (78.7)	87 (79.8)		59 (80.8)	62 (87.3)	
T			0.169			0.324
T1	87 (21.3)	16 (14.7)		12 (16.4)	10 (14.1)	
T2	88 (21.6)	14 (12.8)		25 (34.2)	8 (11.3)	
T3	145 (35.5)	63 (57.8)		18 (24.7)	44 (62.0)	
T4	88 (21.6)	16 (14.7)		18 (24.7)	9 (12.6)	
N			0.749			0.615
N0	181 (44.4)	43 (39.4)		30 (41.1)	28 (39.4)	
N1	50 (12.2)	16 (14.7)		12 (16.4)	7 (9.9)	
N2	61 (15.0)	19 (17.4)		10 (13.7)	15 (21.1)	
N3	116 (28.4)	31 (28.4)		21 (28.8)	21 (29.6)	
M			0.096			0.135
M0	388 (95.1)	108 (99.1)		69 (94.5)	71 (100)	
M1	20 (4.9)	1 (0.9)		4 (5.5)	0	
Procedure			0.430			0.246
Total	211 (51.7)	61 (56.0)		31 (42.5)	37 (52.1)	
Subtotal	197 (48.3)	48 (44.0)		42 (57.5)	34 (47.9)	

[a]History of abdominal surgery. 3D-HD, three-dimensional high-definition; ASA, American Society of Anesthesiologists. Categorical variables were compared using the χ^2 test or Fisher's exact test. Continuous variables were compared using Student's t-test or the Wilcoxon rank-sum test.

Table II. Operative outcomes, and postoperative morbidity and mortality of patients.

	All patients			Patients treated by LC		
Characteristic	Robotic, n=408 (%)	3D-HD laparoscopic, n=109 (%)	P-value	Robotic, n=73 (%)	3D-HD laparoscopic, n=71 (%)	P-value
Conversion	3 (0.7)	1 (0.9)	0.847	1 (1.4)	1 (1.4)	0.984
Operative time (min)	208.6±59.7	228.0±69.2	0.004	225.0±71.7	217.2±55.7	0.468
Estimated blood loss (ml)	148.8±181.8	142.2±133.6	0.723	145.8±133.5	146.8±138.8	0.965
No. of retrieved lymph nodes	24.9±10.6	33.8±16.3	0.001	27.4±14.8	32.6±14.8	0.038
Margin			0.059			0.057
Positive	3 (0.7)	4 (3.7)		0	4 (5.6)	
Negative	405 (99.3)	105 (96.3)		73 (100)	67 (94.4)	
Hospitalization (days)	19.8±12.7	18.8±8.5	0.416	17.0±4.8	17.6±6.2	0.506
Flatus (PODs)	3.3±1.9	4.05±5.2	0.025	3.2±1.4	3.6±1.5	0.118
Drainage tube removal (PODs)	11.7±6.7	8.7±3.3	0.001	9.0±3.0	8.3±2.5	0.109
Nasogastric tube removal (PODs)	6.4±4.1	3.5±6.7	0.001	5.0±2.6	2.8±2.9	<0.001
Postoperative complications	87 (21.3)	10 (9.2)	0.003	6 (8.2)	7 (9.9)	0.731
Clavien-Dindo			0.014			0.652
Grade I	38 (9.3)	2 (1.8)		4 (5.5)	6 (8.5)	
Grade II	28 (6.9)	7 (6.4)		0	1 (1.4)	
Grade III	6 (1.5)	0		1 (1.4)	0	
Grade IV	15 (3.6)	1 (1.0)		1 (1.4)	0	
Readmission	3 (0.7)	0	0.369	0	0	-
Mortality	0	0	-	0	0	-

3D-HD, three-dimensional high-definition; PODs, postoperative days. Categorical variables were compared using the χ^2 test or Fishe's exact test. Continuous variables were compared using Student's t-test or the Wilcoxon rank-sum test.

gastrectomy groups. Table II presents the operative outcomes, and postoperative morbidity and mortality rates of all 517 patients. The robotic group had a shorter mean skin-to-skin OT than the 3D-HD laparoscopic group (209 vs. 228 min, respectively; P=0.004), with a similar estimated blood loss (149 vs. 142 ml, respectively; P=0.723). The number of retrieved lymph nodes was higher in the 3D-HD laparoscopic group than in the robotic group (34 vs. 25, respectively; P=0.001). The positive resection margin rates were 0.7% (3/408) and 3.7% (4/109), respectively, in the robotic group and 3D-HD laparoscopic group without a significant difference (P=0.059). The mean length of hospital stay was also not significantly different between the two groups (20 vs. 19 days, respectively; P=0.416). The robotic group had fewer PODs until first flatus (3 vs. 4 days, P=0.025), but more PODs to removal of the drainage tube (12 vs. 9 days, P=0.001) and nasogastric tube (6 vs. 4 days, P=0.001) compared with in the 3D-HD laparoscopic group.

Another important finding was that the robotic group had more postoperative complications (21.3 vs. 9.2%, P=0.003) and much more severe complications according to the Clavien-Dindo classification (P=0.014) compared with in the 3D-HD laparoscopic group. The specific types of postoperative complications and their treatments are summarized in Fig. 2. Of all 517 patients, 97 (18.8%) had postoperative complications. There were 66 local complications and 31 systemic complications. Of the 66 local complications, anastomotic leakage (n=22) was the most common, followed by gastroparesis (n=13) and incision infection (n=7). Of the systemic complications, pulmonary infection (n=9) was the most common. With respect to the severity of the complications, there were 40 grade I (41.2%), 35 grade II (36.1%), six grade III (6.2%) and 16 grade IV (16.5%) complications according to the Clavien-Dindo classification. The distribution of postoperative complications in the two groups is summarized in Table II.

Financial cost analysis: Comparison of inpatient expenses between robotic and 3D-HD laparoscopic gastrectomy groups. The average inpatient expense for patients who underwent robotic gastrectomy was 137,604 RMB (range, 11,957-525,349 RMB). In comparison, patients who underwent 3D-HD laparoscopic gastrectomy had a much lower average cost of 97,394 RMB (range, 53,814-162,302). Statistical analysis using Student's t-test revealed that the difference between the groups was significant (P<0.001; F=93.429) (data not shown).

Balancing the surgical safety and financial cost evaluation within one treatment team: Comparison of short-term

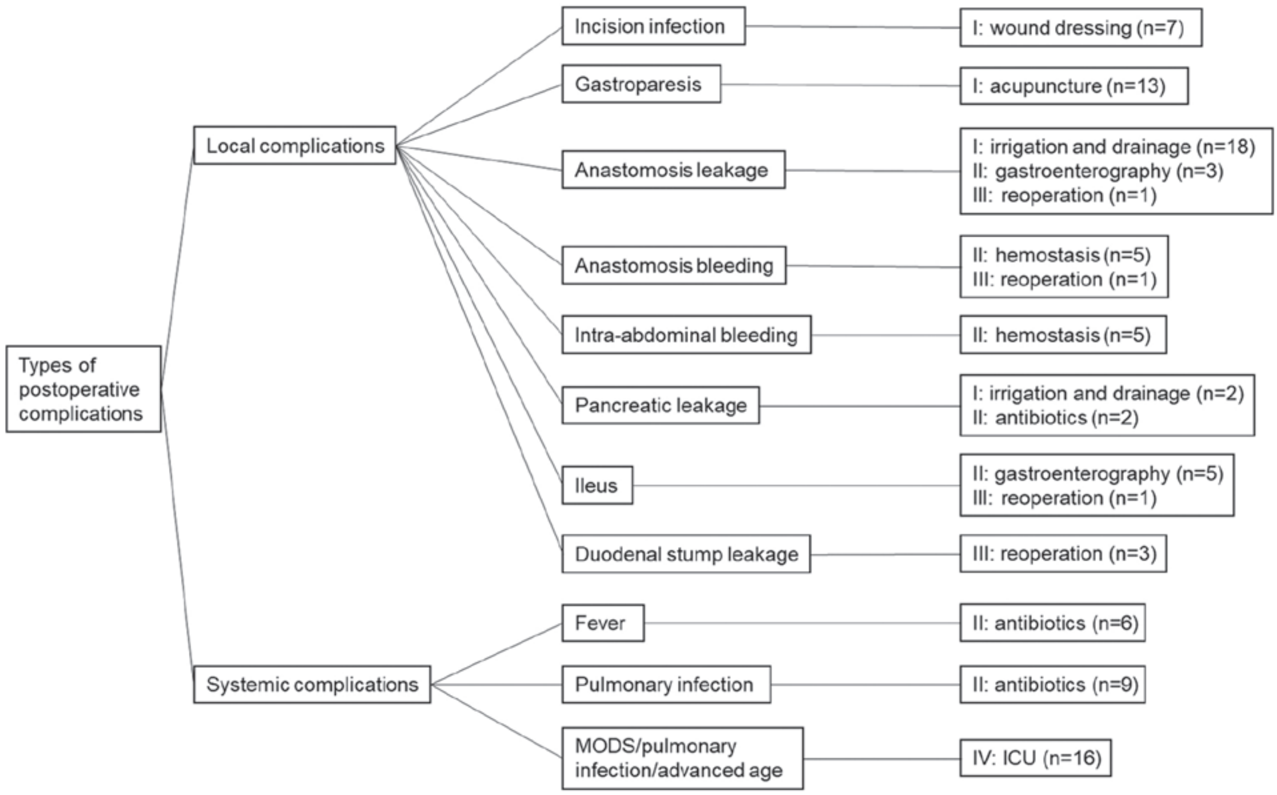

Figure 2. Summary of specific types of postoperative complications and their treatments. There were 66 local complications and 31 systemic complications. Of the 66 local complications, anastomosis leakage was the most common, followed by gastroparesis and incision infection. Of the systemic complications, pulmonary infection was most common. With respect to the severity of the complications, there were 40 grade I (41.2%), 35 grade II (36.1%), six grade III (6.2%) and 16 grade IV (16.5%) complications according to the Clavien-Dindo classification. ICU, intensive care unit; MODS, multiple organ dysfunction syndrome.

surgical outcomes and inpatient expenses between robotic and 3D-HD laparoscopic gastrectomy performed by LC. The intraoperative and postoperative data of treatments with robotic and 3D-HD laparoscopic gastrectomy performed by LC, are shown in Table II. Only the number of retrieved lymph nodes and PODs until removal of the nasogastric tube were significantly different between the groups. The 3D-HD laparoscopic gastrectomy group had more retrieved lymph nodes (33 vs. 27, P=0.038) and fewer PODs until removal of the nasogastric tube (3 vs. 5 days, P<0.001) compared with the robotic gastrectomy group. Additionally, there was no significant difference in postoperative complications between the two groups. The cost-effectiveness analysis was consistent, indicating that robotic gastrectomy had a significantly higher total cost than 3D-HD laparoscopic gastrectomy (124,907 vs. 94,395 RMB; P<0.001) (data not shown).

Surgeons' acceptance analysis: Comparison of learning curves of robotic and 3D-HD laparoscopic gastrectomy performed by LC using CUSUM analysis based on skin-to-skin OT. According to the change in the slope of the learning curves, the CUSUM learning curves were divided into three unique phases: Phase I represents the initial training phase (the initial N1 cases), Phase II represents the well-developed phase (the middle N2 cases), and Phase III represents increasing surgeon capacity (the final N3 cases) (26,27).

As shown in Fig. 3, Phases I, II and III of robotic gastrectomy were delineated by Cases 1-21, Cases 22-46, and Cases 47-73, respectively. Additionally, R^2 was equal to 0.8543, proving a high degree of fit. Table III indicated that the baseline clinicopathological characteristics of the patients in the three phases were comparable (all P>0.05). There were no positive surgical margins in any patient. The skin-to-skin OT was reduced from 313 to 245 min (P=0.004), with an increasing number of retrieved lymph nodes from 17 to 34 (P<0.001) and similar estimated blood loss (P=0.415). The length of hospitalization was reduced from 19 to 15 days (P=0.005). Although the number of PODs until first flatus was not significantly reduced (P=0.069), the number of PODs until removal of the drainage tube (10 to 8 days, P=0.041) and nasogastric tube (6 to 3 days, P<0.001) was greatly reduced. The postoperative complications and their Clavien-Dindo classification were stable between cases over time. Finally, no mortality or readmission occurred within 30 days postoperatively.

Fig. 4 shows that for 3D-HD laparoscopic gastrectomy, Case 19 represented the cut-off between Phases I and II, and Case 49 represented the cut-off between Phases II and III. Additionally, R^2 was equal to 0.9055, proving good fit. The baseline clinicopathological characteristics of the three phases were comparable (all P>0.05) as shown in Table IV. The skin-to-skin OT was reduced from 246 to 205 min (P=0.028), with an increasing number of retrieved lymph nodes from 24 to 39 (P=0.007) and similar estimated blood loss (P=0.871). Postoperative factors, such as the length of hospitalization, PODs until flatus, PODs until removal of the drainage and nasogastric tubes, and postoperative complications and their Clavien-Dindo classification were not significantly different (all P>0.05). Finally, no mortality or readmission occurred

Table III. Baseline clinicopathological characteristics, operative outcomes, postoperative morbidity and mortality of patients treated with robotic gastrectomy in the different phases.

Characteristic	Phase I, n=21 (%)	Phase II, n=25 (%)	Phase III, n=27 (%)	P-value
Age (years)	59.1±11.2	59.0±10.6	58.2±12.3	0.948
Sex				0.853
Male	14 (66.7)	15 (60.0)	18 (66.7)	
Female	7 (33.3)	10 (40.0)	9 (33.3)	
BMI (kg/m^2)	22.6±4.4	23.4±3.2	24.0±2.6	0.413
ASA score				0.238
I	1 (4.8)	1 (4.0)	0	
II	18 (85.7)	24 (96.0)	23 (85.2)	
III	2 (9.5)	0	4 (14.8)	
Diabetes	0	3 (12.0)	2 (7.4)	0.365
Smoking status	10 (47.6)	6 (24.0)	9 (33.3)	0.241
History[a]	4 (19.0)	3 (12.0)	1 (3.7)	0.235
Preoperative chemotherapy	0	1 (4.0)	1 (3.7)	0.461
Tumor location				0.157
Upper	1 (4.8)	5 (20.0)	4 (14.8)	
Middle	2 (9.5)	5 (20.0)	7 (25.9)	
Lower	15 (71.4)	11 (44.0)	16 (59.3)	
Diffuse	3 (14.3)	4 (16.0)	0	
Size (cm)	3.8±2.7	4.0±2.1	4.1±2.6	0.929
Borrmann type				0.069
Mass	1 (4.8)	0	2 (7.4)	
Ulcerative	14 (66.7)	19 (76.0)	8 (29.6)	
Infiltrative ulcerative	5 (23.8)	6 (24.0)	16 (59.3)	
Diffuse infiltrative	1 (4.8)	0	1 (3.7)	
Differentiation				0.932
Well	3 (14.3)	2 (8.0)	1 (3.7)	
Moderate	0	2 (8.0)	6 (22.2)	
Poor or signet-ring	18 (85.7)	21 (84.0)	20 (74.1)	
T				0.621
T1	4 (19.0)	6 (24.0)	2 (7.4)	
T2	9 (43.0)	3 (12.0)	13 (48.1)	
T3	4 (19.0)	7 (28.0)	7 (25.9)	
T4	4 (19.0)	9 (36.0)	5 (18.6)	
N				0.892
N0	9 (43.0)	9 (36.0)	12 (44.5)	
N1	4 (19.0)	3 (12.0)	5 (18.5)	
N2	4 (19.0)	4 (16.0)	2 (7.4)	
N3	4 (19.0)	9 (36.0)	8 (29.6)	
M				0.671
M0	20 (95.2)	24 (96.0)	25 (92.6)	
M1	1 (4.8)	1 (4.0)	2 (7.4)	
Procedure				0.168
Total	6 (28.6)	14 (56.0)	11 (40.7)	
Subtotal	15 (71.4)	11 (44.0)	16 (59.3)	
Conversion	1 (4.8)	0	0	0.180
Operative time (min)	313.3±81.3	250.0±38.9	244.6±89.1	0.004
Estimated blood loss (ml)	167.1±155.4	117.6±39.3	155.2±167.8	0.415
No. of retrieved lymph nodes	17.3±6.5	28.4±13.3	34.4±16.6	<0.001

Table III. Continued.

Characteristic	Phase I, n=21 (%)	Phase II, n=25 (%)	Phase III, n=27 (%)	P-value
Margin	0	0	0	-
Hospitalization (days)	19.2±4.8	17.5±5.9	14.8±2.6	0.005
Flatus (PODs)	3.8±2.0	3.0±1.1	2.9±0.8	0.069
Drainage tube removal (PODs)	9.8±2.9	9.7±2.9	7.9±2.9	0.041
Nasogastric tube removal (PODs)	5.7±2.2	6.1±2.2	3.4±2.6	<0.001
Postoperative complications	3 (14.3)3 (12.0)	0		0.067
Clavien-Dindo				0.358
Grade I	3 (14.3)	1 (4.0)	0	
Grade II	0	0	0	
Grade III	0	1 (4.0)	0	
Grade IV	0	1 (4.0)	0	
Readmission	0	0	0	-
Mortality	0	0	0	-

[a]History of abdominal surgery. ASA, American Society of Anesthesiologists; PODs, postoperative days. Three groups were compared using one-way analysis of variance.

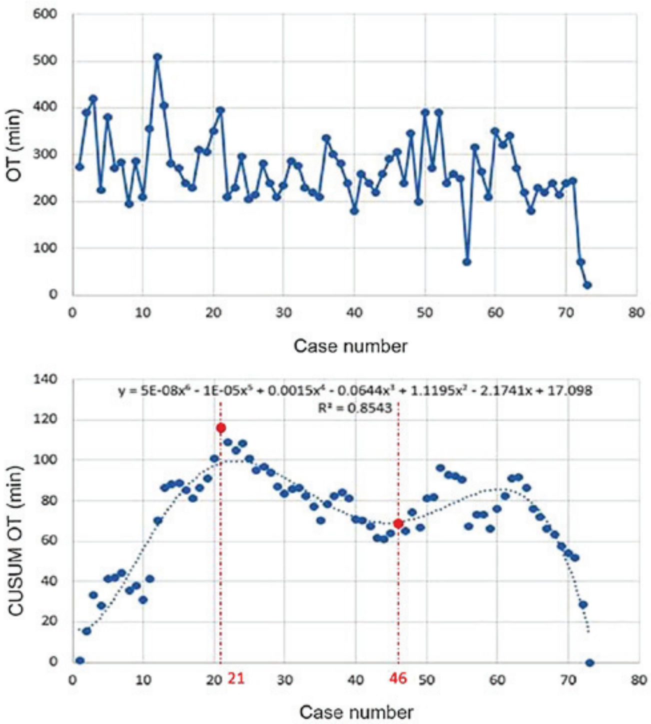

Figure 3. Learning curve of robotic gastrectomy based on skin-to-skin OT. Phases I, II and III of robotic gastrectomy were delineated by Cases 1-21, Cases 22-46, and Cases 47-73, respectively. Additionally, R^2 was equal to 0.8543, proving a high degree of fit. CUSUM, cumulative summation; OT, operative time.

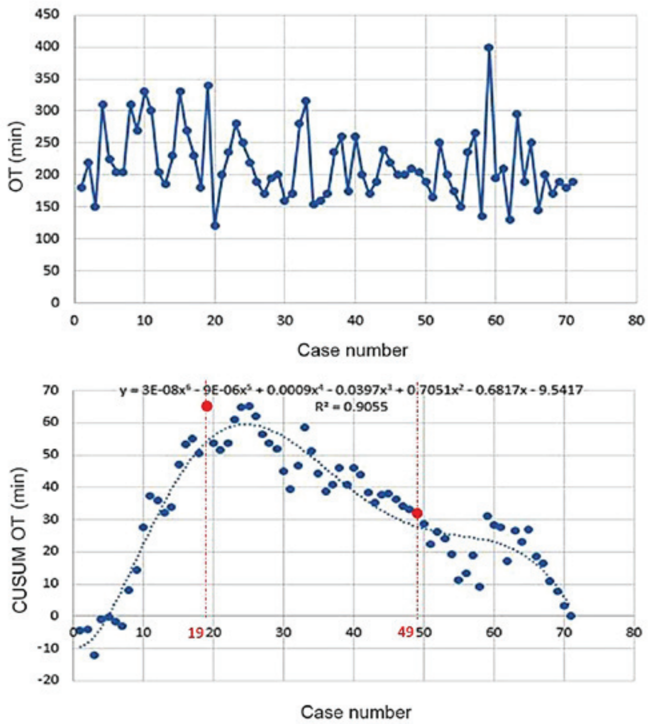

Figure 4. Learning curve of 3D-HD laparoscopic gastrectomy based on skin-to-skin OT. Case 19 represented the cut-off between Phases I and II, and Case 49 represented the cut-off between Phases II and III. Additionally, R^2 was equal to 0.9055, proving good fit. 3D-HD, three-dimensional high-definition; CUSUM, cumulative summation; OT, operative time.

within 30 days postoperatively. In addition, OT was compared between robotic and 3D-HD laparoscopic gastrectomy groups before and after the OT stabilized in the patients treated by LC, as well as in the different phases (Table V). Comparison of the OT between robotic and 3D-HD laparoscopic gastrectomy groups before and after stabilization in all patients is shown in Table SI. The cut-off cases for robotic and 3D-HD laparoscopic gastrectomy before and after the OT stabilized were chosen as Cases 21 and 19, respectively. There was no significant difference in these stratified analyses. In addition, the time to flatus in the robotic and 3D-HD laparoscopic gastrectomy groups was compared before and after OT stabilization

Table IV. Baseline clinicopathological characteristics, operative outcomes, postoperative morbidity and mortality of patients treated with three-dimensional high-definition laparoscopic gastrectomy in the different phases.

Characteristic	Phase I, n=19 (%)	Phase II, n=30 (%)	Phase III, n=22 (%)	P-value
Age (years)	54.6±13.2	60.7±11.2	55.8±9.5	0.130
Sex				0.366
Male	13 (68.4)	24 (80.0)	19 (86.4)	
Female	6 (31.6)	6 (12.0)	3 (13.6)	
BMI (kg/m^2)	23.4±3.0	24.4±2.2	25.1±3.2	0.161
ASA score				0.281
I	0	0	1 (4.5)	
II	17 (89.5)	26 (86.7)	20 (90.9)	
III	2 (10.5)	4 (13.3)	1 (4.6)	
Diabetes	0	3 (10.0)	2 (9.1)	0.278
Smoking status	4 (21.1)	6 (20.0)	5 (22.7)	0.972
History	2 (10.5)	5 (16.7)	4 (18.2)	0.762
Preoperative chemotherapy	2 (10.5)	1 (3.3)	2 (9.1)	0.898
Tumor location				0.200
Upper	5 (26.3)	6 (20.0)	6 (27.4)	
Middle	8 (42.1)	9 (30.0)	1 (4.5)	
Lower	5 (26.3)	15 (50.0)	14 (63.6)	
Diffuse	1 (5.3)	0	1 (4.5)	
Size (cm)	5.1±2.8	3.9±2.1	4.4±2.7	0.297
Borrmann type				0.078
Mass	2 (10.5)	0	2 (9.1)	
Ulcerative	4 (21.1)	16 (53.3)	14 (63.6)	
Infiltrative ulcerative	13 (68.4)	13 (43.3)	5 (22.7)	
Diffuse infiltrative	0	1 (3.4)	1 (4.5)	
Differentiation				0.221
Well	0	0	0	
Moderate	0	6 (20.0)	3 (13.6)	
Poor or signet-ring	19 (100)	24 (80.0)	19 (86.4)	
T				0.690
T1	1 (5.3)	5 (16.7)	4 (18.2)	
T2	2 (10.5)	4 (13.3)	2 (9.1)	
T3	15 (78.9)	17 (56.7)	12 (54.5)	
T4	1 (5.3)	4 (13.3)	4 (18.2)	
N				0.876
N0	8 (42.1)	10 (33.3)	10 (45.5)	
N1	2 (10.5)	2 (6.7)	3 (13.6)	
N2	4 (21.1)	8 (26.7)	3 (13.6)	
N3	5 (26.3)	10 (33.3)	6 (27.3)	
M				-
M0	19 (100)	30 (100)	22 (100)	
M1	0	0	0	
Procedure				0.055
Total	14 (73.7)	15 (50.0)	8 (36.4)	
Subtotal	5 (26.3)	15 (50.0)	14 (63.6)	
Conversion	1 (5.3)	0	0	0.170
Operative time (min)	246.1±59.4	207.8±43.5	205.0±60.6	0.028
Estimated blood loss (ml)	138.4±163.8	157.0±142.7	140.0±113.5	0.871
No. of retrieved lymph nodes	24.3±7.9	33.5±16.2	38.6±14.8	0.007

Table IV. Continued.

Characteristic	Phase I, n=19 (%)	Phase II, n=30 (%)	Phase III, n=22 (%)	P-value
Margin				0.130
Positive	0	1 (3.3)	3 (13.6)	
Negative	19 (100)	29 (96.7)	19 (86.4)	
Hospitalization (days)	16.9±5.3	17.9±5.8	17.7±7.6	0.843
Flatus (PODs)	3.2±1.2	3.6±1.5	3.8±1.7	0.527
Drainage tube removal (PODs)	7.9±1.8	9.0±2.8	7.6±2.4	0.099
Nasogastric tube removal (PODs)	2.5±2.3	3.6±3.7	2.1±2.0	0.155
Postoperative complications	1 (5.3)	5 (16.7)	1 (4.5)	0.878
Clavien-Dindo				0.883
Grade I	1 (5.3)	4 (13.3)	1 (4.5)	
Grade II	0	1 (3.3)	0	
Grade III	0	0	0	
Grade IV	0	0	0	
Readmission	0	0	0	-
Mortality	0	0	0	-

ASA, American Society of Anesthesiologists; PODs, postoperative days. Three groups were compared using one-way analysis of variance.

Table V. Comparison of the operative time between robotic versus 3D-HD laparoscopic gastrectomy groups before and after the operative time stabilized in patients treated by LC, as well as in different phases.

Phase	Robotic	3D-HD laparoscopic	P-value
Phase I	313.3±81.3	246.1±59.4	0.213
Phases II and III	247.2±69.0	206.6±50.9	0.230
Phase II	250.0±38.9	207.8±43.5	0.891
Phase III	244.6±89.1	205.0±60.6	0.240

3D-HD, three-dimensional high-definition. Continuous variables were compared using Student's t-test or the Wilcoxon rank-sum test.

in the patients treated by LC, as well as in the different phases (Table SII). There were no significantly different or meaningful values in Tables V, SI and SII.

Discussion

This cohort study confirmed that surgical outcomes were comparable between 3D-HD laparoscopic gastrectomy and robotic gastrectomy; however, more lymph nodes were retrieved and there were fewer PODs until removal of the nasogastric tube when performing 3D-HD laparoscopic gastrectomy. Laparoscopic gastrectomy also involved lower financial costs and earlier adaptation than robotic gastrectomy.

The number of retrieved lymph nodes is a crucial parameter with which to evaluate the multidimensional aspects of surgical outcomes (22). In this study, the insufficient number of harvested lymph nodes was the most common reason for surgical failure. According to a study by Son *et al* (28), an insufficient number of harvested lymph nodes does not allow for adequate prediction of patient survival following curative gastrectomy. The present study demonstrated that 3D-HD laparoscopic gastrectomy resulted in retrieval of more lymph nodes than robotic gastrectomy, regardless of whether it was balanced by the treatment group. Additionally, there was no significant difference in skin-to-skin OT, which is consistent with a study by Hyun *et al* (29). The OT was comparable between robotic and laparoscopic gastrectomy groups when performed by experienced surgeons. The additional OT of robotic surgery is usually caused by robot-specific procedures, such as preparation for docking and the docking time (30).

Undoubtedly, robotic technology provides a theoretically superior operative environment for minimally invasive surgery. With respect to patient benefit, few studies have demonstrated a lower rate of major complications with robotic gastrectomy than with laparoscopic gastrectomy (6,22,30,31). Notably, the rate and severity of postoperative complications were higher in the robotic group in the present study; however, this phenomenon disappeared after balancing the surgical safety analysis within a single treatment team (patients operated on by LC).

CUSUM is a statistical tool used to assess the introduction of a novel technology. In the present study, CUSUM was used to monitor the surgical outcomes and make surgeons aware of their performance as time progressed. Another reason for the use of CUSUM, a time-ordered statistical process control method, was to compare the surgeons' acceptance of 3D-HD laparoscopic vs. robotic gastrectomy; these two systems were applied to general surgeries at almost the same time following the complete adoption of traditional laparoscopy, which had already prepared the surgeons with the necessary skills for minimally invasive surgery. This study may be superior to previous studies (32) because it balanced the difference between surgeons moving from laparoscopic to robotic or 3D-HD laparoscopic surgery.

The total financial cost of robotic gastrectomy was 40,210 RMB more than that of 3D-HD laparoscopic gastrectomy. Although the Chinese National Health Insurance System covers perioperative care for both procedures, it covers only part of the operation fees for laparoscopic gastrectomy and none of the operation fees for robotic gastrectomy. This means that robotic surgery is a huge financial burden, even for patients with medical insurance.

The raw data of OT was initially plotted chronologically; CUSUM was then applied to analyze the change in consecutive cases, generating a six-order polynomial curve. The learning curves were then divided into three unique phases. Phase I refers to the process of acquiring a new skill and is expected to be a rising curve (33). The performance of an individual surgeon reaches a steady state at the end of Phase I. In Phase II, the surgeons accumulate experience and achieve proficiency. During Phase III, the surgeons master the technique, and are open to more complicated and demanding cases, which explains the fluctuant performance based on the difficulty of the cases.

Because laparoscopic gastrectomy has facilitated postoperative recovery of open gastrectomy due to reduced blood loss, earlier bowel function recovery, and a shorter length of hospitalization, there may not be much room left for improvement in robotic surgery (30). Robotic gastrectomy was performed using the same surgical principles and procedures in a similar environment but with different instruments compared with laparoscopic gastrectomy (32).

This study had some limitations. Firstly, selection bias was inherent to this retrospective study despite the prospectively constructed database. Secondly, the sample size was insufficient. With regards to the linear relationship between time to flatus and time to soft diet, this study did not analyze the time to soft diet; however, the time to soft diet is an important factor to evaluate functional recovery of the gastrointestinal tract. Thirdly, because 3D-HD laparoscopic gastrectomy has only been applied for ~3 years, long-term oncological outcomes, including late complications, recurrence and survival were not recorded in this study. We aim to continue collecting these data in this prospectively enrolled cohort, in order to assess the long-term outcomes. Future studies will focus on these limitations and provide better solutions. Despite these limitations, to the best of our knowledge, this study is the first comprehensive investigation to compare the short-term outcomes, including the financial cost and learning curves, of robotic and 3D-HD laparoscopic surgery for patients with GC.

The aim of this study was not to deny that robotic operation systems are the future of surgery. In consideration of economic factors, the widespread use of robotic surgery may take a long time. In the meantime, 3D-HD laparoscopic surgery may be a promising alternative for patients with GC.

In conclusion, with comparable surgical outcomes, lower financial cost and higher surgeon acceptance, 3D-HD laparoscopy is highly recommended as a minimally invasive surgical method for patients with GC prior to the popularization of robotic surgery.

Acknowledgements

Not applicable. The present study was presented as an Abstract at the 2018 Gastrointestinal Cancers Symposium (ascopubs.org/doi/abs/10.1200/JCO.2018.36.4_suppl.162).

Funding

This work was supported by grants from the Beijing Nova Program (grant no. xx2018114), the Chinese People's Liberation Army General Hospital Medical Big Data Project (grant no. 2016MBD-012), the National Nature Science Foundation of China (grant nos. 81602507, 81272698 and 81672319), and the National Key R&D Program of China (grant no. 2017YFC0908305). The funding bodies had no role in the design of the study; collection, analysis, or interpretation of the data; or manuscript writing.

Availability of data and materials

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

Authors' contributions

JL participated in the study design and drafted the manuscript. HX and XG analyzed and interpreted the data. YG and TX collected the clinical data and performed follow-up. ZQ and LC participated in the study design, carried out the surgical operation and gave final approval of the version to be published. All of the authors are in agreement with the manuscript's content.

Ethics approval and consent to participate

All enrolled patients gave their written informed consent for treatment. This study was approved by the institutional review board of the Chinese People's Liberation Army General Hospital.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Choi YY, Noh SH and Cheong JH: Evolution of gastric cancer treatment: From the golden age of surgery to an era of precision medicine. Yonsei Med J 56: 1177-1185, 2015.
2. Kim HH, Hyung WJ, Cho GS, Kim MC, Han SU, Kim W, Ryu SW, Lee HJ and Song KY: Morbidity and mortality of laparoscopic gastrectomy versus open gastrectomy for gastric cancer: An interim report - a phase III multicenter, prospective, randomized Trial (KLASS Trial). Ann Surg 251: 417-420, 2010.
3. Lu J, Zheng CH, Zheng HL, Li P, Xie JW, Wang JB, Lin JX, Chen QY, Cao LL, Lin M, *et al*: Randomized, controlled trial comparing clinical outcomes of 3D and 2D laparoscopic surgery for gastric cancer: An interim report. Surg Endosc 31: 2939-2945, 2017.

4. Corcione F, Esposito C, Cuccurullo D, Settembre A, Miranda N, Amato F, Pirozzi F and Caiazzo P: Advantages and limits of robot-assisted laparoscopic surgery: Preliminary experience. Surg Endosc 19: 117-119, 2005.
5. Hur H, Kim JY, Cho YK and Han SU: Technical feasibility of robot-sewn anastomosis in robotic surgery for gastric cancer. J Laparoendosc Adv Surg Tech A 20: 693-697, 2010.
6. Suda K, Man-I M, Ishida Y, Kawamura Y, Satoh S and Uyama I: Potential advantages of robotic radical gastrectomy for gastric adenocarcinoma in comparison with conventional laparoscopic approach: A single institutional retrospective comparative cohort study. Surg Endosc 29: 673-685, 2015.
7. Uyama I, Kanaya S, Ishida Y, Inaba K, Suda K and Satoh S: Novel integrated robotic approach for suprapancreatic D2 nodal dissection for treating gastric cancer: Technique and initial experience. World J Surg 36: 331-337, 2012.
8. Sørensen SM, Savran MM, Konge L and Bjerrum F: Three-dimensional versus two-dimensional vision in laparoscopy: A systematic review. Surg Endosc 30: 11-23, 2016.
9. Kim YM, Son T, Kim HI, Noh SH and Hyung WJ: Robotic D2 lymph node dissection during distal subtotal gastrectomy for gastric cancer: Toward procedural standardization. Ann Surg Oncol 23: 2409-2410, 2016.
10. Song J, Oh SJ, Kang WH, Hyung WJ, Choi SH and Noh SH: Robot-assisted gastrectomy with lymph node dissection for gastric cancer: Lessons learned from an initial 100 consecutive procedures. Ann Surg 249: 927-932, 2009.
11. Son T, Lee JH, Kim YM, Kim HI, Noh SH and Hyung WJ: Robotic spleen-preserving total gastrectomy for gastric cancer: Comparison with conventional laparoscopic procedure. Surg Endosc 28: 2606-2615, 2014.
12. Lianos GD, Rausei S, Dionigi G and Boni L: Assessing safety and feasibility of minimally invasive surgical approaches for advanced gastric cancer. Future Oncol 12: 5-8, 2016.
13. Junfeng Z, Yan S, Bo T, Yingxue H, Dongzhu Z, Yongliang Z, Feng Q and Peiwu Y: Robotic gastrectomy versus laparoscopic gastrectomy for gastric cancer: Comparison of surgical performance and short-term outcomes. Surg Endosc 28: 1779-1787, 2014.
14. Shen W, Xi H, Wei B, Cui J, Bian S, Zhang K, Wang N, Huang X and Chen L: Robotic versus laparoscopic gastrectomy for gastric cancer: Comparison of short-term surgical outcomes. Surg Endosc 30: 574-580, 2016.
15. Nakauchi M, Suda K, Susumu S, Kadoya S, Inaba K, Ishida Y and Uyama I: Comparison of the long-term outcomes of robotic radical gastrectomy for gastric cancer and conventional laparoscopic approach: A single institutional retrospective cohort study. Surg Endosc 30: 5444-5452, 2016.
16. Obama K, Kim YM, Kang DR, Son T, Kim HI, Noh SH and Hyung WJ: Long-term oncologic outcomes of robotic gastrectomy for gastric cancer compared with laparoscopic gastrectomy. Gastric Cancer 21: 285-295, 2018.
17. Coratti A, Fernandes E, Lombardi A, Di Marino M, Annecchiarico M, Felicioni L and Giulianotti PC: Robot-assisted surgery for gastric carcinoma: Five years follow-up and beyond: A single western center experience and long-term oncological outcomes. Eur J Surg Oncol 41: 1106-1113, 2015.
18. Rozner MA: The American Society of Anesthesiologists physical status score and risk of perioperative infection. JAMA 275: 1544, 1996.
19. Borrmann R: Geschwulste des Magens und des Duodenums. In: Handbuch Spez Pathol Anat und Histo. Henke F and Lubarsch O (eds). Springer Verlag, Berlin, pp812-1054, 1926.
20. Ajani JA, D'Amico TA, Almhanna K, Bentrem DJ, Chao J, Das P, Denlinger CS, Fanta P, Farjah F, Fuchs CS, *et al*: Gastric cancer, version 3.2016, NCCN clinical practice guidelines in oncology. J Natl Compr Canc Netw 14: 1286-1312, 2016.
21. Dindo D, Demartines N and Clavien PA: Classification of surgical complications: A new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 240: 205-213, 2004.
22. Yang SY, Roh KH, Kim YN, Cho M, Lim SH, Son T, Hyung WJ and Kim HI: Surgical Outcomes After Open, Laparoscopic, and Robotic Gastrectomy for Gastric Cancer. Ann Surg Oncol 24: 1770-1777, 2017.
23. Maguire T, Mayne CJ, Terry T and Tincello DG: Analysis of the surgical learning curve using the cumulative sum (CUSUM) method. Neurourol Urodyn 32: 964-967, 2013.
24. Zhou J, Shi Y, Qian F, Tang B, Hao Y, Zhao Y and Yu P: Cumulative summation analysis of learning curve for robot-assisted gastrectomy in gastric cancer. J Surg Oncol 111: 760-767, 2015.
25. Biswas P and Kalbfleisch JD: A risk-adjusted CUSUM in continuous time based on the Cox model. Stat Med 27: 3382-3406, 2008.
26. Pendlimari R, Holubar SD, Dozois EJ, Larson DW, Pemberton JH and Cima RR: Technical proficiency in hand-assisted laparoscopic colon and rectal surgery: Determining how many cases are required to achieve mastery. Arch Surg 147: 317-322, 2012.
27. Biau DJ, Resche-Rigon M, Godiris-Petit G, Nizard RS and Porcher R: Quality control of surgical and interventional procedures: A review of the CUSUM. Qual Saf Health Care 16: 203-207, 2007.
28. Son T, Hyung WJ, Lee JH, Kim YM, Kim HI, An JY, Cheong JH and Noh SH: Clinical implication of an insufficient number of examined lymph nodes after curative resection for gastric cancer. Cancer 118: 4687-4693, 2012.
29. Hyun MH, Lee CH, Kwon YJ, Cho SI, Jang YJ, Kim DH, Kim JH, Park SH, Mok YJ and Park SS: Robot versus laparoscopic gastrectomy for cancer by an experienced surgeon: Comparisons of surgery, complications, and surgical stress. Ann Surg Oncol 20: 1258-1265, 2013.
30. Kim HI, Han SU, Yang HK, Kim YW, Lee HJ, Ryu KW, Park JM, An JY, Kim MC, Park S, *et al*: Multicenter Prospective Comparative Study of Robotic Versus Laparoscopic Gastrectomy for Gastric Adenocarcinoma. Ann Surg 263: 103-109, 2016.
31. Lanfranco AR, Castellanos AE, Desai JP and Meyers WC: Robotic surgery: A current perspective. Ann Surg 239: 14-21, 2004.
32. Kim HI, Park MS, Song KJ, Woo Y and Hyung WJ: Rapid and safe learning of robotic gastrectomy for gastric cancer: Multidimensional analysis in a comparison with laparoscopic gastrectomy. Eur J Surg Oncol 40: 1346-1354, 2014.
33. Jeong O, Ryu SY, Choi WY, Piao Z and Park YK: Risk factors and learning curve associated with postoperative morbidity of laparoscopic total gastrectomy for gastric carcinoma. Ann Surg Oncol 21: 2994-3001, 2014.