Journal of Robotic Surgery (2023) 17:557–564
https://doi.org/10.1007/s11701-022-01434-5

ORIGINAL ARTICLE

Cost analysis of robotic assisted general surgery cases in a single academic institution

Eva Munshower[1] · Emily Ren[1] · Wayne B. Bauerle[2] · Janice Ruland[3] · Jill Stoltzfus[2] · Marian McDonald[4] · Daniel R. Baillie[4] · Maher El Chaar[5]

Received: 27 September 2021 / Accepted: 6 June 2022 / Published online: 8 August 2022
© The Author(s), under exclusive licence to Springer-Verlag London Ltd., part of Springer Nature 2022

Abstract

Laparoscopy is currently the standard approach for minimally invasive general surgery procedures. However, robotic surgery is now increasingly being used in general surgery. Robotic surgery provides several advantages such as 3D-visualization, articulated instruments, improved ergonomics, and increased dexterity, but is also associated with an increased overall cost which limits its widespread use. In our institution, the robotic assisted approach is frequently used for the performance of general surgery cases including inguinal hernias, cholecystectomies and paraesophageal hernia (PEH) repairs. The primary aim of the study was to evaluate the differences in cost between a robotic and laparoscopic approach for the above-mentioned cases. With IRB approval, we conducted a retrospective cost analysis of patients undergoing inguinal hernia repairs, cholecystectomies and PEH repairs between June 2018 and November 2020. Patients who had a concomitant procedure, a revisional surgery, or bilateral inguinal hernia repair were excluded from the study. Cost analysis was performed using a micro-costing approach. Statistical significance was denoted by $p < 0.05$. There were no differences among the different groups in relation to age, gender, ethnicity, and BMI. The overall cost of the robotic (R-) approach compared to a laparoscopic (L-) approach was significantly lower for cholecystectomy ($3,199.96 vs $4019.89, $p < 0.05$). For inguinal hernia repairs and PEH repairs without mesh, we found no significant difference in overall costs between the R- and L- approach (R- $3835.06 vs L- $3783.50, $p = 0.69$) and (R- $6852.41 vs L- $6819.69, $p = 0.97$), respectively. However, the overall cost of PEH with mesh was significantly higher for the R- group compared to the L- group (R- $7,511.09 vs L- $6,443.32, $p < 0.05$). Based on our institutional cost data, use of a robotic approach when performing certain general surgery cases does not seem to be cost prohibitive.

Keywords Cost · Robotic surgery · Cholecystectomy · Inguinal hernia repair · Paraesophageal hernia repair

✉ Maher El Chaar
Maher.Elchaar@sluhn.org

1 Temple/St. Luke's School of Medicine, Bethlehem, PA, USA

2 Department of Research and Innovation, St. Luke's University Health Network, Bethlehem, PA, USA

3 Cost Accounting Department, St. Luke's University Health Network, Bethlehem, PA, USA

4 Department of Surgery, Division of Minimally Invasive Surgery, St. Luke's University Hospital and Health Network, Allentown, PA, USA

5 Department of Surgery, Division of Bariatric Surgery, St. Luke's University Hospital and Health Network, Allentown, PA, USA

Introduction

Currently, laparoscopy is the standard approach for minimally invasive general, bariatric, and gynecologic surgical procedures. However, laparoscopy has several limitations including the limited range of motion, poor visibility, poor ergonomics, and loss of dexterity [1]. Robotic surgery overcomes several of the previously aforementioned limitations associated with conventional laparoscopic surgery by providing 3D-visualization of the surgical field, articulated instruments, improved ergonomics, and increased dexterity [1]. Although some studies have demonstrated similar clinical outcomes between the robotic (R-) and laparoscopic (L-) approach, the increased overall cost associated with robotic surgery continues to be a barrier to more widespread implementation [2, 3]. Given the increased utilization costs associated with our healthcare system in the United States, cost has become an increasingly important parameter to consider when comparing surgical approaches [4].

The cost associated with robotic surgery remains one of the main arguments against adoption of a robotic approach in the fields of bariatric surgery and general surgery. Several studies have demonstrated higher costs associated with R- assisted surgical procedures when compared to L- procedures due to increased instrument costs and longer operative times [2–12]. However, once surgeons surpass the initial learning curve, surgeons tend to achieve better outcomes in conjunction with shorter operative times, resulting in lower overall costs [13–16]. At our institution, we previously demonstrated that a R- approach to sleeve-gastrectomy and Roux-en-Y gastric bypass is not cost prohibitive when compared to the standard L-approach. Surgeons with significant robotic surgery experience can potentially achieve a reduction in the overall operative time, resulting in additional savings and cost reduction [13, 15]. At our institution, general surgery is one of the surgical specialties that has witnessed a rapid increase in robotic surgery utilization over the past few years. Given the rapid growth in robotic surgery utilization, the primary objective of the study was to evaluate the direct medical costs of using a R- approach in comparison to a L- approach for three commonly performed general surgery procedures at our institution including cholecystectomies, inguinal hernia repairs, and paraesophageal hernia (PEH) repairs.

Methods

After receiving Institutional Review Board (IRB) approval, retrospective chart review and data collection was performed on 367 patients who underwent primary cholecystectomy, 285 patients who underwent primary inguinal hernia repair, and 164 patients who underwent primary PEH repair from June 28th, 2018, through November 30th, 2020. All robotic assisted procedures were performed using the Xi da Vinci platform. Data sources consisted of both inpatient and outpatient clinical datasets. Patients who had a concomitant procedure, a revisional surgery, or bilateral inguinal hernia repair were excluded from the study. All patients underwent the same preoperative workup and followed a similar postoperative protocol for their respective procedures.

Direct cost data were entered daily into EPIC, the institutions electronic medical record (EMR), and cost data were generated using StrataJazz. Of note, the EMR system only contains hospital-based data. Diagnosis-Related Group (DRG) codes 417, 418, and 419 were used to classify inpatient cholecystectomies. DRG codes 350, 351, and 352 were used to classify inpatient inguinal hernia repairs; however, the data collected for inpatient L- inguinal hernia repairs were not used because there were zero patients who underwent inpatient R- inguinal hernia repair within the study period timeframe. DRG codes 326, 327, and 328 were used to classify inpatient PEH repairs. Outpatient cases for these procedures were classified via Current Procedural Terminology (CPT) codes. Outpatient cholecystectomy was classified with CPT code 47562. Outpatient inguinal hernia repair was classified with CPT code 49650. Patients who underwent PEH repair were further stratified based on the use or absence of mesh. Outpatient PEH was classified with CPT codes 43281 (without mesh) and 43282 (with mesh). For insurance purposes, PEH repairs were entered into the hospitals data collection system as inpatient or outpatient; however, those categories were combined for the purpose of our analysis given that outpatient PEH repairs (just like the inpatient ones) were admitted to the hospital following the index procedure as per our protocol for postoperative management. PEH repairs were further classified as R- or L- based on information from the hospital EMR.

The various components of overall cost included in the analysis consisted of (1) operating room (OR) time, (2) hospital length of stay (LOS) when the index case was an inpatient case, (3) instrument costs, and (4) miscellaneous costs, with miscellaneous costs representing variable costs for the entire patient encounter.

OR time included the total cost for the OR time. Hospital stay costs included room, bed, and nursing costs. Instrument costs included chargeable costs (surgical instruments) in addition to non-chargeable operating room costs (such as gowns, gloves, dressing supplies and others). Chargeable and non-chargeable instrument costs are based upon actual invoice costs. Miscellaneous costs included the direct costs for laboratory work, radiology, pharmacy, respiratory, in addition to other departmental costs. All cost data were obtained using the institution's StrataJazz accounting system, a software platform that is used for financial analytics and for tracking financial outcomes [17]. Costs were actual costs, and not charges. Robot cost data included depreciation and maintenance expenses. Robotic capital investment cost was not included in the analysis.

Surgical technique

Unilateral inguinal hernia repairs followed a standard, well-described technique, using mesh in a pre-peritoneal approach. One surgeon preferred the "self-adherent" mesh (DB) and the other surgeon in the study preferred the preformed mesh tacked by two Vicryl sutures (MM).

Cholecystectomy was performed using standard techniques. The critical view of safety was obtained with a clearly defined Triangle of Calot and posterior cystic plate. In most cases, indocyanine green (ICG) was utilized. In select cases, an intraoperative cholangiogram (IOC) was obtained and the decision to perform an IOC was based upon the patient's presentation and surgeon preference.

PEH repairs were performed using a standard approach, and hernias were repaired posteriorly with non-absorbable sutures, with or without mesh, as indicated. PEH repairs were performed with complete or partial fundoplication based on preoperative manometry and surgeon preference. Preoperatively, all PEH patients underwent an extensive work-up including a combination of upper endoscopy, upper gastrointestinal series, 24 pH studies or wireless probe studies in conjunction with functional esophageal studies including high resolution manometry or a motility esophagram. Patients were discharged on or after postoperative day 1 when discharge criteria were met. Discharge criteria included: tolerance of a liquid diet, absence of nausea/vomiting, stable hemoglobin and hematocrit, absence of tachycardia at rest, frequent ambulation without assistance, and greater than 93% oxygen saturation.

Data analysis

We compared costs of the operating room time, instruments, miscellaneous costs, and hospital length of stay for the R- and L- cohorts separately by procedure type (1) cholecystectomy patients (2) inguinal hernia repair patients (outpatient only); and (3) PEH repair patients (with and without mesh). To analyze cost differences while taking into account possible temporal trends, we conducted a subgroup analysis for each procedure type with two-way analysis of variance (ANOVA) for normally distributed outcomes with sufficient sample sizes, with fiscal year (FY) included as a factor. Given the limited outcomes for fiscal year 2019, we combined 2019 and 2020 and retained 2021 as its own category. Due to the retrospective nature of our data, we were unable to control for medical cost inflation. For groups with very limited sample sizes, we reported descriptive outcomes only. As secondary outcomes for inpatient surgical groups, we reported median operating room time and hospital length of stay due to their skewed distributions, with no statistical comparisons due to only 6 patients in the R- group. We used SPSS version 28 to analyze our data (Armonk, NY: IBM Corp.) and reported means and standard deviations, with $p < 0.05$ denoting statistical significance, and no adjustment for the multiple comparisons.

Results

Patient characteristics

Demographic characteristics for patients with complete data who met all inclusion criteria are presented in Tables 1, 2, 3. (Cholecystectomy, $n = 367$; Inguinal Hernia, $n = 285$;

Table 1 Cholecystectomy group demographic characteristics

Characteristics	Robotic (R-) ($n = 98$)	Laparoscopic (L-) ($n = 269$)	p value[a]	Total ($n = 367$)
Age (mean ± SD[b])	49.0 ± 15.9	48.3 ± 17.7	0.23	48.5 ± 17.2
Gender (n, %)	69 female (70.4%) 29 male (29.6%)	198 female (73.6%) 71 male (26.4%)	0.54	267 female (72.8%) 100 male (27.2%)
Ethnicity (n, %)	21 Hispanic or Latino (21.4%)	62 Hispanic or Latino (23.0%)	0.11	83 Hispanic or Latino (22.6%)
BMI (mean ± SD[b])	32.0 ± 6.9	31.0 ± 6.5	0.22	31.3 ± 6.6

[a]Based on separate chi square or independent samples t tests, as appropriate

[b]SD: standard deviation

[c]BMI: body mass index

Table 2 Inguinal hernia group demographic characteristics

Characteristics	Robotic (R-) ($n = 165$)	Laparoscopic (L-) ($n = 120$)	p value[a]	Total ($n = 285$)
Age (mean ± SD[b])	57.2 ± 13.3	58.5 ± 14.6	0.37	57.7 ± 13.9
Gender (n, %)	7 female (4.2%) 158 male (95.8%)	7 female (5.8%) 113 male (94.2%)	0.54	14 female (4.9%) 271 male (95.1%)
Ethnicity (n, %)	11 Hispanic or Latino (6.7%)	10 Hispanic or Latino (8.3%)	0.79	21 Hispanic or Latino (7.4%)
BMI (mean ± SD[b])	27.4 ± 4.3	26.2 ± 4.2	0.46	26.9 ± 4.3

[a]Based on separate chi square or independent samples t-tests, as appropriate

[b]SD: standard deviation

[c]BMI: body mass index

PEH repair, $n = 164$). Mean age for R-cholecystectomy and L-cholecystectomy was 49.0 and 48.3, respectively ($p = 0.23$). Mean age for R-inguinal hernia and L-inguinal hernia was 57.2 and 58.5, respectively ($p = 0.37$). Mean age for R-PEH repair and L-PEH repair was 61.1 and 61.8, respectively ($p = 0.20$). Mean BMI for R-cholecystectomy and L-cholecystectomy was 32.0 and 31.0, respectively ($p = 0.22$). Mean BMI for R-inguinal hernia and L-inguinal hernia was 27.4 and 26.2, respectively ($p = 0.46$). Mean BMI for R-PEH repair and L-PEH repair was 31.2 and 31.8, respectively ($p = 0.55$). Similarly, there were no significant between-group differences in gender and ethnicity ($p > 0.05$).

Cholecystectomy group

Table 4 compares R- and L- costs for all cholecystectomy patients (inpatient and outpatient). Our results showed that the total cost of a R- cholecystectomy is significantly lower than the cost of a L- cholecystectomy ($3,199 vs $4,019, $p < 0.05$). Operating room cost and miscellaneous costs were all significantly lower in the R- group compared to the L- group ($p < 0.05$). Instrument costs, however, were significantly higher in the R- group compared to the L- group ($1349.51 vs $712.42, respectively, $p < 0.05$).

The costs of inpatient cholecystectomy cases are represented in Table 5. Again, total cost of the R- group was lower than that of the L- group, but no statistical comparison was performed because of the small n value ($4,964 vs $5,640). In the outpatient group (Table 6), the overall cost of the R-group was also significantly lower compared to the L-group ($3,175 vs $3,421 respectively, $p < 0.02$).

A descriptive analysis of the secondary outcomes of operating room time and hospital length of stay for the cholecystectomy inpatient group revealed a median (and range) operating room time of 90.5 min (46–225 min) and 87.5 min (70–103 min) for L-cholecystectomy ($n = 156$)

Table 3 Paraesophageal hernia (PEH) repair group demographic characteristics

Characteristics	Robotic (R-) ($n = 65$)	Laparoscopic (L-) ($n = 99$)	p value[a]	Total ($n = 164$)
Age (mean ± SD[b])	61.1 ± 14.1	61.8 ± 12.6	0.20	61.5 ± 13.2
Gender (n, %)	49 female (75.4%) 16 male (24.6%)	79 female (79.8%) 20 male (20.2%)	0.50	128 female (78.0%) 36 male (22.0%)
Ethnicity (n, %)	6 Hispanic or Latino (9.2%)	5 Hispanic or Latino (5.1%)	0.55	11 Hispanic or Latino (9.2%)
BMI (mean ± SD[b])	31.2 ± 5.9	31.8 ± 6.4	0.55	31.6 ± 6.2

[a]Based on separate chi square or independent samples t-tests, as appropriate

[b]SD: standard deviation

[c]BMI: body mass index

Table 4 Cholecystectomy group: all patients

	Operating room costs (mean ± standard deviation)	Instrument chargeable + non-chargeable costs (mean ± standard deviation)	Miscellaneous costs (mean ± standard deviation)	Total costs (mean ± standard deviation)
Laparoscopic (L-) ($n = 269$)	$1,282.47 ± $626.08	$712.42 ± $310.43	$2,025.01 ± $1,041.43	$4,019.89 ± $1,637.42
Robotic (R-) ($n = 98$)	$932.52 ± $177.35	$1,349.51 ± $273.65	$917.94 ± $428.29	$3,199.96 ± $571.28
p value*	< 0.0001	< 0.0001	< 0.0001	< 0.0001

*Based on separate independent samples t-tests

Table 5 Cholecystectomy group: inpatient

	Operating room costs (mean ± standard deviation)	Instrument chargeable + non-chargeable costs (mean ± standard deviation)	Miscellaneous costs (mean ± standard deviation)	Hospital length of stay costs (mean ± standard deviation)	Total costs (mean ± standard deviation)
Laparoscopic (L-) ($n = 144$)	$1,448.83 ± $745.47	$789.84 ± $360.54	$2,300.95 ± $1,196.22	$1,100.86 ± $850.87	$5,640.47 ± $2,334.42
Robotic (R-) ($n = 6$)	$903.10 ± $152.27	$1,532.25 ± $291.36	$1,132.86 ± $183.89	$1,396.66 ± $407.11	$4,964.87 ± $753.10

and R-cholecystectomy ($n = 6$), respectively. Median hospital length of stay was 2.0 days (0.8–10.1 days) and 3.1 days (1.8–5.0 days) for L-cholecystectomy and R-cholecystectomy, respectively. Robotic group patients experienced lower median operating room time (difference = 3.0 min), but higher median length of stay (difference = 1.1 days).

Inguinal hernia group

In the hernia group (Table 7) the costs of instruments were significantly higher in the R- group compared to the L- group ($1,715 vs $1,313, $p < 0.05$). However, miscellaneous costs were significantly lower in the R- group ($868 vs $1,209 for R- and L- groups respectively, $p < 0.05$). Total costs were not significantly different between the R- and L- groups ($3,835 and $3,783 for R- and L- groups respectively, $p = 0.69$).

Paraesophageal hernia repair group

PEH repairs were divided into two separate groups, PEH repairs with mesh (Table 8) and PEH repairs without mesh (Table 9). In the mesh group (Table 8), the instrument costs were significantly higher in the R- group compared to the L- group ($3,234 vs $2,378, $p < 0.05$). The total costs of the R- group were also significantly higher compared to the L- group ($7,511 vs $6,443, $p < 0.05$). However, in the PEH repair without mesh groups, (Table 9) there was no difference in the total costs between the two groups ($6,852 vs $6,819 for R- and L- groups respectively, $p > 0.05$).

Table 6 Cholecystectomy group: outpatient

	Operating room costs (mean ± standard deviation)	Instrument chargeable + non-chargeable costs (mean ± standard deviation)	Miscellaneous costs (mean ± standard deviation)	Total costs (mean ± standard deviation)
Laparoscopic (L-) ($n = 125$)	$1,090.82 ± 370.32	$623.23 ± $208.29	$1,707.13 ± $709.64	$3,421.18 ± $997.71
Robotic (R-) ($n = 92$)	$934.44 ± $179.42	$1,337.59 ± $269.84	$903.92 ± $436.38	$3,175.95 ± $572.12
p value*	< 0.0001	< 0.0001	< 0.0001	0.02

*Based on separate independent samples *t*-tests

Table 7 Inguinal hernia group costs: outpatient

	Operating room costs (mean ± standard deviation)	Instrument chargeable + non-chargeable costs (mean ± standard deviation)	Miscellaneous costs (mean ± standard deviation)	Total costs (mean ± standard deviation)
Laparoscopic (L-) ($n = 105$)	$1,260.39 ± 381.46	$1,313.45 ± $655.19	$1,209.66 ± $786.15	$3,783.50 ± $1,195.19
Robotic (R-) ($n = 165$)	$1,251.77 ± $396.57	$1,715.14 ± $308.53	$868.15 ± $373.98	$3,835.06 ± $694.21
p value*	0.86	< 0.0001	< 0.0001	0.69

*Based on separate independent samples *t*-tests

Table 8 Paraesophageal hernia (PEH) repair with mesh

	Operating room costs (mean + standard deviation)	Instrument chargeable + non-chargeable costs (mean + standard deviation)	Miscellaneous costs (mean + standard deviation)	Total costs (mean + standard deviation)
Laparoscopic (L-) ($n = 66$)	$2,183.23 ± $1,115.33	$2,378.29 ± $839.25	$1,881.80 ± $1,510.05	$6,443.32 ± $2,805.50
Robotic (R-) ($n = 44$)	$2,455.62 ± $596.25	$3,234.28 ± $1,093.50	$1,821.19 ± $966.23	$7,511.09 ± $1,700.95
p value*	0.10	< 0.0001	0.80	0.02

*Based on separate independent samples *t*-tests

Subgroup analysis

The interactional differences between cost and fiscal year were further assessed using two-way ANOVA. Two-way ANOVA for R- and L- cholecystectomy inpatients revealed significant group × year interactional effects for all cost categories except instrument costs ($p<0.05$), with significantly lower R- costs in both FY 2019–2020 and FY 2021. For instrument costs, there were significant main effects for surgical group (with R- patients having higher costs across both years, $p<0.05$) and fiscal year (with FY 2021 yielding lower costs across both surgical groups, $p<0.05$).

For outpatient cholecystectomy costs, there were no group x year interactional effects in the two-way ANOVAs for any cost outcome because only FY 2021 data were available for L- patients. For operating room costs, there was a significant main effect for year, with R- patients having higher costs in FY 2021 ($p < 0.05$). For instrument costs, there was a significant main effect for surgical group, with R- patients having higher overall costs ($p < 0.05$). For miscellaneous costs, there was a significant main effect for surgical group, with patients having lower overall costs ($p < 0.05$). Finally, for total costs, there were no significant main effects for either surgical group or year, indicating that values were comparable for R- and L- patients.

Results of two-Way ANOVA for inguinal hernia patients revealed a significant group x time interactional effect for operating room costs, with R- patients having higher costs in FY 2021 compared to FY 2019–2020, and L- patients having lower costs in FY 2021 compared to higher costs in FY 2019–2020 ($p<0.05$). For instrument costs, there were significant main effects for surgical group (with R- patients having higher costs across both fiscal years, $p<0.05$), and year (with lower costs in FY 2019–2020 compared to FY 2021 across both surgical groups, $p<0.05$). For miscellaneous costs, there was a significant main effect for surgical group, with R- patients having lower costs across both fiscal years ($p<0.05$). Finally, for total costs, there was a significant main effect for year, with lower costs in FY 2019–2020 compared to FY 2021 across both surgical groups ($p<0.05$).

For PEH repairs with mesh, results of two-way ANOVA revealed significant group × year interactional effects for operating room and total costs, with R- patients experiencing higher costs in FY 2021 compared to FY 2019–2020, and L- patients experiencing lower costs from FY 2019–2020 to FY 2021 ($p<0.05$). For instrument costs, there was a significant main effect for surgical group, with R- patients having higher costs across both fiscal years ($p<0.05$). Finally, for miscellaneous costs, there were no significant main effects for surgical group or year, although the group × year interaction trended toward significance ($p=0.06$), with R- costs increasing over time, and L- costs decreasing over time.

Table 9 Paraesophageal hernia (PEH) repair without mesh

	Operating room costs (mean + standard deviation)	Instrument chargeable + non-chargeable costs (mean + standard deviation)	Miscellaneous costs (mean + standard deviation)	Total costs (mean + standard deviation)
Laparoscopic (L-) ($n=20$)	$2,532.81 ± 1,247.18	$1,629.37 ± $519.04	$2,657.51 ± $2,506.26	$6,819.69 ± $3,839.52
Robotic (R-) ($n=14$)	$2,301.29 ± $723.78	$2,341.15 ± $517.51	$2,209.97 ± $851.51	$6,852.41 ± $1,517.23
p value*	0.50	< 0.0001	0.47	0.97

*Based on separate independent samples *t*-tests

Discussion

Robotic surgery has been shown to overcome several of the limitations commonly seen with the laparoscopic approach. A few of the advantages robotic surgery provides over laparoscopy includes 3D-imaging, wristed instruments, improved ergonomics, and increased dexterity [1]. However, despite those advantages, many have expressed major concerns regarding cost of the robotic platform when compared to laparoscopy, especially in the era of the Triple Aim and the focus on reduction of health care costs. Previous literature has demonstrated increased overall costs and similar clinical outcomes when the robotic approach was compared to the laparoscopic approach [1–3, 5]. Given the lack of strong evidence to suggest that robotic surgery improves patient clinical outcomes, the issue of cost has become extremely important when surgeons evaluate whether they should adopt this new technology. The primary drivers of the increased costs associated with robotic surgery can be attributed to the increased instrument costs and the costs associated with prolonged operative times [1–12, 18]. On the contrary, studies investigating the robotic surgery learning curve have shown that with more experience, surgeons can achieve a significant decrease in OR time and overall cost [12, 13, 15, 16]. Although clinical outcomes and learning curves are important parameters to consider, the primary objective of the present study was to evaluate the cost of robotic and laparoscopic general surgery procedures commonly performed at our institution, including cholecystectomies, inguinal hernia repairs, and PEH repairs.

In previous studies, we demonstrated no significant cost difference between R- and L- approaches in performing sleeve gastrectomy and Roux-en-Y gastric bypass cases [13, 15, 19]. Similarly, in our present study, we found no significant total cost difference between R- and L- approaches when an inguinal hernia repair or PEH repair without mesh was performed. Interestingly, when comparing the cost of a R-PEH repair with mesh to a L-PEH repair with mesh, the cost of R-PEH repair with mesh was significantly higher, probably because the PEH repairs performed with mesh included patients with larger hernias, which may have required the use of additional instrumentation. In the current study, the cost of instruments was consistently higher in the R-group compared to the L-group. Notably, we found that our institution's average total costs associated with performing a R- cholecystectomy were significantly less compared to the L- approach. This finding differs from previously published literature that demonstrated higher total costs for robotic surgery compared to laparoscopic surgery, primarily due to increased instrument costs and operating room time costs [1–12]. While instrument costs remained higher for the R- approach compared to the L- approach for all three procedures analyzed in our study, the average operating room time costs associated with R-cholecystectomy were significantly less than the L-group ($p < 0.001$). This may be explained by the fact that surgeons at our institution have exceeded their robotic surgery learning curves and have become very efficient in performing the more common general surgery procedures, resulting in shorter operative times, therefore lowering overall costs. Also, the miscellaneous costs of the R-cholecystectomy group were significantly lower than the L-group. Although we do not have a clear explanation for this significant difference, one explanation may be the selective use of intraoperative cholangiogram (IOC) in certain L-patients which can add substantial cost to the case. On the other hand, the R- group did not undergo any IOC, but routine ICG using the firefly technology was used, which in comparison doesn't add much to the overall cost of the case.

Despite our encouraging results, we acknowledge that our study has several limitations. First, the study conducted was a single-center study using institution-specific data, therefore the results of the study cannot be generalized to other institutions. In addition, the study was retrospective in nature and failed to capture detailed cost data in relation to the miscellaneous costs which seemed to be higher in the L-group for both the cholecystectomy and inguinal hernia groups. Also, the study did not include any long-term cost data related to complications or readmissions. Our analytical software that captures cost data doesn't include any long-term cost data, although collecting such data is important. Second, cost is institution specific due to the fact hospital contracts vary between different hospital systems, therefore, other hospitals are encouraged to compare their own cost data to obtain more meaningful comparisons. Additionally, given the retrospective nature of the study, selection bias may have resulted in skewed outcomes favoring the R-cohort, however, surgeons performing those cases are well experienced and selection of approach may be related to access issues more than personal preference or patient demographics. Another limitation is the "upfront" costs or capital investment made when purchasing the robotic platform. The capital investment was not part of our analysis because we did not have access to the data on the capital investment made to set up the laparoscopic towers, therefore, a meaningful comparison between both approaches was not possible. Lastly, this study is not a cost effectiveness study because clinical outcomes where not compared. Future cost effectiveness studies need to be conducted in a prospective fashion to compare both approaches in order to reach more definitive conclusions.

Improving the cost of a surgical procedure is a complicated task that requires a multidisciplinary approach. Attention to detail and responsible use of surgical equipment is essential in order to reduce operating room time costs and instrument costs. While patient safety is always the primary concern, avoiding unnecessary costs in the operating room is also becoming important. Operating room time is also of significant importance. Having a trained team that uses the robot frequently allows for a more efficient set up, faster turnover time, and lower use of disposables. In our study, the surgeons were able to demonstrate that by implementing a team approach with standardized techniques, three commonly performed surgical procedures: cholecystectomy, inguinal hernia repair, and PEH repair, can be performed using a robotic approach in an effective manner without a significant increase in overall health care costs.

Conclusion

Despite a significant increase in the number of procedures performed robotically, the use of robotic assisted surgery in general surgery remains controversial because of cost concerns. At our institution, our study findings indicate that the use of a robotic assisted approach for the performance of cholecystectomy, inguinal hernia repair, and PEH repair is not cost prohibitive when compared to the standard laparoscopic approach. However, cost is institution specific, and surgeons are encouraged to collect their own cost data to perform more meaningful comparisons prior to adoption of the technology.

Funding The authors have no funding to disclose.

Availability of data and materials Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The senior author (MEC) is a paid consultant for Intuitive Surgical. All other authors declare they have no financial conflicts of interest to disclose.

References

1. Huang Y, Chua TC, Maddern GJ, Samra JS (2017) Robotic cholecystectomy versus conventional laparoscopic cholecystectomy: a meta-analysis. Surgery 161(3):628–636
2. Quilici PJ, Wolberg H, McConnell N (2022) Operating costs, fiscal impact, value analysis and guidance for the routine use of robotic technology in abdominal surgical procedures. Surg Endosc 36(2):1433–1443
3. Pokala B, Samuel S, Yanala U, Armijo P, Kothari V (2020) Elective robotic-assisted bariatric surgery: Is it worth the money? A national database analysis. Am J Surg 220(6):1445–1450
4. Abdelmoaty WF, Dunst CM, Neighorn C, Swanstrom LL, Hammill CW (2019) Robotic-assisted versus laparoscopic unilateral inguinal hernia repair: a comprehensive cost analysis. Surg Endosc 33(10):3436–3443
5. Roh HF, Nam SH, Kim JM (2018) Robot-assisted laparoscopic surgery versus conventional laparoscopic surgery in randomized controlled trials: a systematic review and meta-analysis. PLoS ONE 13(1):e0191628
6. Tandogdu Z, Vale L, Fraser C, Ramsay C (2015) A systematic review of economic evaluations of the use of robotic assisted laparoscopy in surgery compared with open or laparoscopic surgery. Appl Health Econ Health Policy 13(5):457–467
7. Khorgami Z, Li WT, Jackson TN, Howard CA, Sclabas GM (2019) The cost of robotics: an analysis of the added costs of robotic-assisted versus laparoscopic surgery using the National Inpatient Sample. Surg Endosc 33(7):2217–2221
8. Higgins RM, Frelich MJ, Bosler ME, Gould JC (2017) Cost analysis of robotic versus laparoscopic general surgery procedures. Surg Endosc 31(1):185–192
9. Prabhu AS, Carbonell A, Hope W, Warren J, Higgins R, Jacob B et al (2020) Robotic inguinal vs transabdominal laparoscopic inguinal hernia repair: the RIVAL randomized clinical trial. JAMA Surg 155(5):380–387
10. Aguayo E, Dobaria V, Nakhla M, Seo YJ, Hadaya J, Cho NY et al (2020) National trends and outcomes of inpatient robotic-assisted versus laparoscopic cholecystectomy. Surgery 168(4):625–630
11. Mehaffey JH, Michaels AD, Mullen MG, Yount KW, Meneveau MO, Smith PW et al (2017) Adoption of robotics in a general surgery residency program: at what cost? J Surg Res 213:269–273
12. Zayan NE, Meara MP, Schwartz JS, Narula VK (2019) A direct comparison of robotic and laparoscopic hernia repair: patient-reported outcomes and cost analysis. Hernia 23(6):1115–1121
13. King K, Galvez A, Stoltzfus J, Claros L, El Chaar M (2020) Cost analysis of robotic roux-en-Y gastric bypass in a single academic center: how expensive is expensive? Obes Surg 30(12):4860–4866
14. Awad MA, Buzalewski J, Anderson C, Dove JT, Soloski A, Sharp NE et al (2020) robotic inguinal hernia repair outcomes: operative time and cost analysis. JSLS 24(4):e2020.00058
15. El Chaar M, Gacke J, Ringold S, Stoltzfus J (2019) Cost analysis of robotic sleeve gastrectomy (R-SG) compared with laparoscopic sleeve gastrectomy (L-SG) in a single academic center: debunking a myth! Surg Obes Relat Dis 15(5):675–679
16. Avondstondt AM, Wallenstein M, D'Adamo CR, Ehsanipoor RM (2018) Change in cost after 5 years of experience with robotic-assisted hysterectomy for the treatment of endometrial cancer. J Robot Surg 12(1):93–96
17. Strata Online: Strata Decision Technology (2022) https://www.stratadecision.com/.
18. Li K, Zou J, Tang J, Di J, Han X, Zhang P (2016) Robotic versus laparoscopic bariatric surgery: a systematic review and meta-analysis. Obes Surg 26(12):3031–3044
19. Salem JF, Bauerle WB, Arishi AA, Stoltzfus J, El Chaar M (2022) Direct medical costs of robotic sleeve gastrectomy compared to laparoscopic approach in a single academic center. J Robot Surg. https://doi.org/10.1007/s11701-022-01385-x

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.