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Cost Analysis for Robotic and Open Gastrectomy

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Objective: To determine the magnitude of the perioperative costs associated with robotic gastrectomy (RG).

Background: A robotic surgery platform has a high implementation cost and requires maintenance costs; however, whether the overall cost of RG, including all perioperative costs, is higher than conventional open gastrectomy (OG) remains unknown.

Methods: Patients who underwent a major gastrectomy during February 2018 through December 2021 were retrospectively identified. We calculated the perioperative costs of RG and OG and compared them overall as well as in different phases, including intraoperative costs and 30-day postsurgery inpatient and outpatient costs. We investigated factors potentially associated with high cost and estimated the likelihood of RG to reduce overall cost under a Bayesian framework. All cost data were converted to ratios to the average cost of all operations performed at our center in year FY2021.

Results: We identified 119 patients who underwent gastrectomy. The incidence of postoperative complications (Clavien-Dindo >IIIa; RG, 10% vs OG, 13%) did not significantly differ between approaches. The median length of stay was 3 days shorter for RG versus OG (4 vs 7 days, $P < 0.001$). Intraoperative cost ratios were significantly higher for RG (RG, 2.6 vs OG, 1.7; $P < 0.001$). However, postoperative hospitalization cost ratios were significantly lower for RG (RG, 2.8 vs OG, 3.9; $P < 0.001$). Total perioperative cost ratios were similar between groups (RG, 6.1 vs OG, 6.4; $P = 0.534$). The multiple Bayesian generalized linear analysis showed RG had 76.5% posterior probability of overall perioperative cost reduction (adjusted risk ratio of 0.95; 95% credible interval, 0.85–1.07).

Conclusions: Despite increased intraoperative costs, total perioperative costs in the RG group were similar to those in the OG group because of reduced postoperative hospitalization costs.

INTRODUCTION

Minimally invasive gastrectomy, such as laparoscopic gastrectomy (LG) and robotic gastrectomy (RG), has been increasingly performed for gastric cancer (GC) globally.[1] Several phase III randomized clinical trials in patients with early or advanced GC have shown that the short- and long-term outcomes achieved with LG are not inferior to those achieved with open gastrectomy (OG).[2–5] In addition, RG has several technical advantages, such as 3D visualization and augmented surgical skills, which allow high-quality resection of GC with lymph node dissection and may overcome some of the limitations of LG.[6–9] According to recent prospective studies, RG takes longer operation time but has shorter length of hospital stay (LOS) and fewer postoperative complications than LG.[10–14] The robotic surgery platform also improves surgeons' ergonomics during operations.[15] While RG appears promising for providing improved outcomes for GC patients, among the largest hazards of implementation of RG is cost.[10,16] A robotic surgery platform has a high implementation cost and requires maintenance costs[17]; however, the reports of the overall cost of RG, including all perioperative costs, are limited, and the cost of RG is expected to vary by countries and institutions with different health care systems.[18] RG may cost more for the operation itself, but with reported shorter LOS and lower complication rates of RG compared to OG,[12,14] the magnitude of the total cost difference between RG and OG needs comprehensive assessment.

In our institution, we initiated an RG program in 2018 and found equivalent safety outcomes and improved LOS as well as reduced opioid use in RG patients compared with OG patients during our implementation period.[9,19] We hypothesized that RG has equivalent or lower overall perioperative costs compared to OG, via its reduction of LOS and postoperative complications despite higher operation costs. The main objective of this study was to compare costs associated with RG and OG, to determine whether the cost of RG was substantially increased during this implementation period. Thus, we calculated the perioperative costs of RG and OG, compared them overall and in different phases, investigated factors associated with high cost, and estimated the likelihood of RG to reduce overall cost using Bayesian analyses.

MATERIALS AND METHODS

Patients

After obtaining approval from our institutional review board, we queried a prospectively maintained departmental database of gastric surgery cases and retrospectively analyzed the records of patients who had undergone major gastrectomy (total, distal, or proximal gastrectomy) at our institution during January

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2018 through December 2021. All cases were managed according to our standardized Enhanced Recovery After Surgery opioid-reduction protocol during the perioperative period.[20, 21] Patients who had undergone multiple organ resection, hyperthermic intraperitoneal chemotherapy, or prophylactic total gastrectomy owing to an inherited CDH1 mutation were excluded. One patient who received postoperative chemotherapy within 30 days after surgery was also excluded, since chemotherapy cost could not be reliably excluded from the cost calculation. Gastrectomies were performed by 3 surgical oncologists at our institution during this period. RG program was implemented in October 2018, and it was performed by 2 surgeons during this study period. The current study included the first patient who underwent RG after implementation of the program.

Surgical Outcomes

The patient and tumor characteristics collected were age, sex, race and ethnicity, body mass index (BMI), type of resection, type of preoperative therapy, and clinical and pathologic T and N categories (defined according to the Cancer Staging Manual, 8th edition[22]). Short-term surgical outcomes collected were the operation time, estimated blood loss, LOS, use of jejunostomy tube, prescribed opioid use at discharge, postoperative complications within 30 days (according to the Clavien-Dindo [CD] classification), and postoperative readmission within 30 days.

Cost Outcomes

The cost is obtained from the hospital's internal enterprise cost accounting system. We used revenue codes defined by National Uniform Billing Committee[23] to calculate and subgroup hospital costs in different phases. Revenue codes are 3- or 4-digit codes used by providers in the United States for billing purposes to describe to the payers the type of service provided to a patient, where it was provided, and an associated dollar amount. The system breaks down the total costs for the hospital from the general ledger and views the costs at the individual patient level by utilizing multiple allocation methods, including time-driven allocation method for estimation of labor costs. The cost estimation process was carefully conducted by our institution's financial division using detailed costing data.[24, 25] The primary outcome of this study was total perioperative cost (ie, the best estimate to represent how much the hospital paid to provide the service during both the index hospitalization and 30 days of postoperative care). We calculated costs of (1) the operation, (2) postoperative inpatient care, (3) readmission, and (4) outpatient care within 30 days from surgery. The sum of (1) the operation and (2) postoperative inpatient care costs was defined as the total index hospitalization cost, and the sum of (3) readmission and (4) outpatient care costs was defined as the after-discharge cost. The sum of all the costs was defined as the total perioperative cost (the primary outcome). Cost categories are detailed in

TABLE 1.

Cost Breakdown and Revenue Codes

Cost	Contents	Revenue Code
First hospitalization		
Operation		
Anesthesia	General anesthesia instrument cost (intubation tube, anesthesia machine, monitor, block anesthesia)	370, 374
Operation room	OR charge, operation instruments fees (including implementation and maintenance cost), intraoperative radiation imaging, labor cost	360, 361
Postoperative hospitalization		
Laboratory	Laboratory tests and pathology costs during the hospitalization (including them in OR, ICU, intermediate room, recovery room, intermediate room and regular surgery unit)	300, 301, 302, 305, 306, 309, 310, 311, 312, 314, 319
Radiation imaging	X-ray, CT, MRI, US, endoscopy, interventional radiology (except OR)	320, 350, 351, 352, 402, 404, 610, 611, 612, 614, 615, 616, 618, 750, 761
ICU	ICU room charge, labor cost	200, 202
Intermediate room	Intermediate room charge, labor cost	206
Recovery room	Recovery room charge, labor cost	710
Regular surgery unit and supply	Regular surgery unit charge, dressing materials, feeding tube-related costs, labor cost	110, 119, 270, 271, 272, 273, 274, 275, 278, 279, 623
Pharmacy	Medication, discharge prescription, intravenous fluid, and transfusion-related cost during the hospitalization (including OR, ICU, intermediate room, recovery room, intermediate room and regular surgery unit)	250, 251, 252, 253, 255, 257, 258, 259, 260, 331, 335, 380, 381, 383, 384, 386, 387, 390, 391, 636, 637, 647
Rehabilitation	PT, OT, ST during the hospitalization	420, 429, 430, 439, 440, 444, 449, 471, 479
Others	Inpatient consultation professional fees (cardiology, infectious disease, etc), dialysis-related cost, respiratory therapy service (ventilator), durable medical equipment, counseling (nutrition, mental), pulmonary function test, EEG, EKG	292, 410, 460, 480, 481, 482, 483, 730, 731, 740, 750, 762, 769, 780, 800, 801, 809
After discharge		
Readmission	Same as above	
Outpatient (30 d after surgery)		
Follow-up, ER	Outpatient clinic visit fee, ER visit fee, laboratory tests performed in outpatient clinic and ER	300, 301, 302, 305, 306, 309, 310, 311, 312, 314, 319, 450, 456, 510, 519
Pharmacy	Medications, intravenous fluid, transfusion in clinic or ER	250, 251, 252, 255, 257, 258, 259, 260, 331, 335, 380, 381, 383, 384, 386, 387, 390, 391, 450, 456, 636, 637, 647
Endoscopy	Outpatients endoscopy-related cost	750
Image	X-ray, CT, MRI, US, fluoroscopy in clinic or ER	320, 350, 351, 352, 402, 404, 610, 611, 612, 614, 615, 616, 618, 761
Others	Dressing materials, drain and feeding tube-related costs, disinfectant, dialysis-related cost, respiratory therapy service, durable medical equipment, counseling (nutrition, mental), pulmonary function test, EEG, EKG in clinic or ER	270, 271, 272, 273, 274, 275, 278, 279, 292, 410, 460, 420, 429, 430, 439, 440, 444, 449, 460, 471, 479, 480, 481, 482, 483, 623, 730, 731, 740, 762, 769, 780, 829, 900, 914, 915, 916, 918

ER indicates emergency room; ICU, intensive care unit.

Table 1. For example, the cost of "operation room" included the cost of operating room use (based on the duration of the room's use, from patient's entry to exit), instruments' cost (including initiation and maintenance cost of instruments, including surgical robots, appropriately calculated for each individual use), cost of radiology imaging performed in the operating room (added according to the modality used and based on the minutes that it was used.), and labor costs. The labor costs in this study included nurses, respiratory therapist, physical therapist, occupational therapist, and speech and language therapist. We decided not to include professional costs for surgeons or anesthesiologists since we were not able to estimate their procedure costs reliably and consistently because of significant variation in physicians' salaries and lack of Current Procedural Terminology codes for robotic procedures. Additional costs specific to the use of the robotic surgical system (lease, depreciation, maintenance, etc) were updated each year and were added as a cost under Rev code 360. Costs of "laboratory" and "pharmacy" represent the sum of those costs incurred during the entire hospitalization (including those incurred during operation and the rest of the hospital stay). Similarly, operation cost included costs required for reoperation during the same hospitalization, because it was difficult to distinguish those costs separately. All cost data were converted to ratios to the average cost of all operations performed at our center in year FY2021, to represent costs without sharing proprietary financial data.

$$\text{Cost ratio} = \frac{\text{Each cost}}{\text{Average cost of all operations at our center}}$$

Data Analyses

The primary exposure of this study was surgical approach (OG vs RG). Descriptive analyses were performed to compare the 2 approaches in terms of patient and tumor characteristics, short-term surgical outcomes, and costs. Categorical variables were compared using the χ^2 test or Fisher exact test where appropriate. Continuous variables were compared using the Student *t* test or Mann-Whitney *U* test where appropriate. Categorical and continuous variables were presented as the median (range) and as count (percentage), respectively. We also performed stratified perioperative cost analysis using analysis of variance. Patients were stratified by age, sex, race and ethnicity, BMI, tumor histology, pathologic T and N category, type of surgery, postoperative complication occurrence and grade, and readmission 30 days after surgery. Unless otherwise specified, $P < 0.05$ was considered statistically significant. Under a Bayesian framework, we estimated the cost-effectiveness of RG compared to OG after adjusting for covariates including age, sex, BMI, and the type of surgery. These covariates were selected from preoperative factors that were either significant in univariate analysis or considered clinically significant. The cost-effectiveness was determined by the posterior probability that the "risk ratio" of the mean perioperative costs of RG to those of OG would be less than 1 (ie, that RG would reduce the perioperative cost compared to OG). This posterior probability was referred to as the probability of RG benefit. Using the brms package[26] in R, we used simple and multiple Bayesian generalized linear models with gamma distribution and log link. Because there was no robust evidence to date of perioperative cost reduction with RG, we used a neutral prior probability centered at a cost ratio of 1.0 (ie, no difference in cost between RG and OG) and a 95% credible interval (CrI) of 0 to 0.4. Using the same specifications, we performed simple Bayesian generalized linear regression analyses with each covariate for adjustment to assess the cost-effectiveness of each. All statistical analyses were conducted using Stata 14.1 and R version 3.6.1.

RESULTS

Patient Characteristics and Surgical Outcomes

Patient characteristics and surgical outcomes are summarized in Tables 2 and 3. A total of 119 patients were included. Seventy-eight patients (66%) underwent OG and 41 (34%) underwent RG. The groups had no significant differences in patient or disease characteristics. Compared with OG, RG had a longer median operation time (346 minutes vs 270 minutes), smaller median estimated blood loss (50 mL vs 150 mL), shorter median LOS (4 days vs 7 days), and lower median prescribed opioid dose at discharge (0 mg vs 50 mg) (all $P < 0.001$). A feeding jejunostomy tube was placed exclusively in the OG group (88%); none was placed in the RG group (0%; $P < 0.001$). The groups showed similar incidences of postoperative complications (CD grade ≥IIIa) (RG, 10% vs OG, 13%; $P = 0.622$) and readmission (RG, 10% vs OG, 15%; $P = 0.392$).

Cost Outcomes

Cost analysis results are summarized in Table 4. Operative cost ratio was significantly higher in the RG group (2.54 vs 1.67; $P < 0.001$) (Fig. 1A). However, the postoperative inpatient cost ratio was significantly lower in the RG group (2.80 vs 3.93; $P < 0.001$) (Fig. 1B). Taken together, total index hospitalization cost ratios were similar between groups (RG, 5.35 vs OG, 5.60; $P = 0.442$) (Fig. 1C). In the breakdown of operation cost, RG cost ratios were significantly higher for anesthesia (0.36 vs 0.34; $P = 0.041$) and operation room (2.18 vs 1.33; $P < 0.001$), likely driven by longer operation time and robotic implementation/maintenance costs. Conversely, in the breakdown of postoperative hospitalization cost, RG had significantly lower cost ratios for ICU (0.50 vs 0.65; $P = 0.014$), pharmacy (0.52 vs 0.84; $P < 0.001$), and the room charge of regular surgery unit and various supplies (0.77 vs 0.84; $P < 0.001$). There was no significant difference in readmission cost ratios (RG, 0.43 vs OG, 0.38; $P = 0.845$) (Fig. 1D). RG had a lower follow-up and emergency room cost ratio (RG, 0.17 vs OG, 0.26; $P = 0.002$) in the breakdown analysis; however, total outpatient cost ratios did not differ between groups (RG, 0.33 vs OG, 0.40; $P = 0.287$) (Fig. 1E). In sum, the total postdischarge cost ratios were similar between groups (RG, 0.76 vs OG, 0.78; $P = 0.931$) (Fig. 1F). Altogether, total perioperative cost ratios were similar between the 2 groups (RG, 6.11 vs OG, 6.38; $P = 0.534$) (Fig. 1G).

Variables Associated With Higher Cost

Univariable analyses of factors associated with higher cost are summarized in Table 5. The perioperative cost ratio was significantly higher with older age (<60, 5.92; 61–74, 6.17; ≥75, 7.44; $P = 0.040$), higher complication grade (CD grade >II, 5.75; II–IIIa, 7.85; ≥IIIb, 13.59; $P < 0.001$), and readmission (no readmission, 5.77; readmission, 9.41; $P < 0.001$). No other factors in this analysis significantly increased cost.

Bayesian Regression Analysis

The results of Bayesian generalized linear regression models are summarized in Table 6. Based on a simple regression model, it was very unlikely (0.28%) that the total perioperative cost for patients aged ≥75 was less than that of patients aged <60 (risk ratio, 1.26; 95% CrI, 1.07–1.47). The probability that female patients have lower costs than male patients was 92% (risk ratio, 0.92; 95% CrI, 0.81–1.03). After adjustment for age, sex, BMI, and surgery type, RG had a 76.5% posterior probability of overall perioperative cost reduction (adjusted risk ratio, 0.95; 95% CrI, 0.85–1.07) compared to OG (Fig. 2).

TABLE 2.

Patient and Tumor Characteristics

		Gastrectomy Type		
	Total (n = 119)	**Open (n = 78)**	**Robotic (n = 41)**	***P***
Patient characteristics				
Age, median (range), yr	64 (21–85)	66 (21–84)	63 (37–85)	0.460
Sex, n (%)				0.116
Male	78 (66)	55 (71)	23 (56)	
Female	41 (34)	23 (29)	18 (44)	
Race/ethnicity, n (%)				0.605
Non-Hispanic White	56 (47)	39 (50)	17 (41)	
Non-Hispanic Black	17 (14)	12 (15)	5 (12)	
Asian	15 (26)	8 (10)	7 (17)	
Hispanic/Latino	31 (13)	19 (24)	12 (29)	
BMI, median (range)	26 (17–48)	26 (17–37)	26 (19–48)	0.665
Tumor characteristics				
Histology				0.084
Adenocarcinoma	111 (93)	75 (96)	36 (88)	
Nonadenocarcinoma	8 (7)	3 (4)	5 (12)	
Tumor location, n (%)				0.777
GEJ, cardia	39 (33)	25 (32)	14 (34)	
Body	33 (28)	20 (26)	13 (32)	
Antrum	39 (33)	28 (36)	11 (27)	
Whole stomach	8 (6)	5 (6)	3 (7)	
Clinical T category, n (%)				0.172
1	16 (13)	14 (18)	2 (5)	
2	18 (15)	12 (15)	6 (15)	
3	65 (55)	41 (53)	24 (59)	
4	12 (10)	8 (10)	4 (10)	
NA*	8 (7)	3 (4)	5 (12)	
Clinical N status, n (%)				0.205
Negative	68 (57)	47 (60)	21 (51)	
Positive	43 (36)	28 (36)	15 (37)	
NA*	8 (7)	3 (4)	5 (12)	

*Not included in statistical analysis.
GEJ indicates gastroesophageal junction.

DISCUSSION

In this study, we compared the overall perioperative cost between RG and OG. To our knowledge, this is the first study to do so in the United States, using detailed and thorough financial data. As expected, intraoperative costs were significantly higher in the RG group due to longer operation time in addition to the implementation and maintenance costs associated with robotic surgical systems. However, the total hospitalization costs were similar between groups because of lower postoperative inpatient costs in the RG group. Overall, the total 30-day perioperative costs were similar between groups. Additionally, the Bayesian analysis showed that RG has a 76.5% probability to reduce the mean of the total perioperative cost. Furthermore, this study included patients treated during the implementation phase of RG in our institution, and thus indicated the possibility of further reducing perioperative costs in the future with maturing experience and techniques of surgeons.[27, 28]

The cost of health care in the United States has been sharply rising during the past 2 decades.[29, 30] This is driven by the development of new medical technologies and drugs, as well as demographic changes such as population growth and aging.[31] In the United States, the Food and Drug Administration approves newly developed medical devices and drugs based on clinical benefits, regardless of their high prices.[29] In contrast, some other countries with national insurance coverage have more strict value analyses to determine new device/drug approval in different degrees.[32] For example, while RG was recently approved in Japan based on data with improved clinical outcomes,[13] it requires patients' additional payment in Korea.[10, 25] On the contrary, robotic surgery overall is not covered by insurance in Canada because the potential clinical benefits are not considered justified by the significant increase in operative cost.[33] In the United States, although robotic procedures usually do not have an increased charge for hospitals under most insurance contracts,[34, 35] the use of robotic approaches has consistently increased over the past decade to improve patients' outcomes and satisfaction, including for gastrectomy.[1] As studies showed previously, the cost of implementation and maintenance of robotic surgery is substantial[36]; however, the total cost of robotic surgery should be accounted for by including total perioperative cost. Moreover, the total costs of surgery for patients do not end there; considerations should include traveling and lodging or surgery and loss of income due to taking off work during functional recovery, and the robotic approach has the potential to reduce these costs as well. Ultimately, the total value of robotic surgery for patients and society will be determined by improved patients' outcomes, improved quality of life, reduction of opioid use (and potential prevention of addiction), and so on.[21, 37] The cost and value of newer technologies should be analyzed thoroughly and holistically to support or restrict implementation.

Two previous studies of the cost of RG included costs during postoperative hospitalization. Lu et al[17] from China compared perioperative costs between RG and LG (101 RG vs 303 LG). They showed that total indirect cost for RG was higher than that of LG (RG, \$3, 727 vs LG, \$757; $P < 0.001$), while total direct was similar between groups (RG, \$10, 572 vs LG, \$10, 284; $P = 0.348$). This study indicated that RG is unlikely to reduce postoperative cost enough to overcome the increased operative cost in centers where LG practice is already established and in countries where postoperative cost is less expensive than in the United States. Caruso et al[38] conducted a cost-effectiveness

TABLE 3.

Surgical Outcomes

		Gastrectomy Type		
	Total (n = 119)	**Open (n = 78)**	**Robotic (n = 41)**	***P***
Surgical outcomes				
Type of resection, n (%)				0.695
Total/proximal gastrectomy	61 (51)	41 (53)	20 (49)	
Distal/subtotal gastrectomy	58 (49)	37 (47)	21 (51)	
Surgery time, median (range); min	290 (125–608)	270 (125–459)	346 (210–608)	<0.001
Estimated blood loss, median (range), mL	100 (10–450)	150 (50–450)	50 (10–250)	<0.001
Length of stay, median (range), d	7 (2–22)	7 (5–22)	4 (2–14)	<0.001
Jejunostomy tube, n (%)				<0.001
Yes	69 (58)	69 (88)	0 (0)	
No	50 (42)	9 (12)	41 (100)	
Prescribed OME at discharge, median (range), mg	50 (0–100)	50 (0–100)	0 (0–50)	<0.001
Pathology				
Pathologic T category, n (%)				0.381
0	16 (13)	10 (13)	6 (15)	
1	35 (29)	22 (28)	13 (32)	
2	14 (12)	11 (14)	3 (7)	
3	39 (33)	26 (33)	13 (32)	
4	7 (6)	6 (8)	1 (2)	
NA*	8 (7)	3 (4)	5 (12)	
Pathologic N category, n (%)				0.578
0	68 (57)	47 (60)	21 (51)	
1	24 (20)	15 (19)	9 (22)	
2	9 (8)	6 (8)	3 (7)	
3a	8 (7)	6 (8)	2 (5)	
3b	2 (1)	1 (1)	1 (2)	
NA*	8 (7)	3 (4)	5 (12)	
Complications CD ≥IIIa 30 d after surgery				0.622
No	105 (88)	68 (87)	37 (90)	
Yes	14 (12)	10 (13)	4 (10)	
Readmission 30 d after surgery				0.637
No	102 (86)	66 (85)	36 (88)	
Yes	17 (14)	12 (15)	5 (12)	

*Not included in statistical analysis.

OME indicates oral morphine equivalent.

TABLE 4.

Cost Comparison Between Open Gastrectomy and Robotic Gastrectomy

		Gastrectomy Type		
Cost Ratio, Mean (SD)	**Total (n = 119)**	**Open (n = 78)**	**Robotic (n = 41)**	***P***
Hospitalization				
Operation	1.97 (0.56)	1.67 (0.38)	2.54 (0.36)	<0.001
Anesthesia	0.34 (0.08)	0.34 (0.06)	0.36 (0.11)	0.041
Operation room	1.62 (0.52)	1.33 (0.35)	2.18 (0.30)	<0.001
Postoperative hospitalization	3.54 (1.52)	3.93 (1.60)	2.80 (1.01)	<0.001
Laboratory	0.43 (0.16)	0.42 (0.17)	0.45 (0.15)	0.283
Radiation imaging	0.08 (0.12)	0.09 (0.14)	0.05 (0.01)	0.190
ICU	0.60 (0.32)	0.65 (0.24)	0.50 (0.42)	0.014
Intermediate room	0.24 (0.37)	0.26 (0.39)	0.17 (0.31)	0.155
Recovery room	0.20 (0.09)	0.20 (0.09)	0.21 (0.08)	0.507
Regular surgery unit and supplies	1.08 (0.74)	1.32 (0.78)	0.77 (0.47)	<0.001
Pharmacy	0.73 (0.46)	0.84 (0.49)	0.52 (0.30)	<0.001
Rehabilitation	0.06 (0.12)	0.07 (0.14)	0.04 (0.07)	0.152
Others	0.07 (0.15)	0.07 (0.11)	0.07 (0.18)	0.185
Hospitalization total	5.51 (1.65)	5.60 (1.84)	5.35 (1.23)	0.442
Cost after 30-d discharge				
Readmission	0.40 (1.29)	0.38 (1.23)	0.43 (1.41)	0.845
Outpatient	0.38 (0.35)	0.40 (0.27)	0.33 (0.46)	0.287
Follow-up, ER	0.23 (0.16)	0.26 (0.13)	0.17 (0.20)	0.002
Pharmacy	0.07 (0.17)	0.06 (0.12)	0.09 (0.24)	0.477
Endoscopy	0.02 (0.07)	0.02 (0.08)	0.01 (0.05)	0.414
Radiation imaging	0.03 (0.08)	0.03 (0.06)	0.03 (0.09)	0.836
Others	0.02 (0.09)	0.02 (0.09)	0.03 (0.08)	0.652
After-discharge total	0.77 (1.35)	0.78 (1.25)	0.76 (1.52)	0.931
Total				
Total perioperative cost	6.29 (3.34)	6.38 (2.34)	6.11 (2.03)	0.534

SD indicates standard deviation; ER indicates emergency room; ICU indicates intensive care unit.

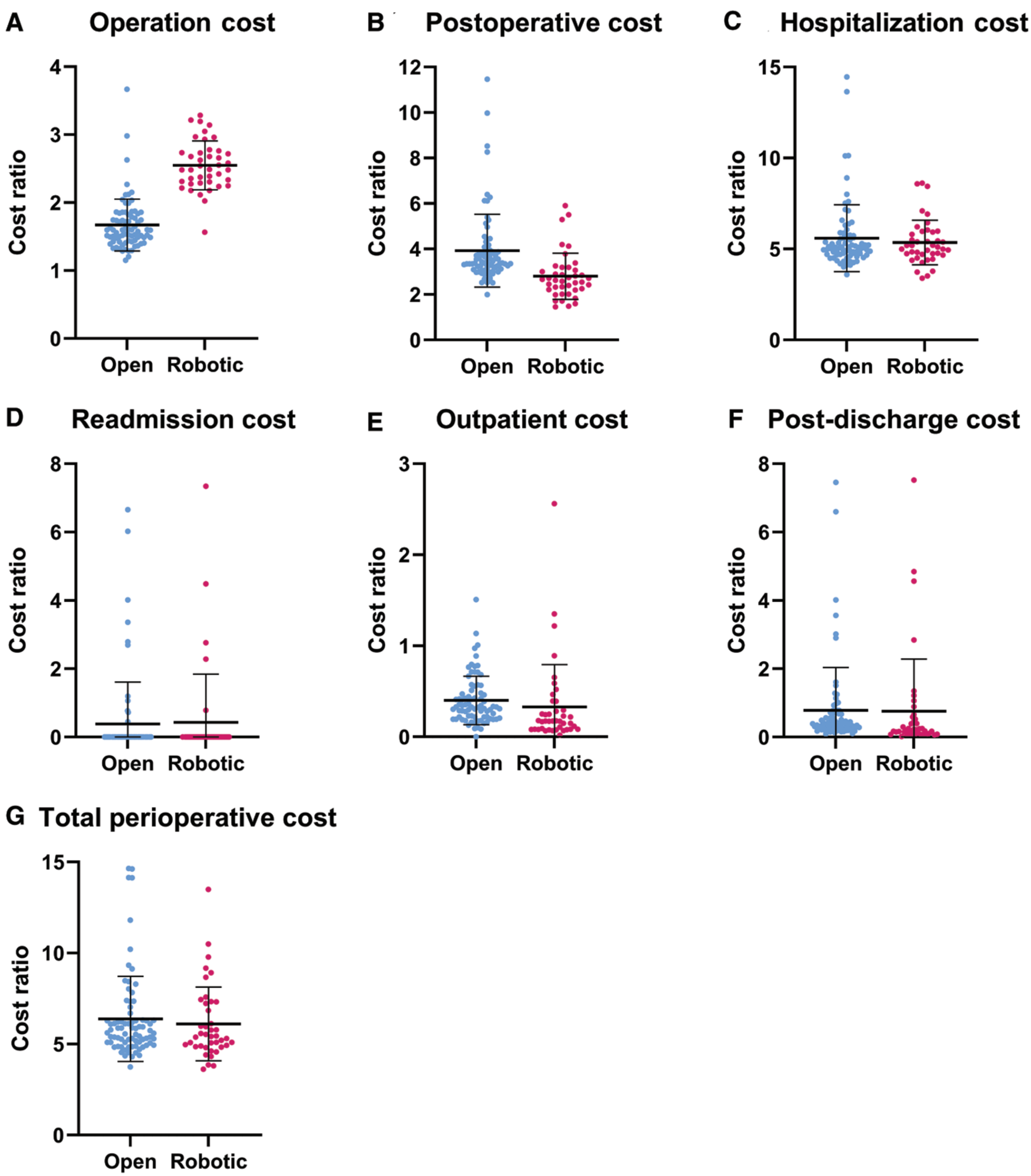

FIGURE 1. Cost comparison (open vs robotic gastrectomy). A, Operation cost. B, Postoperative hospitalization cost. C, Hospitalization cost. D, Readmission cost. E, Outpatient cost. F, Post-discharge cost. G, Total perioperative cost.

analysis of RG in Spain. They included 50 patients who underwent RG or OG and analyzed the costs (from surgery to 90 days after surgery). They demonstrated that the incremental utility was 0.038 quality-adjusted life years in the RG group, and the estimated incremental cost-effectiveness ratios were dominant; therefore, they concluded RG for GC is cost-effective.

In the current study, we found that postoperative inpatient cost was the largest part of the total perioperative cost (56% [3.54/6.29]), while operative cost was a relatively minor component of the cost (31% [1.97/6.29]) overall. Moreover, we observed significant increases in cost with the rise of complication grade. These findings indicated that preventing postoperative complications is critical to reduce perioperative cost. Two randomized controlled trials showed RG may reduce the incidence of postoperative complications compared to LG. Ojima et al[12] conducted a 2 centers randomized controlled trial that enrolled 241 patients. They showed a significantly lower overall incidence of postoperative complications

TABLE 5.

Total Perioperative Cost Analysis Stratified by Patients', Tumor Characteristics, and Surgical Outcomes (Total N = 119)

Outcome, n (%)	Total Perioperative Cost Ratio, Mean (SD)	P
Age		0.040
<60 yr; 43 (36)	5.92 (1.61)	
61–74 yr; 53 (45)	6.17 (2.07)	
≥75 yr; 23 (20)	7.44 (3.39)	
Sex		0.230
Male; 78 (66)	6.47 (2.38)	
Female; 41 (34)	5.95 (1.88)	
Race and ethnicity		0.948
Non-Hispanic White; 56 (47)	6.27 (2.45)	
Non-Hispanic Black; 17 (14)	6.56 (1.41)	
Asian; 15 (26)	6.10 (2.63)	
Hispanic; 31 (13)	6.27 (2.06)	
BMI ≥35		0.603
No; 109 (92)	5.94 (1.13)	
Yes; 10 (8)	6.32 (2.31)	
Histology		0.110
Adenocarcinoma; 111 (93)	6.38 (2.24)	
Nonadenocarcinoma; 8 (7)	5.07 (1.82)	
Pathologic T category*		0.344
0; 16 (14)	6.24 (2.53)	
1; 35 (32)	6.16 (1.55)	
2; 14 (13)	7.18 (2.78)	
3; 39 (35)	6.21 (2.27)	
4; 7 (6)	7.06 (3.22)	
Pathologic N category*		0.454
0; 68 (61)	6.48 (2.41)	
1; 24 (22)	6.05 (1.75)	
2; 9 (8)	7.03 (2.89)	
3a; 8 (7)	5.96 (1.40)	
3b; 2 (2)	5.28 (0.14)	
Type of surgery		0.810
Total/proximal; 61 (51)	6.33 (2.19)	
Subtotal/distal; 58 (49)	6.24 (2.29)	
Complications 30 d after surgery		<0.001
CD <II; 105 (88)	5.75 (1.28)	
CD II–IIIa; 8 (7)	7.85 (2.17)	
CD ≥IIIb; 6 (5)	13.59 (1.58)	
Readmission 30 d after surgery		<0.001
No; 102 (86)	5.77 (1.52)	
Yes; 17 (14)	9.41 (3.15)	

*Eight patients with nonadenocarcinoma were excluded.
SD indicates standard deviation.

TABLE 6.

Bayesian Generalized Linear Models for Perioperative Cost (Gamma Distribution, Weakly Informative Prior Probability)

Multivariable Analysis	Bayesian aRR (95% CrI)*	Posterior Probability of Benefit (%)†
Robotic (ref. open)	0.95 (0.85–1.07)	78.6
Univariable Analysis	**Bayesian Risk Ratio**	**Posterior Probability of Benefit (%)‡**
Age (ref. <60)		
61–74	1.04 (0.92–1.17)	24.7
≥75	1.26 (1.07–1.47)	0.28
Female (ref. male)	0.92 (0.81–1.03)	92.0
BMI	1.01 (0.95–1.06)	42.6
Total/proximal gastrectomy (ref. subtotal/distal gastrectomy)	1.02 (0.90–1.14)	39.1

*After adjustment for covariates including age, sex, BMI, and type of surgery.
†The probability of RG benefit was determined by the posterior probability that the ratio of the mean perioperative costs of the robotic group to that of the open group is less than 1.
‡The posterior probability that the ratio of the mean perioperative costs of the group of interest to the reference group is less than 1.
aRR indicates adjusted risk ratio; ref, reference group.

with RG (CD ≥IIIa, RG, 5.3% vs LG, 16.2%; $P = 0.001$). Lu et al[14] conducted a single-center randomized controlled trial that enrolled 283 patients. The RG group again had a lower overall incidence of postoperative complications (RG, 9.2% vs LG, 17.6%; $P = 0.039$). Thus, RG, which is moving from implementation toward the dissemination phase in the United States, has the potential to reduce perioperative costs if it can be safely implemented and effectively reduce incidence of complication. The biggest challenge of safe implementation of RG practice is its reportedly long learning curve.[27, 28] A strategic approach is important to maintain the safety and oncological quality of RG during the implementation phase,[9] and that would also provide financial benefits to patients and hospitals.

Several potential limitations of this study warrant discussion. First, its retrospective, single-institution cohort design may have incurred selection bias. However, we made our best efforts to minimize it by excluding patients who would not be considered for a robotic approach. As a result, clinicopathological characteristics, such as clinical stage, pathological stage, and BMI, were well balanced between the RG and OG groups (BMI range was rather higher in the robotic cohort). Second, postoperative feeding jejunostomy tubes were used almost exclusively in the OG group. However, we were not able to include the cost of jejunostomy feeding after discharge in this analysis because the cost of home health care was outside our reach. Therefore, outpatient cost for OG patients and potential cost reduction by RG were likely underestimated, further supporting our conclusions. The small sample size in this study is another limitation that likely resulted in lack of power to detect differences. The clinical investigators frequently (and improperly) categorize the results of the Frequentists' approaches as significant or not significant based on a predetermined threshold (ie, P value <0.05).[39] Here, a P value is heavily influenced by sample size, occasionally making it challenging to detect the true intervention effect in studies with small sample sizes. To avoid an excessive reliance on the P value and to provide a probability of benefit (or harm) for a given intervention, we conducted the analysis under a Bayesian framework. We used cost ratio as a measure of cost outcome, which made the interpretations of results of cost analyses and their financial impact difficult. This approach was necessary due to the confidentially required by our institution; furthermore, given the current substantial inflation of hospital care costs, the actual number in US dollars may become irrelevant soon. We believe the presented cost ratio data are sufficient for the intended comparisons between RG and OG to assure nonincreased cost during the implementation phase of the RG program. Finally, this study focused on the hospital's costs; we did not take into account the payment amount by the patients out of pocket or by the payor. However, we carefully determined the magnitude of the impact of RG on perioperative costs using detailed institutional financial data, which was considered the most reliable since it is not affected by insurance policy. Further studies are warranted to include hospital profit, patients' out-of-pocket costs, and magnitude of financial burden on the patients.

In conclusion, despite increased operation costs, total perioperative costs in the RG group were similar to those in the OG group because of the reduction in postoperative hospitalization costs. As expected, preventing postoperative complications is critical to reducing perioperative costs. Our results were obtained during the implementation phase of RG, suggesting that RG has the potential to reduce perioperative costs as surgeons' experience mature in the future.

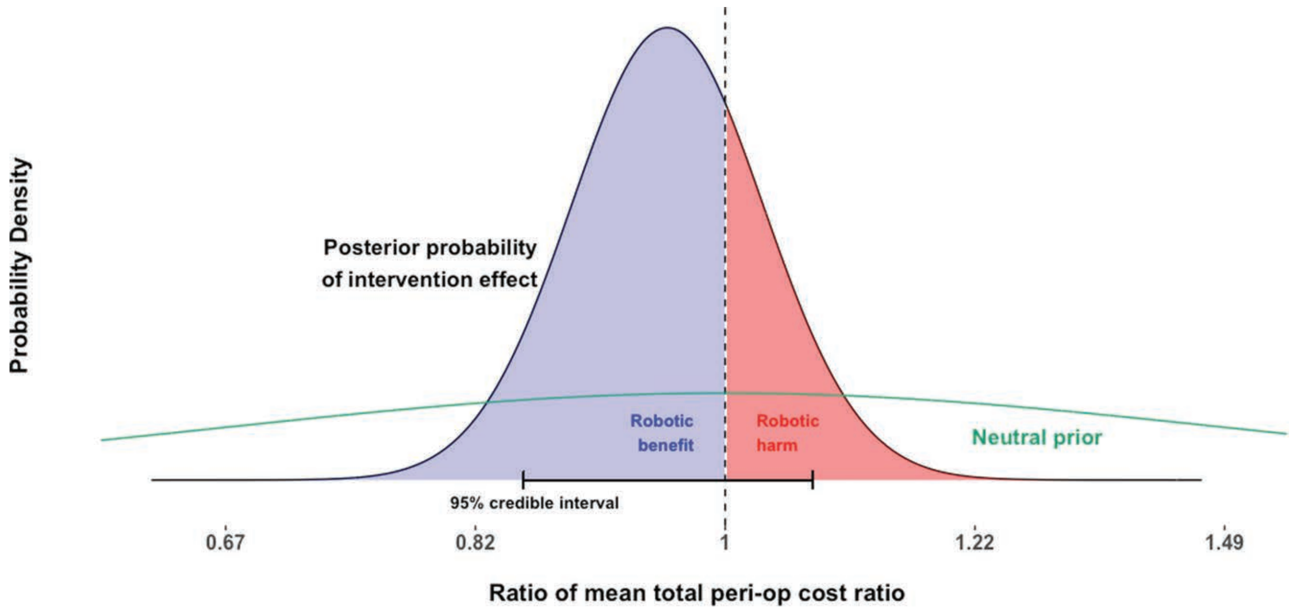

FIGURE 2. Posterior probability of total perioperative cost reduction using robotic gastrectomy.

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