ORIGINAL ARTICLE

Identifying Hospital Cost Savings Opportunities by Optimizing Surgical Approach for Distal Pancreatectomy

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Abstract

Background The economic implications of relevant clinicopathologic factors on the surgical approach to distal pancreatectomy (DP) should be clearly defined and understood to potentially allow the implementation of cost reduction strategies.

Methods Administrative and clinical datasets of patients undergoing a DP between 2012 and 2016 were merged and queried. Univariate and multivariate analyses were used to identify clinicopathologic predictors of cost differentials for minimally invasive DP (MIDP) relative to open DP (ODP). Time trends in cost were also assessed to identify opportunities for cost containment.

Results Among two hundred and twenty five patients, 128 underwent an ODP (57%) and 97 a MIDP (43%). The DP groups were comparable with regard to relevant perioperative and disease characteristics. Total hospitalization and total OR costs for MIDP were significantly lower (-12%, $P = 0.0048$) and higher ($+16\%$, $P < 0.0001$) respectively, compared to ODP. On univariate analysis, age > 60 (-12%, $P = 0.0262$), BMI > 25 (-10%, $P = 0.0222$), ASA class ≥ 3 (-11%, $P = 0.0045$), OpTime > 230 min (-16%, $P = 0.0004$), and T stage ≥ 3 (-8%, $P = 0.0452$) were associated with decreased total costs after MIDP compared to ODP. Linear regression analysis revealed that BMI > 25 (Estimate -0.31, SE 0.15, $P = 0.0482$), ASA class ≥ 3 (Estimate -0.36, SE 0.17, $P = 0.0344$), and T stage ≥ 3 (Estimate -0.57, SE 0.26, $P = 0.0320$) were associated with decreased hospitalization costs after MIDP compared to ODP. Overtime, total hospitalization cost for MIDP increased from -21 to 1% ($P = 0.0197$), while OR costs for MIDP decreased from $+41\%$ to -2% ($P = 0.0049$), nearly equalizing the cost differences between ODP and MIDP.

Conclusions Relevant clinicopathologic factors predicted decreased hospitalization costs after MIDP relative to ODP. In equivalent stages of disease, optimizing the surgical approach to DP based on specific clinicopathologic characteristics may afford significant cost-saving opportunities.

Keywords Total hospitalization costs · Cost savings · Distal pancreatic resection · Robotic · Laparoscopic · Minimally invasive · Clinicopathologic factors

Introduction

In an era of increased awareness of healthcare costs, expenditures associated with major surgical procedures should be scrutinized. Procedural cost-effectiveness has become an important metric in evaluating surgical outcomes and cost reduction pathways have been progressively emphasized as important tools to increase value.[1–3] Investigating the contribution of patient, clinicopathologic and perioperative factors on increased hospitalization cost would allow surgeons to comprehend the economic aspects of surgical care, and potentially modify their practice accordingly to avoid worsening financial challenges. Thorough economic analyses are required to better understand cost variations in order to minimize healthcare expenses when clinically indicated.

Distal pancreatectomy (DP) can be technically challenging and often associated with substantial morbidity and cost. Therefore, it represents a suitable model to investigate the complex aspects of healthcare economics. Although data from randomized controlled studies are lacking, the efficacy and safety of minimally invasive DP (MIDP), regarding both

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postoperative and oncologic outcomes, has been repeatedly demonstrated.[4–10] The cost-effectiveness of MIDP compared to the open approach has also been investigated.[10–17] Nevertheless, total hospitalization costs and operating room (OR) costs associated with DP are subjected to numerous different factors and therefore can vary widely across different institutions. For this reason, factors influencing the cost-effectiveness of the operative approach to DP remain in dispute.[10–17]

In depth analyses of the impact of relevant patient and clinicopathologic factors on hospitalization costs after DP are lacking; these are essential to recognize the potential economic consequences of performing a MIDP vs. ODP in equivalent clinical circumstances. These comparisons are also crucial in order to identify specific areas of incurred costs, which once recognized, could promote the implementation of focused mechanisms for cost reduction. Additionally, these cost analyses could assist hospital administrators to accurately predict increased costs after a DP and embrace measures to further improve the usage of healthcare resources. A better understanding of the factors impacting cost could also be the basis for developing a bundled payment for patients undergoing a DP.

In this study, we compared total and direct hospitalization costs between patients undergoing MIDP vs. ODP. Our primary aim was to determine whether demographics, patient comorbidities, or relevant clinicopathologic characteristics influence hospitalization costs after MIDP relative to ODP. In addition, we sought to evaluate overtime trends in total hospitalization and OR costs for both operative approaches to DP to assess the cost-effectiveness of existing design mechanisms in promoting surgical care and to potentially identify future cost containment opportunities.

Material and Methods

Data Sources, Patients, and Measures

The study was approved by the *Brigham and Women's Hospital* (BWH) Review Board (IRB). Data for patients who underwent a DP between December 2012 and December 2016 were collected by using a prospectively maintained database. Our hospital participates in the American College of Surgeons National Surgical Quality Improvement Project (NSQIP). All patient, clinicopathologic, procedural, and diagnostic data used in this study were retrieved from a prospectively maintained BWH NSQIP database. The data were thoroughly reviewed by specifically trained surgical case reviewers and conform to NSQIP standardized, nation-wide adopted criteria and protocols, which accurately define all the variables measured.

All DPs were confirmed using ICD-9 procedure code 52.52. Patients were divided into two groups according to operative technique, MIDP vs. ODP. Univariate analysis associations between the two groups were assessed regarding age, gender, ethnicity, body mass index (BMI), American Society of Anesthesiologist (ASA) physical status classification, tobacco use, preoperative body weight loss of > 10%, and comorbidities such as diabetes mellitus (DM), severe chronic obstructive pulmonary disease (COPD), hypertension requiring medications, neoadjuvant therapy, preoperative sepsis, preoperative transfusion, bleeding disorder, or steroid use for a chronic condition. Clinicopathologic and operative variables included operative time (OpTime) in minutes, histology type (benign vs. malignant), pancreatic adenocarcinoma rates, splenectomy, and T and N stage of disease. Postoperative complications included any of the following outcomes that occurred within 30 days after a DP: surgical site infection (superficial, deep or organ/space), sepsis, respiratory complications (unplanned re-intubation, pneumonia), thromboembolism [pulmonary embolism (PE), deep vein thrombosis (DVT)], cardiac arrest, stroke, renal complications [progressive renal insufficiency, urinary tract infection (UTI)], hemorrhage (bleeding requiring transfusion of at least 4 U of packed red blood cells), or pancreatic fistula (POPF). Hospital length of stay (LOS), discharge disposition, reoperation, 30-day re-admission, and 30-day overall and serious morbidity were also assessed. Serious morbidity included organ/space SSI, neurological event (stroke or cerebrovascular accident), cardiac arrest, PE, progressive or acute renal insufficiency, or sepsis. Overall morbidity included any serious morbidity as well as superficial or deep incision SSI, pneumonia, unplanned re-intubation, UTI, or DVT. Ten MIDPs converted to ODPs were analyzed on an intention-to-treat basis.

Cost Analysis

A case-costing analysis was performed using standard tariffs set by our hospital's independent coding and costing committee, which were retrieved by medical record linkage to our institution's financial cost accounting system. For both the MIDP and ODP groups, costs included total hospitalization, total direct, and operating room (OR) costs. Total hospitalization costs were defined as the sum of the hospital's expenditures in caring for the patient, which are an aggregate of direct and indirect costs. Direct costs were identified with a patient care service, and included all costs associated with the inpatient encounter, from admission to discharge, for all hospital services provided and specifically for clinical costs, intraoperative and postoperative blood transfusion costs, nursing, pharmacy, and radiology costs. "Other costs" included anesthesia, cardiac noninvasive testing, emergency department costs, gastrointestinal endoscopy, nutrition services, OR special charges, physical and occupational therapy, radiation therapy,

and respiratory/pulmonary therapy costs. Direct costs also included total OR costs such as OR team costs driven by the duration of the case, supplies (imaging systems, trocars, and devices for dissection and hemostasis), and recovery room costs. The cost of maintenance of the robotic system is allocated as indirect cost.

Statistical Analysis

Descriptive statistics of costs were performed between the MIDP and ODP groups. Continuous variables were compared between the two groups using Student's t test or Wilcoxon rank-sum test, whereas categorical variables were compared using Pearson's chi-squared test or Fisher's exact test as appropriate. Continuous variables are reported as medians and interquartile ranges (IQR), whereas categorical variables are presented as numbers (n) and percentages (%). Univariate associations between relevant patient, clinicopathologic, and perioperative characteristics and total and direct costs were assessed using the Wilcoxon rank-sum test. All cost analyses were based on the cost of providing services (payments) and not patient bills (charges). Costs in United States dollars (USD) were used to perform all analyses; however, according to our institution's financial disclosure policies, univariate cost analysis results are presented as ratios of median costs (relative cost MIDP/ODP) and percentage of change in median cost [increase (+) or decrease (−)] for each cost category. Multiple linear regression analysis was used to identify associations among patient and clinicopathologic variables and costs for MIDP relative to ODP. Linear regression analysis results are reported as estimates [increase (+) or decrease (−) in total hospitalization cost for one unit of change in the predictor variable] and standard errors (SE). In assessing overtime cost trends for DP, cost differences between different years were detected using the Wilcoxon rank-sum test. Statistical analyses were conducted using the SAS statistical software program version 9.2 (SAS Institute, Cary, NC). A P value of less than 0.05 was considered to be statistically significant.

Results

Preoperative Clinical Data, Clinicopathologic Characteristics, and Postoperative Outcomes

Hospitalization cost data for a total of 225 patients, of whom 128 underwent an ODP (57%) and 97 a MIDP (43%), were analyzed. The MIDP cases consisted of 67 laparoscopic and 30 robotic DPs. No differences between the ODP and MIDP groups were observed with regard to age, gender, ethnicity, BMI, ASA class, and relevant comorbidities (Table 1). Patients who underwent an ODP were more likely to have

experienced preoperative weight loss > 10% (11% vs. 1%, $P = 0.0032$) and to have received neoadjuvant therapy (11% vs. 3%, $P = 0.0275$) compared with patients in the MIDP group. OpTime, malignant histology type, splenectomy rates, and T and N stages of disease did not differ between the two operative approaches to DP.

Detailed information on postoperative outcomes is reported in Table 2. Although patients undergoing ODP demonstrated higher rates of organ SSI, PE, stroke, cardiac arrest, sepsis, and bleeding requiring transfusion, overall morbidity (23% vs. 19%, $P = 0.4884$) and serious 30-day morbidity (18% vs. 13%, $P = 0.3548$) did not significantly differ between the two groups. LOS was considerably longer after ODP (8 vs. 6 days, $P < 0.0001$), while reoperation and 30-day readmission rates were similar compared to patients who underwent MIDP.

Total and Direct Costs for DP on Univariate Analysis

Total hospitalization costs were lower after MIDP (− 12%, $P = 0.0048$) compared with ODP. While total direct costs were also lower following MIDP (− 11%, $P = 0.0150$), OR costs were higher (+ 16%, $P < 0.0001$). A detailed breakdown of the relative difference in median costs between MIDP and ODP is reported in Table 3. Univariate predictors of costs savings for MIDP compared to ODP included age > 60 years (− 12%, $P = 0.0262$), BMI > 25 (− 10%, $P = 0.0222$), ASA ≥ 3 (− 11%, $P = 0.0045$), OpTime > 230 min (− 16%, $P = 0.0004$), and T stage ≥ 3 (− 8%, $P = 0.0452$). Direct hospitalization costs followed a similar financial pattern to total costs.

To further explore why these factors predicted reduced costs for MIDP compared to ODP, additional analyses were performed. Among patients > 60 years old, a greater percentage experienced a prolonged hospital LOS (>6 days) after ODP than MIDP (58% vs. 40%, $P = 0.0336$). Patients with ASA ≥ 3 in the ODP group had higher rates of postoperative morbidity and consequently an increased hospital LOS (56% vs. 39%, $P = 0.0492$) compared to patients with ASA ≥ 3 in the MIDP group. Patients with a BMI > 25 in the ODP group also experienced increased postoperative morbidity, which resulted in higher rates of prolonged hospitalization (54% vs. 33%, $P = 0.0118$) compared to patients with a BMI > 25 in the MIDP group. Despite patients with a T stage ≥ 3 in the MIDP group having longer operative times, their rates of postoperative morbidity and increased LOS were lower compared to similar patients undergoing ODP (Table 4).

Predictors of Increased Total Hospitalization Costs with Linear Regression Analysis

A multiple linear regression model was performed to identify clinicopathologic predictors of increased total hospitalization costs for MIDP relative to ODP (Table 5). A BMI > 25

Table 1 Comparison of demographics, clinicopathologic and operative characteristics of patients undergoing ODP vs. MIDP. Asterisks (*) denote statistically significant results

	ODP (n = 128)	MIDP (n = 97)	P value
Demographics			
Age in years, n (IQR)	60 (50–68)	63 (49–69)	0.8515
Male gender, n (%)	64 (50%)	39 (40%)	0.1442
Caucasian race, n (%)	109 (85%)	89 (91%)	0.4460
Clinical			
ASA classification, n (%)			
II	39 (30%)	42 (43%)	0.0863
III	89 (70%)	55 (57%)	
Body mass index (kg/m^2), n (IQR)	27.6 (24–31)	28.7 (26–33)	0.0802
> 10% lost body weight in last 6 months, n (%)	14 (11%)	1 (1%)	0.0032*
Diabetes mellitus with oral agents or insulin, n (%)	27 (21%)	19 (19%)	0.7815
Current smoker within 1 year, n (%)	15 (12%)	19 (19%)	0.1027
Severe chronic obstructive pulmonary disease, n (%)	3 (2%)	5 (5%)	0.2595
Hypertension requiring medications, n (%)	58 (45%)	42 (43%)	0.7634
Neoadjuvant therapy, n (%)	14 (11%)	3 (3%)	0.0275*
Preoperative sepsis, n (%)	2 (1.5%)	0	0.2162
Steroid use for a chronic condition, n (%)	5 (4%)	2 (2%)	0.4300
Bleeding disorders, n (%)	9 (7%)	2 (2%)	0.0869
Preoperative transfusion, n (%)	3 (2%)	0	0.1290
Clinicopathologic			
Operative time in minutes, n (IQR)	230 (178–286)	233 (196–283)	0.5188
Malignant histology, n (%)	71 (55%)	42 (43%)	0.0706
Pancreatic adenocarcinoma, n (%)	24 (18%)	10 (10%)	0.0800
Splenectomy, n (%)	76 (59%)	53 (55%)	0.9678
T stage ≥ 3, n (%)	59 (72%)	28 (60%)	0.1488
Node-positive disease, n (%)	32 (40%)	16 (35%)	0.5977

ASA American Society of Anesthesiologists;

(Estimate − 0.31, SE 0.15, $P = 0.0482$), ASA class ≥ 3 (Estimate − 0.36, SE: 0.17, $P = 0.0344$), and T stage ≥ 3 (Estimate − 0.57, SE 0.26, $P = 0.0320$) were associated with significant cost savings after MIDP compared to ODP. In contrast, clinical characteristics such as advanced age, gender, neoadjuvant therapy, malignant histology, pancreatic adenocarcinoma, and N-positive disease were cost neutral between the different surgical approaches to DP.

Total and OR Cost Trends Overtime

Median total hospitalization and OR costs were compared between year 2012 (beginning of the study) and 2016 (end of the study). The relative total hospitalization cost associated with MIDP compared to ODP increased from − 21% in 2012 to 1% in 2016 ($P = 0.0197$). During the same period of time, the relative OR costs of MIDP vs. ODP decreased from + 41 to − 2% ($P = 0.0049$, Fig. 1). Postoperative morbidity rates between the first and second half period of the study were not significantly different for patients undergoing ODP (25% vs. 15%, $P = 0.4081$) or MIDP (20% vs 14%, $P = 0.5279$).

However, the decrease in morbidity was to a greater extent for the ODP group. Similarly, the LOS for patients undergoing ODP decreased overtime (8 vs. 6 days, $P = 0.0045$), whereas the LOS for the MIDP group patients remained stable (6 vs. 5 days, $P = 0.8967$). Additionally, we noted a decrease in the cost of OR supplies for the MIDP between the first and second half of the study (− 57%, $P < 0.0001$). Similarly, the operative time for MIDP was also decreased between the first and second half of the study period (251 vs. 224 min, $P = 0.0671$); however, this change was not observed among patients undergoing ODP (231 vs. 229 min, $P = 0.5653$). Finally, we estimated a 12% decrease and a 5% increase in indirect costs for laparoscopic DP/ODP and robotic DP/ODP, respectively.

Discussion

Pancreatic operations are complex and costly, and therefore represent a prototype for healthcare financial analyses. We sought to investigate how patient and clinicopathologic factors influence total hospitalization and OR cost differentials

Table 2 Comparison of 30-day postoperative outcomes of patients undergoing ODP vs. MIDP. Asterisks (*) denote statistically significant results

	ODP (n = 128)	MIDP (n = 97)	P value
Unplanned re-intubation, n (%)	1 (1%)	2 (2%)	0.4069
Superficial surgical site infection, n (%)	4 (3%)	2 (2%)	0.6240
Organ/space surgical site infection, n (%)	18 (14%)	11 (11%)	0.5462
Pancreatic fistula, n (%)	15 (12%)	20 (20%)	0.0681
Pneumonia, n (%)	6 (5%)	4 (5%)	0.8390
Pulmonary embolism, n (%)	1 (1%)	0	0.3830
Progressive renal insufficiency, n (%)	1 (1%)	0	0.3830
Urinary tract infection, n (%)	4 (3%)	2 (2%)	0.6240
Stroke, n (%)	2 (2%)	0	0.2162
Cardiac arrest, n (%)	1 (1%)	0	0.3830
Bleeding requiring transfusion, n (%)	23 (18%)	10 (10%)	0.1078
Deep venous thrombosis/thrombophlebitis, n (%)	6 (5%)	2 (2%)	0.2922
Sepsis, n (%)	15 (12%)	7 (7%)	0.2601
Length of hospital stay in days, n (IQR)	8 (6–11)	6 (5–7)	< 0.0001*
Discharge destination to home, n (%)	121 (94%)	88 (91%)	0.2709
30-day readmission, n (%)	19 (15%)	10 (10%)	0.3148
Reoperation, n (%)	4 (3%)	2 (2%)	0.6240
30-day overall morbidity, n (%)	30 (23%)	19 (19%)	0.4884
30-day serious morbidity, n (%)	23 (18%)	13 (13%)	0.3548

between the open and minimally invasive approaches to DP and evaluate overtime trends in total and OR cost to examine potential cost reduction strategies. Our results revealed several interesting findings. First, similar to prior studies, although MIDP incurred higher OR costs, total hospitalization costs were decreased compared to ODP, which is largely driven by a shorter hospital LOS.[12,13,17] Second, we identified

Table 3 Breakdown of ratio (relative cost MIDP/ODP) and percentage change [increase (+) or decrease (−)] in median total costs, total direct, and indirect costs between ODP and MIDP. Asterisks (*) denote statistically significant results

	Relative cost (MIDP/ODP)	% change in cost (MIDP/ODP)	P value
Total cost	0.88	− 12%	0.0048*
Total direct cost	0.89	− 11%	0.0150*
Blood	0.62	− 38%	< 0.0001*
Clinical	0.62	− 38%	< 0.0001*
Nursing	0.85	− 15%	< 0.0001*
Pharmacy	0.69	− 31%	< 0.0001*
Radiology	0.40	− 60%	0.0023*
Other	1.03	+ 3%	0.6030
Total OR	1.16	+ 16%	< 0.0001*
OR time and team	1.05	+ 5%	0.1959
Supplies	1.65	+ 65%	< 0.0001*
Recovery	0.80	− 20%	0.0216*
Total indirect cost	0.90	− 10%	0.0005*

predictors of maximal cost savings using minimally invasive approaches compared to ODP, which may represent cost reduction opportunities where MIDP should be emphasized if clinically appropriate. Finally, total cost savings associated with MIDP have decreased overtime while OR cost savings have increased. Despite these trends being most likely multifactorial, their thorough examination may offer new avenues to explore for cost containment.

On univariate analysis, older age (> 60 years), higher rates of comorbidities (ASA ≥ 3) and BMI > 25, increased operative time (> 230 min), and a more advanced T stage of disease (≥ 3) were associated with decreased total hospitalization costs after MIDP relative to ODP. These findings suggest that in equivalent clinicopathologic situations, a minimally invasive approach should be encouraged as a means to maximize hospital cost savings. The mechanism through which this cost containment occurred is related to significant reductions in specific postoperative complications and hospital LOS for the MIDP patients. In fact, we observed that patients of older age, those with higher percentages of comorbidities, higher BMI, or more challenging tumors especially benefited from a minimally invasive approach because they experienced reduced postoperative morbidity and hospital LOS compared to patients with similar clinicopathologic characteristics undergoing an ODP. These findings provide insight into future potential cost-minimizing strategies after DP.

In linear regression analysis, BMI > 25, ASA ≥ 3, and T stage ≥ 3 remained associated with decreased costs after MIDP compared to ODP. Previous studies have shown that

Table 4 Impact of relevant clinicopathologic factors on total and direct costs on univariate analysis. Asterisks (*) denote statistically significant results

	Total cost			Total direct cost		
	Relative cost (MIDP/ODP)	% change in cost (MIDP/ODP)	P value	Relative cost (MIDP/ODP)	% change in cost (MIDP/ODP)	P value
Age > 60	0.88	− 12%	0.0262*	0.91	− 9%	0.0450*
Male	0.78	− 22%	0.0082*	0.81	− 19%	0.0253*
ASA ≥ 3	0.89	− 11%	0.0045*	0.92	− 8%	0.0121*
Body mass index > 25	0.90	− 10%	0.0222*	0.91	− 9%	0.0582
Neoadjuvant therapy	0.60	− 40%	0.0588	0.62	− 38%	0.0778
Malignant histology	0.93	− 7%	0.1912	0.93	− 7%	0.3299
Pancreatic adenocarcinoma	1.01	+ 1%	0.9397	0.99	− 1%	0.7623
Operative time > 230 min	0.84	− 16%	0.0004*	0.87	− 13%	0.0014*
T stage ≥ 3	0.92	− 8%	0.0452*	0.95	− 5%	0.1618
N-positive disease	0.89	− 11%	0.0965	0.93	− 7%	0.1313
LOS > 6 days	0.92	− 8%	0.1084	0.94	− 6%	0.3080
30-day morbidity	0.80	− 20%	0.0678	0.77	− 23%	0.1238

ASA American Society of Anesthesiologists, *LOS* length of hospital stay

higher BMI for surgical patients has been associated with less severe postoperative complications and better prognosis, and consequently decreased costs.[18–20] In contrast, having a low BMI is often an indicator of malnutrition and can result in respiratory muscles weakness, postoperative re-intubation, prolonged intubation time, ICU stay time, and LOS and therefore increased hospitalization costs.[19] The results of this study indicate that emphasizing minimally invasive approaches to DP in patients with higher rates of comorbidities, obesity, or with larger tumors, all of which are predictors of postoperative morbidity and longer LOS, may allow for significant cost savings.

Table 5 Linear regression analysis demonstrating the impact of relevant clinicopathologic factors on total hospitalization cost after adjusting for operative approach. Asterisks (*) denote statistically significant results

Total Cost MIDP/ODP

	Estimate	Std. error	P value
Age > 60	− 0.33	0.18	0.0766
Male	− 0.13	0.08	0.1155
Body mass index > 25	− 0.31	0.15	0.0482*
ASA ≥ 3	− 0.36	0.17	0.0344*
Neoadjuvant therapy	− 0.94	0.54	0.0802
Malignant histology	− 0.25	0.19	0.1845
Pancreatic adenocarcinoma	− 0.26	0.35	0.4420
T stage ≥ 3	− 0.57	0.26	0.0320*
N-positive disease	− 0.55	0.30	0.0703

ASA American Society of Anesthesiologists

Trends in relative total hospitalization and OR costs for DP varied overtime. The total cost of MIDP increased; the reverse was observed for the ODP group. Consequently, at the end of the study period, cost differences between the two operative groups were nearly equalized (ratio MIDP/ODP = 1%). Several considerations can explain these findings. First, as it is also evidenced by current literature, the implementation of standardized pancreatectomy enhanced recovery after surgery (ERAS) protocols in our institution, resulted in decreased postoperative morbidity and LOS overtime, which specifically affected the ODP group.[21–23] Second, the increase in the relative total indirect cost for robotic but not for laparoscopic DP compared to ODP indicates that the introduction of robotics has inevitably increased the total hospitalization costs for the MIDP group overtime. The high cost of acquisition, the expensive maintenance, and the longer docking time for the robotic operations likely account for these increased costs. Nevertheless, as aforementioned, the overall total cost for MIDP relative to ODP was counterbalanced due to the decreased postoperative morbidity and shorter LOS after the minimally invasive operations.

In contrast, the gradual overtime expansion of MIDP resulted in decreased OR costs. As demonstrated by the significant overtime reduction in the cost of OR supplies, the more frequent use of MIDP most likely led to industry competition in the market of minimally invasive equipment, which is one of the most important factors that drive costs.[24] Industry competition in correlation with the technological development may steadily reduce the cost of specialized surgical equipment, making minimally invasive operations more cost-effective and affordable. Additionally, we noted an overtime gradual and significant decrease in the operative time for

Fig. 1 Trends in relative total hospitalization and OR costs (MIDP/ODP) overtime: Total costs increased from −21% in 2012 to 1% in 2016 (*P* = 0.0197) while OR costs decreased from + 41 in 2012 to − 2% in 2016 (*P* = 0.0049)
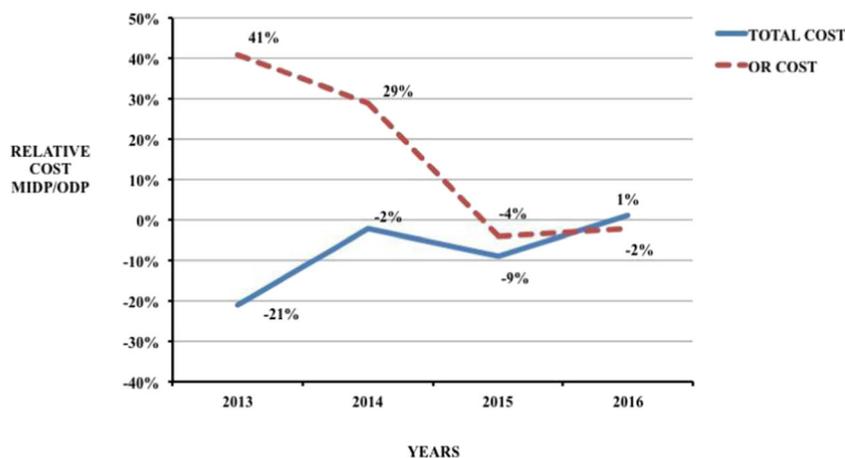
MIDP. The most plausible explanation of this finding is the progressive overcoming of the learning curve for the minimally invasive operations. It is well documented that both surgeon's capability and experience are important factors that considerably influence the learning curve of MIDP and consequently OR costs.[25]

Presuming that both MIDP and ODP are valid surgical approaches in equivalent clinical situations, understanding the factors which impact the total and OR cost of a specific operative technique may result in cost containment. Undoubtedly, an individualized assessment of each patient should guide the decision to perform an ODP vs. MIDP. This decision making is influenced by the anatomic characteristics of the tumor, anticipated technical issues, previous history of abdominal surgery as well as the surgeon's personal experience and training. Obesity and advanced comorbidities, in and of themselves, do not represent absolute contraindications to minimally invasive surgery, and therefore our results suggest that significant cost savings could be obtained by emphasizing MIDP in this patient population. Additionally, the formation of specialized, well-trained, and experienced minimally invasive OR teams, the reduction of operative time per procedure by surgeon's continued, specialized training on MIDP, the increased volume of patients approached with a minimally invasive procedure, the minimization of the number of instruments used per operation, and the potential multiple use of minimally invasive equipment by multiple surgical specialties are important cost-effective strategies to consider.[25–28]

Like all retrospective analyses, this study has limitations. The ODP and MIDP invariably contained differences, both measured and unmeasured, that may lead to selection biases. We attempted to control for these factors through regression analysis. On the other hand, because both increased operative time and hospital LOS are important, well-known drivers of hospitalization costs, we did not account for cost differences between ODP vs. MIDP incurred from these causative factors. Additionally, the cost data analyzed come from a single academic center's cost accounting department; therefore, the

external generalizability of this study is limited. Coding errors are a well-established limitation of accounting data sources; however, such errors follow a random distribution, and thus should not significantly impact the statistical analysis. Finally, the relatively small samples used for this analysis and not being able to disclose absolute costs in USDs for DP are additional limitations. Future, larger randomized controlled studies are warranted to further confirm the impact of clinicopathologic factors on the relative cost of MIDP compared to ODP, evaluate the generalizability of our results, and implement targeted cost-saving strategies for patients undergoing DP.

In conclusion, while MIDP results in similar to improved perioperative outcomes compared to ODP, this study offers additional persuasive arguments for performing a MIDP. An increased BMI, ASA class, and T stage of disease were associated with significant cost savings after MIDP relative to ODP. In equivalent clinicopathologic circumstances, particular attention to these characteristics when selecting the surgical approach to DP may offer opportunities for cost reduction. By increasing the surgeon's cost awareness regarding the potential financial consequences that specific clinicopathologic factors exert on the operative approach to DP, cost effective surgical care can be achieved. Additionally, quality improvement initiatives in minimally invasive surgery should ensure that lack of training are not barriers to the expansion of MIDP, which as demonstrated, in certain situations can incentivize the minimization of hospitalization costs.

Compliance with Ethical Standards

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