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ORIGINAL ARTICLE

Independent Predictors of Increased Operative Time and Hospital Length of Stay Are Consistent Across Different Surgical Approaches to Pancreatoduodenectomy

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Abstract

Background While minimally invasive approaches are increasingly being utilized for pancreatoduodenectomy (PD), factors associated with prolonged operative time (OpTime) and hospital length of stay (LOS) remain poorly defined, and it is unclear whether these factors are consistent across surgical approaches.

Methods The ACS-NSQIP targeted pancreatectomy database from 2014 to 2016 was used to identify all patients who underwent open (OPD), laparoscopic (LPD), or robotic (RPD) pancreatoduodenectomy. Multivariable linear regression analyses were used to evaluate predictors of OpTime and LOS, as well as quantify the changes observed relative to each surgical approach.

Results Among 10,970 patients, PD procedure types varied: 9963 (92%) open, 418 (4%) laparoscopic, and 409 (4%) robotic. LOS was longer for the open and laparoscopic approaches (11 vs. 11 vs. 10 days, $P = 0.0068$), whereas OpTime was shortest for OPD (366 vs. 426 vs. 435 min, $P < 0.0001$). Independent predictors of a prolonged OpTime were ASA class ≥ 3 ($P = 0.0002$), preoperative XRT ($P < 0.0001$), pancreatic duct < 3 mm ($P = 0.0001$), T stage ≥ 3 ($P = 0.0108$), and vascular resection ($P < 0.0001$) for OPD; T stage ≥ 3 ($P = 0.0510$) and vascular resection ($P = 0.0062$) for LPD; and malignancy ($P = 0.0460$) and conversion to laparotomy ($P = 0.0001$) for RPD. Independent predictors of increased LOS were age ≥ 65 years ($P = 0.0002$), ASA class ≥ 3 ($P = 0.0012$), hypoalbuminemia ($P < 0.0001$), and preoperative blood transfusion ($P < 0.0001$) for OPD as well as an OpTime > 370 min (all $p < 0.05$) and specific postoperative complications (all $p < 0.05$) for all surgical approaches.

Conclusions Perioperative risk factors for prolonged OpTime and hospital LOS are relatively consistent across open, laparoscopic, and robotic approaches to PD. Particular attention to these factors may help identify opportunities to improve perioperative quality, enhance patient satisfaction, and ensure an efficient allocation of hospital resources.

Keywords Open · Laparoscopic · Robotic pancreatoduodenectomy · ACS NSQIP database · Predictors · Operative time · Hospital length of stay

Introduction

Operative time (OpTime) and length of hospital stay (LOS) are important surgical metrics.[1–3] Among other things, these variables reflect surgical complexity, underlying patient characteristics, and surgeon experience. Moreover, these factors are frequently correlated with perioperative morbidity and mortality.[4,5] Pancreatoduodenectomy (PD) is a complex, potentially morbid operation, indicated for both benign and malignant conditions of the head of the pancreas, distal bile duct, and/or duodenum. Since the perioperative outcomes of PD demonstrate considerable variability among surgeons, institutions, and reported series, the identification of factors associated with longer OpTimes and LOS could help identify modifiable processes that could lead to improved outcomes, enhanced patient satisfaction, and reduced hospital costs.[2,6,7]

In many surgical disciplines, the evolution towards minimally invasive surgery (MIS) has resulted in reductions in LOS often with similar OpTimes, especially after mastering

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the necessary learning curve.[8–11] Although the adoption of MIS PD has been slower than other operations, PD is now routinely performed laparoscopically and robotically at many high-volume institutions. Paradoxically though, MIS PD has been associated with significant increases in OpTime with stable or slightly improved LOS.[8–11] Predictors of prolonged OpTime and LOS remain poorly defined among all types of PD and it is unclear whether these predictors are consistent across surgical approaches.

The purpose of this study therefore is to use the American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) targeted pancreatectomy database to identify perioperative factors predictive of increased OpTime and LOS for open (OPD), laparoscopic (LPD), and robotic pancreatoduodenectomy (RPD). Given the differences in surgeons performing, patients selected for, and technical factors related to MIS PD, we hypothesized that unique predictors of prolonged OpTime and LOS would exist based on operative approach to PD. Regardless, a more accurate description of factors influencing OpTime and LOS may help identify opportunities to improve perioperative quality and lead to reductions in health care costs.

Material and Methods

ACS-NSQIP Data Acquisition and Study Population

The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) is a multi-institutional, prospective database, which includes preoperative, intraoperative, and 30-day postoperative variables. Patients included in the database are randomly sampled from 500 eligible hospitals across the USA. The method of data collection implemented by the ACS-NSQIP has been standardized, resulting in validated data with good reliability.[1,12] A retrospective review of the 2014–2016 ACS-NSQIP and targeted pancreatectomy ACS-NSQIP databases was performed. All adult patients who underwent PD as the index operation were identified using Current Procedural Terminology codes 48150, 48152 and 48153. Patients were matched between the ACS-NSQIP and targeted pancreatectomy ACS-NSQIP databases based on case ID number. Hybrids of minimally invasive approaches were excluded from final analysis. Minimally invasive PDs converted to laparotomy were analyzed on an intention-to-treat basis.

Study Variables and Outcomes

Independent variables analyzed included demographics, preoperative health status, relevant comorbidities, preoperative laboratory values, operative variables, and postoperative occurrences. Demographics consisted of age, gender, and ethnicity. Variables related to preoperative health included the American Society of Anesthesiologists (ASA) classification, body mass index (BMI), weight loss (10% of total body weight in 6 months), smoking, chronic corticosteroid use, and preoperative sepsis (systemic inflammatory response syndrome or septic shock). Comorbidities included diabetes mellitus, chronic obstructive pulmonary disease (COPD), congestive heart failure, acute renal failure, hypertension requiring medications, ascites, dyspnea, and bleeding disorder. Preoperative laboratory values consisted of white blood cell count (WBC), hematocrit, platelet count, prothrombin time, alkaline phosphatase, total bilirubin, and albumin serum levels. Targeted pancreatectomy variables included neoadjuvant therapy [chemotherapy or radiation therapy (XRT) within 90 days prior to surgery], presence of obstructive jaundice, and biliary stent placement. Operative variables retrieved from the targeted pancreatectomy ACS-NSQIP data included OpTime, conversion to laparotomy, pancreatic duct size and gland texture, vascular resection, T and N stage of disease, and histology type (benign vs. malignant and more specifically pancreatic adenocarcinoma). Postoperative variables recorded included the diagnosis of any of the following within 30 days after PD: surgical site infection (superficial, deep or organ/space), wound dehiscence, sepsis, respiratory complications (unplanned re-intubation, pneumonia), thromboembolism (pulmonary embolism, deep vein thrombosis), cardiac complications (myocardial infarction, cardiac arrest requiring resuscitation), stroke, renal complications (progressive renal insufficiency, urinary tract infection), hemorrhage (bleeding requiring transfusion of at least 4 U of packed red blood cells), pancreatic fistula or delayed gastric emptying. LOS, discharge disposition, reoperation, 30-day readmission, 30-day morbidity, and overall mortality were also assessed.

Statistical Analysis

The primary outcome measures included predictors of OpTime and LOS. Univariate analyses were performed to compare demographics, perioperative variables, and postoperative outcomes among the OPD, LPD, and RPD groups. Categorical variables were compared using the Chi-square test, whereas continuous variables were compared using analysis of variance. The Tukey's test was performed to assess all-possible pairwise comparisons and confirm statistically significant differences between specific operative groups. Categorical variables are presented as numbers and percentages whereas continuous variables are presented as means and interquartile ranges. Multivariable linear regression analysis models were constructed separately for each operative approach (open, laparoscopic, and robotic) in order to identify predictors of OpTime and LOS after adjusting for relevant patient demographics, comorbidities, histology subtype, and stage of disease. Results were reported as variations in OpTime and LOS (mean increase or decrease in minutes or days, respectively) with 95% confident intervals (CI). Linear regression coefficients represent the mean change in the dependent variable (OpTime/LOS) for one unit of change in the independent variable while holding other predictors in the model constant. Variables were entered into the multivariable linear regression models when significant, independent contributions on univariate analysis were provided (P value < 0.1). Analyses were performed using SAS 9.2 (SAS Institute, Inc., Cary, NC, USA). A p value of less than 0.05 was considered to be statistically significant.

Results

Patient Demographics, Preoperative Risk Assessment Characteristics, and Laboratory Data

Among 10,790 patients who underwent PD in the 2014–2016 targeted pancreatectomy ACS-NSQIP database, the operative approach was open for 9963 (92%), laparoscopic for 419 (4%), and robotic for 409 (4%). Comparisons of demographics, relevant comorbidities, and preoperative characteristics among the three operative PD approaches are summarized in Table 1. The three groups were comparable with respect to demographics and relevant clinicopathological characteristics. The mean patient age for the entire cohort was 64 years (range 57–73) with 54% male and 74% Caucasian patients. Patients undergoing an OPD had a higher incidence of preoperative weight loss (17% vs. 11% vs. 10%, OPD vs. LPD vs. RPD respectively, $P < 0.0001$), were more likely to present with preoperative obstructive jaundice (46% vs. 35% vs. 39%, $P < 0.0001$), and had undergone biliary stent placement (53% vs. 45% vs. 51%, $P = 0.0067$). Patients undergoing LPD were more likely to have received preoperative XRT (7% vs. 8% vs. 3%, $P = 0.0133$).

Clinicopathological and Operative Characteristics

Relevant clinicopathologic and operative characteristics are summarized in Table 2. The mean OpTime was shorter for OPD than LPD or RPD (366 vs. 426 vs. 435 min, $P < 0.00001$). Conversion rates were 21 and 12% for LPD and RPD, respectively ($P < 0.0001$). Sixty-one percent of patients undergoing a converted LPD vs. 81% of patients undergoing converted RPD had node-positive stage of disease ($P = 0.0350$). A higher proportion of patients undergoing RPD had a main pancreatic duct of < 3 mm in diameter (24% vs. 23% vs. 32%, $P < 0.0001$) and a soft pancreatic gland (35% vs. 33% vs. 50%, $P < 0.0001$). The majority of patients in all groups had a final histopathologic diagnosis of malignancy (81% vs. 76% vs. 76%, $P = 0.0448$); patients undergoing RPD were the least likely to undergo a vascular resection (19% vs. 21% vs. 11%, $P = 0.0001$). Finally, T stage ≥ 3 ($P = 0.0566$) and node-positive disease were not statistically different among the 3 PD groups ($P = 0.1068$).

Postoperative Outcomes

Detailed information on specific perioperative outcomes is listed in Table 3. LOS was longer for the open and laparoscopic approaches (11 vs. 11 vs. 10 days, $P = 0.0068$). Overall mortality was 2.16%, which was comparable among the operative groups. A higher percentage of patients in the OPD group developed superficial surgical site infection (8% vs. 5% vs. 7%, $P = 0.0244$), pneumonia (4% vs. 3% vs. 2%, $P = 0.0300$), and bleeding requiring transfusion (20% vs. 18% vs. 11%, $P < 0.0001$). In contrast, pulmonary embolism was more frequently encountered in patients having a RPD (1% vs. 2% vs. 3%, $P = 0.0247$). Of note, the incidence of pancreatic fistula did not differ among the groups ($p = 0.3856$).

Predictors of OpTime and LOS for OPD

The results of multivariable linear regression models identifying predictors of OpTime and LOS for patients undergoing OPD are displayed in Table 4. An ASA class of ≥ 3 (12.97 min, CI 6.14–19.80, $P = 0.0002$), preoperative XRT (58.08 min, CI 48.05–68.11, $P < 0.0001$), a pancreatic duct of < 3 mm in diameter (26.39 min, CI 19.48–33.30, $P < 0.0001$), T stage ≥ 3 (8.94 min, CI 2.06–15.81, $P = 0.0108$), and vascular resection (63.23 min, CI 56.21–70.24, $P < 0.0001$) were strongly associated with increased OpTime during an OPD. In contrast, the OpTime for the OPD group was shorter among older patients (≥ 65 years, $P < 0.0001$) and when a soft pancreas was encountered ($P = 0.0015$).

Predictors of a longer hospitalization for patients undergoing OPD included age ≥ 65 (0.73 days, CI 0.35–1.12, $P = 0.0002$), ASA class ≥ 3 (0.75 days, CI 0.29–1.20, $P = 0.0012$), preoperative serum albumin level of < 3.7 (1.46 days, CI 1.08–1.84, $P < 0.0001$), preoperative blood transfusion (5.65 days, CI 3.77–7.53, $P < 0.0001$), and an OpTime of > 370 min (0.72 days, CI 0.35–1.10, $P = 0.0001$). Postoperative complications such as bleeding (2.98 days, CI 2.51–3.44, $P < 0.0001$), pulmonary embolism (9.26 days, CI 7.55–10.97, $P < 0.0001$), pneumonia (8.53 days, CI 7.58–9.49, $P < 0.0001$), and superficial surgical site infection (1.90 days, CI 1.25–2.55, $P < 0.0001$) were associated with longer LOS. In contrast, the LOS of patients who had

Table 1 Comparison of demographics, preoperative risk assessment characteristics and laboratory data of patients undergoing PD via the open, laparoscopic or robotic approach. Asterisks (*) denote statistically significant results

Variables	OPD (*n* = 9963)	LPD (*n* = 418)	RPD (*n* = 409)	*P* value
Demographics				
Mean age in years, *n* (range)	65 (18–89)	63 (19–87)	64 (18–88)	0.0793
Male gender, *n* (%)	5359 (54%)	233 (56%)	216 (53%)	0.6730
Ethnicity/race, *n* (%):				< 0.0001*
• Caucasian	7337 (73%)	302 (72%)	340 (83%)	
• African-American	784 (7.5%)	38 (9%)	27 (7%)	
• Asian	371 (4%)	21 (5%)	9 (2%)	
• Hispanic	453 (5%)	31 (8%)	8 (2%)	
• Other	39 (0.5%)	4 (1%)	0	
• Unknown	979 (10%)	22 (5%)	25 (6%)	
Comorbidities				
ASA classification, *n* (%):				0.0604
• I	37 (1%)	1 (0%)	4 (1%)	
• II	2239 (22%)	104 (25%)	82 (20%)	
• III	7006 (70%)	296 (71%)	302 (74%)	
• IV	671 (6%)	15 (4%)	20 (5%)	
• V	3 (0%)	0	0	
• Unknown	7 (1%)	2 (0%)	1 (0%)	
Mean BMI (kg/m^2), *n* (range)	27.2 (15–69)	27.6 (16–67)	27.5 (19–51)	0.4158
> 10% loss body weight in last 6 months, *n* (%)	1679 (17%)	46 (11%)	40 (10%)	< 0.0001*
Diabetes mellitus with oral agents or insulin, *n* (%)	2525 (25%)	94 (22%)	92 (22%)	0.1917
Current smoker within 1 year, *n* (%)	1821 (18%)	76 (18%)	87 (21%)	0.3075
Dyspnea, *n* (%)	512 (5%)	22 (5%)	13 (3%)	0.2048
Severe chronic obstructive pulmonary disease, *n* (%)	431 (4%)	15 (4%)	20 (5%)	0.6493
Congestive heart failure in 30 days before surgery, *n* (%)	41 (0.4%)	0 (0%)	0 (0%)	0.1812
Acute renal failure, *n* (%)	9 (0.09%)	1 (0.2%)	0 (0%)	0.5079
Hypertension requiring medications, *n* (%)	5305 (53%)	192 (46%)	216 (53%)	0.0135*
Preoperative obstructive jaundice, *n* (%)	4564 (46%)	148 (35%)	160 (39%)	< 0.0001*
Preoperative biliary stent, *n* (%)	5067 (53%)	181 (45%)	207 (51%)	0.0067*
Ascites within 30 days, *n* (%)	29 (0.2%)	1 (0.2%)	1 (0.2%)	0.9681
Preoperative sepsis, *n* (%)	112 (1%)	4 (1%)	3 (1%)	0.7281
Steroid use for a chronic condition, *n* (%)	253 (3%)	14 (3%)	7 (2%)	0.3262
Bleeding disorders, *n* (%)	264 (3%)	14 (3%)	10 (2%)	0.6578
Preoperative transfusion, *n* (%)	94 (1%)	6 (2%)	0 (0%)	0.0807
Chemotherapy in last 90 days, *n* (%)	1663 (17%)	62 (15%)	84 (21%)	0.1289
XRT in last 90 days, *n* (%)	718 (7%)	33 (8%)	13 (3%)	0.0133*
Laboratory data				
Mean serum albumin in g/dL, *n* (range)	3.7 (1.1–7.6)	3.8 (1.7–5.4)	3.8 (1.4–5.3)	< 0.0001*
Mean total bilirubin in mg/dL, *n* (range)	1.7 (0.1–15)	1.4 (0.1–15)	1.2 (0.1–14.5)	< 0.0001*
Mean alkaline phosphatase in U/L, *n* (range)	190 (10–998)	152 (17–980)	132 (20–878)	< 0.0001*
Mean WBC in thousand cells/mm^3, *n* (range)	7.3 (0.4–46)	7.5 (2.3–30)	7.4 (2.7–35.5)	0.2686
Mean hematocrit, % (range)	38 (9–59)	38 (11–52)	38 (10.8–52)	0.1766
Mean prothrombin time, *n* (range)	12.1 (1.1–28)	11.5 (10.6–12)	11.2 (9.8–12)	0.2035

preoperative XRT was reduced (− 1.5 days, CI − 2.2 to − 0.9, *P* < 0.0001) presumably because preoperative XRT was associated with a significantly lower incidence of pancreatic fistula (8.1 vs 18.8%, *P* < 0.0001).

Table 2 Comparison of clinicopathologic and operative characteristics of patients undergoing PD via the open, laparoscopic or robotic approach. Asterisks (*) denote statistically significant results

Variables	OPD ($n = 9963$)	LPD ($n = 418$)	RPD ($n = 409$)	P value
Mean total OpTime in minutes, n (range)	366 (96–1231)	426 (102–979)	435 (95–921)	< 0.0001*
Conversion to ODP, n (%)	–	86 (21%)	50 (12%)	< 0.0001*
Pancreatic duct size < 3 mm, n (%)	2358 (24%)	95 (23%)	131 (32%)	< 0.0001*
Soft pancreatic gland texture, n (%)	3453 (35%)	140 (33%)	204 (50%)	< 0.0001*
Vascular resection, n (%):				0.0001*
Unknown	124 (1%)	9 (2%)	6 (1%)	
Not performed	8102 (81%)	331 (79%)	364 (89%)	
Artery	172 (2%)	15 (4%)	8 (2%)	
Vein	1196 (12%)	46 (11%)	23 (6%)	
Artery and vein	369 (4%)	17 (4%)	8 (2%)	
T stage ≥ 3, n (%)	5899 (75%)	224 (72%)	220 (69%)	0.0566
Node positive stage, n (%)	4897 (62%)	173 (57%)	192 (61%)	0.1068
Malignant histologic subtype, n (%)	8020 (81%)	319 (76%)	310 (76%)	0.0448*
Pancreatic adenocarcinoma, n (%)	5550 (56%)	219 (52%)	221 (54%)	0.3394

Predictors of OpTime and LOS for LPD

Predictors of increased OpTime and LOS among patients undergoing LPD based on multivariate linear regression are displayed in Table 5. A T stage ≥ 3 (36.40 min, CI − 0.56–73.38, $P = 0.0536$) and vascular resection (26.39 min, CI 14.35–86.12, $P = 0.0062$) were associated with increased operative duration. Older age (≥ 65 years, $P = 0.0196$) was the only factor associated with a decreased OpTime for LPD.

Table 3 Comparison of 30-day postoperative occurrences of patients undergoing PD via the open, laparoscopic, or robotic approach. Asterisks (*) denote statistically significant results

Variables	OPD ($n = 9963$)	LPD ($n = 418$)	RPD ($n = 409$)	P value
Unplanned re-intubation, n (%)	389 (4%)	19 (5%)	19 (5%)	0.6178
Superficial surgical site infection, n (%)	844 (8%)	21 (5%)	28 (7%)	0.0244*
Deep incisional surgical site infection, n (%)	185 (2%)	3 (1%)	7 (2%)	0.2281
Organ/space surgical site infection, n (%)	1455 (15%)	61 (15%)	62 (15%)	0.9526
Wound disruption, n (%)	139 (1%)	7 (2%)	2 (0.4%)	0.2619
Pneumonia, n (%)	414 (4%)	13 (3%)	7 (2%)	0.0300*
Pulmonary embolism, n (%)	113 (1%)	8 (2%)	10 (3%)	0.0247*
Progressive renal insufficiency, n (%)	78 (0.7%)	3 (0.7%)	1 (0.2%)	0.4676
Urinary tract infection, n (%)	300 (3%)	15 (4%)	15 (4%)	0.6117
Stroke, n (%)	26 (0.2%)	0	3 (0.7%)	0.1084
Cardiac arrest requiring CPR, n (%)	107 (1%)	7 (2%)	6 (1.4%)	0.4060
Myocardial infarction, n (%)	113 (1%)	1 (0.2%)	3 (0.7%)	0.1752
Bleeding requiring transfusion, n (%)	1953 (20%)	77 (18%)	45 (11%)	< 0.0001*
Deep venous thrombosis/thrombophlebitis, n (%)	272 (3%)	13 (3%)	12 (3%)	0.8743
Sepsis, n (%)	933 (9%)	34 (8%)	28 (7%)	0.1660
Pancreatic fistula, n (%)	1789 (18%)	81 (19%)	74 (18%)	0.3856
Delayed gastric emptying, n (%)	1680 (17%)	71 (17%)	66 (16%)	0.4016
Mean length of hospital stay in days, n (SD)	11 (8.8)	11 (9.4)	10 (8.8)	0.0068*
Discharge destination to home, n (%)	8523 (86%)	373 (90%)	357 (87%)	0.0112*
Reoperation, n (%)	540 (5%)	31 (7%)	24 (6%)	0.2049
30-day readmission, n (%)	1632 (16%)	72 (17%)	92 (22%)	0.0048*
30-day overall morbidity, n (%)	4480 (45%)	161 (39%)	152 (37%)	0.0004*
Overall mortality, n (%)	213 (2%)	11 (2%)	9 (2%)	0.7921

Table 4 Multivariable linear regression analysis of significant predictors of increased OpTime and LOS for patients undergoing OPD

OPD variables	Variation in OpTime (minutes)	95% CI	*P* value
Age ≥ 65 years	− 16.34	− 22.10, − 10.58	< 0.0001
ASA class ≥ 3	12.97	6.14, 19.80	0.0002
Preoperative XRT	58.08	48.05, 68.11	< 0.0001
Preoperative transfusion	− 27.22	− 55.42, 0.97	0.0584
Pancreatic duct size < 3 mm	26.39	19.48, 33.30	< 0.0001
Soft pancreatic gland texture	− 10.24	− 16.56, − 3.92	0.0015
Vascular resection	63.23	56.21, 70.24	< 0.0001
T stage ≥ 3	8.94	2.06, 15.81	0.0108
	Variation in LOS (days)	95% CI	*P* value
Age ≥ 65 years	0.73	0.35, 1.12	0.0002
ASA class ≥ 3	0.75	0.29, 1.20	0.0012
Preoperative serum albumin < 3.7 (g/dL)	1.46	1.08, 1.84	< 0.0001
Preoperative XRT	− 1.57	− 2.23, − 0.90	< 0.0001
Preoperative transfusion	5.65	3.77, 7.53	< 0.0001
Operative time > 370 min	0.72	0.35, 1.10	0.0001
Postoperative bleeding	2.98	2.51, 3.44	< 0.0001
Postoperative pulmonary embolism	9.26	7.55, 10.97	< 0.0001
Postoperative pneumonia	8.53	7.58, 9.49	< 0.0001
Postoperative superficial surgical site infection	1.90	1.25, 2.55	< 0.0001

Predictors of an increased LOS for the laparoscopic group were preoperative hypertension (2.19 days, CI 0.42–3.97, $P = 0.0151$), OpTime of > 370 min (1.61 days, CI − 0.35–3.57, $P = 0.0536$), and specific postoperative complications, such as pulmonary embolism (7.17 days, CI 0.50–13.84, $P = 0.0351$), pneumonia (11.07 days, CI 5.63–16.51, $P < 0.0001$), and superficial surgical site infection (6.67 days, CI 2.95–10.38, $P = 0.0005$).

Predictors of OpTime and LOS for RPD

Predictors of increased OpTime and LOS among patients undergoing RPD are presented in Table 6. A main pancreatic duct of < 3 mm in diameter (62.78 min, CI32.39–93.18, $P < 0.0001$), malignant histology subtype (98.2 min, CI 1.76–194.65, $P = 0.0460$), and conversion to laparotomy (81.07 min, CI 40.39–121.75, $P = 0.0001$) were predictive of a longer operation. In contrast, the duration of a RPD was shorter when soft pancreatic gland texture was present ($P = 0.0151$).

An OpTime of > 370 min (2.77 days, CI 0.58–4.96, $P = 0.0130$) and postoperative bleeding (5.86 days, CI 2.73–8.99, $P = 0.0003$) were the only factors associated with a longer hospitalization for the patients undergoing a RPD.

Table 5 Multivariable linear regression analysis of significant predictors of increased OpTime and LOS for patients undergoing LPD

LPD variables	Variation in OpTime (minutes)	95% CI	P-value
Age ≥ 65 years	− 35.46	− 65.20, − 5.72	0.0196
Vascular resection	50.24	14.35, 86.12	0.0062
T stage ≥ 3	36.85	− 0.15, 73.86	0.0510
	Variation in LOS (days)	95% CI	*P* value
Hypertension	2.19	0.42, 3.97	0.0151
Operative time > 370 min	1.61	− 0.35, 3.57	0.0536
Postoperative pulmonary embolism	7.17	0.50, 13.84	0.0351
Postoperative pneumonia	11.07	5.63, 16.51	< 0.0001
Postoperative superficial surgical site infection	6.67	2.95, 10.38	0.0005

Table 6 Multivariable linear regression analysis of significant predictors of increased OpTime and LOS for patients undergoing RPD

RPD variables	Variation in OpTime (minutes)	95% CI	*P* value
Pancreatic duct size < 3 mm	62.78	32.39, 93.18	< 0.0001
Soft pancreatic gland texture	− 36.01	− 65.01, − 7.0	0.0151
Malignant histology subtype	98.20	1.76, 194.65	0.0460
Conversion to an open operation	81.07	40.39, 121.75	0.0001
	Variation in LOS (days)	95% CI	*P* value
Operative time > 370 min	2.77	0.58, 4.96	0.0130
Postoperative bleeding	5.86	2.73, 8.99	0.0003

Discussion

The duration of the primary operation and the length of hospitalization following surgery represent critical patient-centered outcomes, important to patients, providers, and payers. The identification of reliable predictors of prolonged OpTime and LOS is essential for patient counseling, shared-decision making, hospital planning, and the targeting of processes that could ultimately lead to improvements in these quality metrics. While PD is a complex operation with potential significant morbidity, considerable heterogeneity exists in reported OpTimes and LOS, especially among open and minimally invasive approaches.[13–16] In this study of nearly 11,000 patients using the targeted pancreatectomy ACS-NSQIP database, we found that predictors of increased OpTime and LOS were relatively consistent across various surgical approaches and represent common preoperative and perioperative factors (Fig. 1). To our knowledge, predictors of OpTime and LOS for the different operative techniques to PD using large-scale national registries have not been previously analyzed. Our findings suggest that prolonged OpTime and LOS can be reliably predicted through careful consideration of pre- and peri-operative factors regardless of surgical approach.

The findings of the current study highlight that factors associated with increased OpTime during PD are generally consistent.[17–19] For example, factors associated with malignancy (preoperative XRT use, malignant histopathologic subtype) and anatomical factors that make the PD dissection and reconstruction challenging (e.g., advanced T stage, need for vascular resection, and small pancreatic duct) were each independently associated with increased OpTime during PD. On the other hand, irrespective of operative approach, soft gland texture was associated with shorter OpTime. While soft pancreatic gland texture is a known risk factor for POPF, it may allow for easier dissection which in turn leads to a reduction in OpTime. These data are important as an increased OpTime has recently been identified as an independent risk factor for postoperative morbidity among patients undergoing pancreatectomy.[14] In addition, time in the operating room is associated with high direct and indirect costs.[20] Surgeons could use these data to identify patients at risk for prolonged OpTime and ensure that adequate assistance (e.g., second attending surgeon, trained robotic

	OpTime +	OpTime −	LOS +	LOS −
OPD	• ASA≥3 • Preoperative XRT • Duct <3mm • T≥3 • Vascular Resection	• Age ≥65 years • Soft Pancreas	• Age≥65 years • ASA≥3 • Albumin <3.7 • Preoperative Transfusion • OpTime>370 minutes • Postoperative Complications	• Preoperative XRT
LPD	• T≥3 • Vascular Resection	• Age ≥65 years	• Comorbidities • OpTime≥370 minutes • Postoperative Complications	
RPD	• Duct <3mm • Malignant Histology • Conversion to Laparotomy	• Soft Pancreas	• OpTime≥370 minutes • Postoperative Complications	

Fig. 1 Significant predictors of increased (+) or decreased (−) OpTime and LOS across surgical approaches for PD

surgical technician, etc) is available. Regardless, efforts to safely minimize OpTime, where appropriate, may lead to improvements in perioperative outcomes and hospital costs.

One limitation to the use of the ACS-NSQIP database is the absence of surgeon-level data, since significant variability in operative speed exists among surgeons. Indeed, OpTime is one of the most frequently correlated metrics with surgeon experience and the learning curve.[21] Since MIS PD is a relatively recent innovation and, outside of several high-volume institutions, most surgeons are still relatively early in their learning curve, it will be interesting to evaluate in the future whether predictors of OpTime change over time and whether OpTime could be an objective measure of surgical proficiency and quality. Despite a possible learning curve for the MIS approaches, we noted that the requirement of vascular resection significantly increased the OpTime of open and LPD, but not that of the robotic operations. While the robotic approach may offer some inherent ergonomic advantages for intracorporeal suturing, this finding may be the result of a low number of robotic vascular resections in this study.

Factors associated with prolonged LOS after PD, consistent with previous studies, included preoperative comorbidities (older age, higher ASA class, preoperative hypoalbuminemia, and need for preoperative blood transfusion) as well as postoperative complications.[22–24] Among patients undergoing OPD, preoperative radiation therapy was independently associated with a shorter LOS, presumably because of its association with a lower incidence of POPF, a significant driver of prolonged LOS.[25,26] Interestingly, among all three approaches, a prolonged OpTime was also associated with a longer hospitalization, consistent with the findings of other studies.[14] Indeed, in our study, an OpTime greater than 370 min was associated with roughly a 0.7-, 1.6-, and 2.7-day increase in LOS for patients undergoing OPD, LPD, and RPD, respectively. This exponential increase in LOS likely reflects the steep learning curve in MIS PD, as low volume surgeons and hospitals have previously been associated with longer hospital LOS.[27,28]

Given the median LOS > 10 days across all approaches and the number of identified variables associated with increased length of hospitalization, opportunities for quality improvement should be pursued. Indeed, the primary aim of most enhanced recovery after surgery (ERAS) protocols is to hasten patient recovery and reduce LOS. Previous research has shown that protocols may be implemented in pancreatic surgery without compromising patient safety or increasing LOS.[29–31] Consequently, rigorous preoperative counseling and ERAS programs that incorporate these processes into the perioperative care plan after PD, especially among those patients with risk factors for prolonged LOS, may decrease complications, hasten recovery, shorten LOS, and reduce hospitalization costs. Finally, our study re-demonstrates the significance of postoperative complications on extended length of hospitalization, and therefore, efforts to minimize or prevent complications, regardless of surgical approach, may be most effective at minimizing LOS.

The major strength of this study is the use of a well-established, population-based database linked to pancreatectomy-specific variables, resulting in a large sample size with clinicopathologic, surgical, and outcome variables relevant to PD. This robust dataset allowed for the precise calculation of adjusted estimates of OpTime or LOS for any perioperative factor/event (e.g., a postoperative pneumonia is independently associated with an additional 8.5 days in the hospital). Nevertheless, some information remains missing from this database that could influence OpTime and/or LOS including surgeon experience, postoperative care pathways, and hospital characteristics. In addition, the sample size of LPD and RPD was significantly smaller than OPD, which limits the statistical power to detect factors associated with the outcomes of interest; this may explain why fewer independent predictors of increased OpTime and LOS were identified than with OPD. Furthermore, some differences in preoperative characteristics differed among the three groups, though these differences were likely clinically insignificant and controlled for in multivariable logistic regression models. Finally, as with all large databases, the accuracy of the data used, to a certain degree, are dependent on the accuracy of the coders inputting the data.

In conclusion, perioperative risk factors for prolonged OpTime and hospital LOS are relatively consistent across open, laparoscopic, and robotic approaches to PD. Traditional preoperative patient characteristics and tumor-related factors are independently associated with increased OpTime while preoperative measures of worse health and specific postoperative complications are associated with increased LOS. Particular attention to these factors may lead to a more accurate prediction of the OpTime and LOS of patients undergoing PD via different operative approaches. Consequently, these predictions may aid in the development and implementation of perioperative management systems to enhance patient satisfaction, improve quality of care, and ensure an efficient allocation of hospital resources.

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Authors' Contribution D. Xourafas, T. Pawlik, and J. Cloyd have contributed to the design, analysis, interpretation of data, and drafting of the manuscript. All authors have approved the final version of the manuscript and are accountable for all aspects of the work. The authors verify that the submitted material has not been published and is not currently submitted for publication elsewhere. We agree to the inclusion of our names in the list of authors on the manuscript in the order shown on the title page.

Compliance with Ethical Standards

Conflict of Interest D. Xourafas, T. Pawlik, and J. Cloyd have no conflicts of interest or financial ties to disclose.

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