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ORIGINAL RESEARCH

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Current landscape of minimally invasive pancreatectomy for neoplasms: A retrospective cohort study

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Abstract

Background: To evaluate recent minimally invasive pancreatectomy (MIP) trends for neoplastic disease and compare perioperative outcomes.

Methods: Patients who underwent open (OS) or MIP (laparoscopic-LS or robotic-RS) pancreaticoduodenectomy (PD) or non-pancreaticoduodenectomy resections (non-PD) were identified from PINC AI Healthcare Database. Outcomes were compared using multivariable regressions.

Results: OS was the predominant approach for PD (87.8%); MIP was more common in non-PD (48.5%) than PD with a substantial RS uptake (11.7%–29.9%). In PDs, outcomes were similar except OS had a longer length of stay (LOS) and lower costs. In non-PDs, MIP patients were less likely to have prolonged LOS, intensive care unit admission, and overall complications than OS. Conversion to OS was lower in the RS approach than LS in PD and non-PD.

Conclusions: MIP for non-PD has become the most common operative approach with improved outcomes; MIP-PD has flat adoption and similar outcomes to OS. Robotics facilitates MIP (PD and non-PD) completion through fewer conversions to open surgery (OS).

KEYWORDS

laparoscopic, minimally invasive, non-pancreaticoduodenectomy, pancreatectomy, pancreaticoduodenectomy, robotic

1 | INTRODUCTION

The surgical approach for pancreatic resection for neoplasm is based on anatomic tumor location. Pancreatic head lesions are treated with pancreaticoduodenectomy (PD) and body and tail tumors by non-pancreaticoduodenectomy resections (non-PD). Moreover, resections can be performed via open or minimally invasive approaches further categorized as laparoscopic (LS) or robotic (RS) procedures. Reported benefits of minimally invasive pancreatectomy (MIP) compared to open surgery (OS) include decreased blood loss, length of stay (LOS), recovery times and complications, and improved cost-effectiveness and long-term cosmetic satisfaction of patients. Clinical equipoise, as measured by overall quality of life, is comparable between the two approaches.[1–3]

The adoption of MIP has been gradual. The proportion of minimally invasive non-pancreaticoduodenectomy (MIS non-PD) slowly increased in the USA from 2.4% to 7.8% from 1998 to 2009.[45] In Norway, 59% of non-PDs were performed minimally invasively between 2012 and 2016.[5] A study in the USA showed that among minimally invasive pancreaticoduodenectomy (MIPD), robotic PD for pancreatic adenocarcinoma increased from 12.8% to 34.6% between 2010 and 2020.[6] Technological improvements such as energy, improved image quality, and development of the robotic platform have supported the application of minimally invasive techniques to complex operations. However, national data on the proportion of PDs that are performed minimally invasively in the USA are minimal.

Multiple retrospective studies have demonstrated the feasibility and safety of MIP when compared to the open approach.[7–11] Although oncologic outcomes initially appeared to be inferior to the open technique, subsequent studies have shown acceptable equivalent oncologic and survival outcomes between the two approaches, with some studies showing superior oncologic outcomes with MIP approaches.[12,13] Additionally, the procedure cost of MIP has been reportedly higher than the open approach. However, with reduced LOS, lower hospital costs have been associated with MIP in Europe and the USA.[14,15]

As the field evolves, evaluating MIP adoption and the outcomes is important to inform management decisions. This study aims to report (a) recent trends in the adoption of minimally invasive pancreatectomy (laparoscopic or robotic) for neoplasms in the USA, (b) postoperative clinical outcomes among open, laparoscopic, and robotic approaches for PD and non-PD resections, and (c) costs associated with each approach. We hypothesize that adoption of minimally invasive pancreatectomy is increasing, and that MIP has superior outcomes and reduced total costs when compared to open pancreatectomy.

2 | MATERIALS AND METHODS

2.1 | Data source

This retrospective study uses the PINC AI Healthcare Database (PHD), formerly known as Premier Healthcare Database, an extensive US hospital-based, service-level, and all-payer database containing inpatient discharge data.[16] Hospitals provide administrative, healthcare utilization, and financial information from patient encounters. The PHD captures approximately 25% of US inpatient admissions from more than 740 hospitals located in all the US Census geographic divisions annually. Patients can be followed in the same hospital across inpatient and hospital-based outpatient settings over time. PHD adheres to strict quality control where only 0.01% of data are missing for key categories. As data within the PHD are deidentified and compliant with the Health Insurance Portability and Accountability Act privacy rules, institutional review board approval was exempted and no patient consent was required for the study. The study was reported according to the STROBE guidelines.[17]

2.2 | Study population

Patients aged ≥18 years who underwent an elective, inpatient PD, or non-PD as a primary procedure for benign or malignant neoplasm between January 1, 2013, and December 31, 2020, were included in the study. Each pancreatectomy group was further classified into open (OS), laparoscopic (LS), or robotic-assisted (RS) groups based on the International Classification of Diseases, 9th and 10th Revisions Procedure classification system (ICD-9-PCS/ICD-10-PCS codes), Current Procedural Terminology (CPT) codes, and billing text fields (Supplementary Table 1 in Supporting Information S1). Laparoscopic or robotic cases converted to open were counted as intention-to-treat by the originally planned surgical approach. Patients were excluded if they had operative time <1 h, no operative time data, or had missing demographic, hospital, and cost information (Figure 1).

2.3 | Outcome measures

Outcomes for the index hospital encounter included hospital length of stay (LOS), prolonged LOS, conversion rates to open surgery, splenectomy, operating room (OR) time, intensive care unit (ICU) admission, in-hospital mortality, discharge to home rates, in-hospital reoperations, and complications. Prolonged LOS was defined as ≥14 days and ≥10 days for the PD and non-PD groups, respectively.[18–21] The index encounter was defined as the hospital encounter in which a patient underwent pancreatectomy. ICD codes were used to identify in-hospital complications, including intraoperative, pulmonary, mechanical ventilation, bleeding, blood transfusion, infections, and venous thromboembolism. We assessed 30-day readmission to the same hospital and perioperative hospital costs for service utilization. Perioperative cost is the sum of the index hospitalization cost and any additional costs incurred within 30 days of discharge from the same hospital for each patient. Each hospital uses cost accounting models and systems to determine procedural costs. Healthcare systems that submit ratios of costs to charges also provide charge data to PINC AI. PINC AI and the hospitals ascribe Medicare cost to charge ratios and then PHD validates all costs and charges.

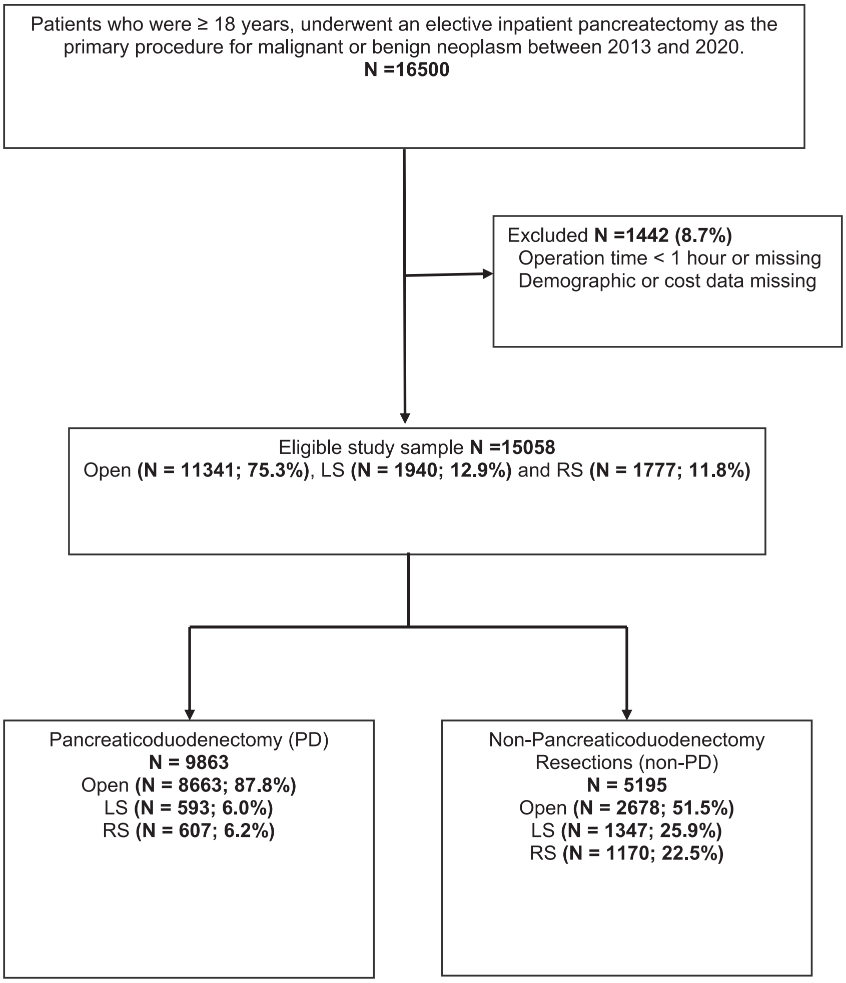

FIGURE 1 Study flowchart. LS, laparoscopic surgery; RS, robotic surgery.

Additional outcomes included the proportion of cases performed via open, laparoscopic, and robotic approaches in a given year. We also determined the percentage of high-volume versus low-volume centers completing MIS-PD and MIS non-PD cases. For PD cases, hospitals were considered high-volume centers if $\geq$ 9 cases were performed yearly and low-volume if $<$ 9 cases were performed yearly.[22,23] For non-PD cases, hospitals were defined as high-volume if $\geq$ 5 cases were performed per year and low-volume non-PD centers if $<$ 5 cases per year were performed.[24,25]

2.4 | Study covariates

Patient and hospital characteristics during the index hospital admission were identified. Patient-level characteristics included age, sex, race, payor type, primary diagnosis (malignant or benign neoplasm), body mass index (BMI), and noncancer Charlson comorbidity index (CCI) scores. Hospital characteristics included geographic region, urban/rural area, teaching status, and bed size.

2.5 | Statistical analysis

Summary statistics were reported as means and standard deviations (SDs) and compared using the Student's *t*-test or analysis of variance (ANOVA) for normally distributed continuous variables. Abnormally distributed continuous variables were compared using the Mann–Whitney *U* test and reported as medians with interquartile range. Categorical variables were compared using the chi-squared test and reported as percentages. Adoption trends were plotted by year and reported as annual volumes and proportions for each surgical approach. Fold change for each surgical approach over time was calculated by dividing the proportional use of the approach in 2020 with its proportional use in 2013. Multivariable logistic regression and gamma regression with identity link models were used to compare outcomes between operative approaches while controlling for baseline patient and hospital characteristics (study covariates) among the groups. The odds ratio (OR)/mean difference (MD) and 95% confidence interval (CI) were calculated and considered statistically significant if $p < 0.05$. All analyses were performed using the *R* software version 4.1.1.

3 | RESULTS

3.1 | Baseline patient and hospital characteristics

The study cohort ($n = 15{,}058$) was largely composed of patients who were White (73.0%), aged ≥65 years (57.8%), and had malignant neoplasm as the primary diagnosis (82.4%). Table 1 shows baseline characteristics for patients who underwent open, laparoscopic, and robotic pancreatectomy.

3.2 | Temporal trends of surgical approaches

A total of 15,058 patients underwent pancreatectomy (PD = 9863 and non-PD = 5195) for neoplasms between 2013 and 2020 (Figure 1). Among PD resections, the open approach was predominant. MIPD (LS and RS) was less commonly performed, with adoption rates fluctuating between 8.2% and 16.8% over the study period (Figure 2A). In non-PD resections, MIP non-PD rates were higher than PD; MIP non-PD became the most common approach in 2016 (53.3%; Figure 2B). Overall, RS had substantial uptake and increased 4.3-fold from 2.3% to 9.9% for PD and 2.6-fold from 11.7% to 29.9% for non-PD over 8 years.

3.3 | Hospital volume trends

In the early years, over half of the hospitals only performed open pancreatectomy procedures in their facilities (2013: 57.2% and 2014: 58.0%) as shown in Figure 2C. The percentage decreased over subsequent years and only a third of hospitals did not perform MIP by 2020 (Figure 2C). This was mainly driven by the proportion of non-PD hospitals doubling from 31.7% to 63.7% over 8 years. In contrast, the hospital uptake of minimally invasive PD (MIPD) was modest from 21.2% to 32.7%. When we stratified by hospital pancreatectomy volume (Supplementary Table 2 in Supporting Information S1), there was an increase in both low- and high-volume hospitals that performed MIP over the study period. High-volume hospitals increased in proportion from 42.9% to 66.0% for PD and 80.8%–95.0% for non-PD, whereas the proportion of low-volume hospitals (<5 cases/year) that performed non-PD cases almost doubled from 34.1% to 65.0%.

3.4 | Comparison of perioperative and postoperative outcomes

3.4.1 | PD resections

Patients with MIPD resections did not have many significantly different outcomes than OS. LS had longer operative time (mean difference 41 min) and a 36% increased risk of blood transfusion (Table 2). RS had an increased operative time (mean difference 107 min), a 26% increased risk of transfusion, and a shorter LOS (mean difference −0.86, $p < 0.001$; 11.3 vs. 10.2 days). The 30-day perioperative costs for MIP were significantly higher than OS (LS: mean difference $4186, $p = 0.015$; RS: mean difference $9977, $p < 0.001$) (Table 2). When compared RS to LS, RS had lower risk of conversion to open (OR 0.30 [0.23–0.40] and $p < 0.001$), lower risk for ICU admission (OR 0.30 [0.23–0.40] and $p < 0.001$), and trended toward higher perioperative costs than the LS group (mean difference $4691, $p = 0.052$; Supplementary Table 3 in Supporting Information S1).

3.4.2 | Non-PD resections

Overall, the MIP approach had improved outcomes compared to OS. Both LS had lower risk of ICU admission, in-hospital complications, and decreased LOS. In addition, RS had lower risk for splenectomy (0.66 [0.57–0.76], $p < 0.001$) (Table 3). Compared to OS, 30-day perioperative costs were lower and higher for LS and RS, respectively (LS: MD $−2066, $p = 0.005$ and RS: MD $5286, $p < 0.001$).

When comparing RS to LS, outcomes were similar except RS had longer OR time (mean difference: 82 min) and lower risk of splenectomy (OR 0.42 [0.33–0.54] and $p < 0.001$) (Supplementary Table 4 in Supporting Information S1).

Additionally, conversion to open surgery was less likely to occur in the RS group than the LS group (OR 0.42 [0.33–0.54] and $p < 0.001$). RS had higher 30-day perioperative costs than LS (mean difference $7351 [5444 to 9291] and $p < 0.001$).

3.5 | Comparison of MIP conversion to open versus nonconversion

The overall conversion rate was higher for MIPD than non-PD (33.7% vs. 15.4%) and patients in the conversion groups had increased risk for complications and perioperative costs. The MIPD conversion group had

TABLE 1 Baseline patient and hospital-related characteristics of patients who underwent pancreatectomy.

	Pancreaticoduodenectomy (PD)					Non-pancreaticoduodenectomy (Non-PD) resections				
		Type of procedure					Type of procedure			
Variable	Overall, $N = 9863$	OS, $N = 8663$	LS, $N = 593$	RS, $N = 607$	*P* Value	Overall, $N = 5195$	OS, $N = 2678$	LS, $N = 1347$	RS, $N = 1170$	*P* Value
Age					0.130					0.430
18–44	371 (3.8)	330 (3.8)	16 (2.7)	25 (4.1)		501 (9.6)	260 (9.7)	139 (10.3)	102 (8.7)	
45–65	3613 (36.6)	3163 (36.5)	242 (40.8)	208 (34.3)		1867 (35.9)	985 (36.8)	466 (34.6)	416 (35.6)	
65+	5879 (59.6)	5170 (59.7)	335 (56.5)	374 (61.6)		2827 (54.4)	1433 (53.5)	742 (55.1)	652 (55.7)	
Sex					0.930					0.850
Female	4705 (47.7)	4133 (47.7)	286 (48.2)	286 (47.1)		2896 (55.7)	1503 (56.1)	747 (55.5)	646 (55.2)	
Male	5158 (52.3)	4530 (52.3)	307 (51.8)	321 (52.9)		2299 (44.3)	1175 (43.9)	600 (44.5)	524 (44.8)	
Race					0.001					0.001
African American	990 (10.0)	886 (10.2)	54 (9.1)	50 (8.2)		598 (11.5)	322 (12.0)	127 (9.4)	149 (12.7)	
Hispanic	683 (6.9)	610 (7.0)	39 (6.6)	34 (5.6)		404 (7.8)	198 (7.4)	125 (9.3)	81 (6.9)	
Caucasian	7253 (73.5)	6312 (72.9)	452 (76.2)	489 (80.6)		3740 (72.0)	1897 (70.8)	1000 (74.2)	843 (72.1)	
Others	937 (9.5)	855 (9.9)	48 (8.1)	34 (5.6)		453 (8.7)	261 (9.7)	95 (7.1)	97 (8.3)	
Payer					0.029					0.070
Commercial	3031 (30.7)	2636 (30.4)	193 (32.5)	202 (33.3)		1826 (35.1)	930 (34.7)	469 (34.8)	427 (36.5)	
Medicaid	612 (6.2)	550 (6.3)	43 (7.3)	19 (3.1)		344 (6.6)	193 (7.2)	95 (7.1)	56 (4.8)	
Medicare	5750 (58.3)	5059 (58.4)	333 (56.2)	358 (59.0)		2779 (53.5)	1417 (52.9)	721 (53.5)	641 (54.8)	
Others	470 (4.8)	418 (4.8)	24 (4.0)	28 (4.6)		246 (4.7)	138 (5.2)	62 (4.6)	46 (3.9)	
Primary diagnosis					<0.001					0.150
Benign	1023 (10.4)	911 (10.5)	36 (6.1)	76 (12.5)		1631 (31.4)	815 (30.4)	423 (31.4)	393 (33.6)	
Malignant	8840 (89.6)	7752 (89.5)	557 (93.9)	531 (87.5)		3564 (68.6)	1863 (69.6)	924 (68.6)	777 (66.4)	
BMI					0.970					0.440
Normal	7083 (71.8)	6217 (71.8)	430 (72.5)	436 (71.8)		3950 (76.0)	2030 (75.8)	1036 (76.9)	884 (75.6)	
Obese	506 (5.1)	441 (5.1)	29 (4.9)	36 (5.9)		384 (7.4)	183 (6.8)	101 (7.5)	100 (8.5)	
Overweight	1068 (10.8)	942 (10.9)	64 (10.8)	62 (10.2)		590 (11.4)	320 (11.9)	141 (10.5)	129 (11.0)	
Underweight	1206 (12.2)	1063 (12.3)	70 (11.8)	73 (12.0)		271 (5.2)	145 (5.4)	69 (5.1)	57 (4.9)	
CCI score					0.008					0.120
0	4699 (47.6)	4154 (48.0)	257 (43.3)	288 (47.4)		2907 (56.0)	1455 (54.3)	772 (57.3)	680 (58.1)	
1	1297 (13.2)	1121 (12.9)	75 (12.6)	101 (16.6)		739 (14.2)	383 (14.3)	192 (14.3)	164 (14.0)	
2+	3867 (39.2)	3388 (39.1)	261 (44.0)	218 (35.9)		1549 (29.8)	840 (31.4)	383 (28.4)	326 (27.9)	
Region					<0.001					<0.001
Midwest	1655 (16.8)	1431 (16.5)	84 (14.2)	140 (23.1)		884 (17.0)	460 (17.2)	170 (12.6)	254 (21.7)	
Northeast	1827 (18.5)	1634 (18.9)	124 (20.9)	69 (11.4)		925 (17.8)	474 (17.7)	294 (21.8)	157 (13.4)	
South	4889 (49.6)	4223 (48.7)	283 (47.7)	383 (63.1)		2679 (51.6)	1306 (48.8)	714 (53.0)	659 (56.3)	
West	1492 (15.1)	1375 (15.9)	102 (17.2)	15 (2.5)		707 (13.6)	438 (16.4)	169 (12.5)	100 (8.5)	
Hospital location					<0.001					0.013
Rural	555 (5.6)	507 (5.9)	36 (6.1)	12 (2.0)		268 (5.2)	148 (5.5)	79 (5.9)	41 (3.5)	
Urban	9308 (94.4)	8156 (94.1)	557 (93.9)	595 (98.0)		4927 (94.8)	2530 (94.5)	1268 (94.1)	1129 (96.5)	
Teaching hospital	7354 (74.6)	6477 (74.8)	416 (70.2)	461 (75.9)	0.032	3771 (72.6)	1902 (71.0)	1030 (76.5)	839 (71.7)	<0.001

(Continues)

TABLE 1 (Continued)

	Pancreaticoduodenectomy (PD)					Non-pancreaticoduodenectomy (Non-PD) resections				
		Type of procedure					Type of procedure			
Variable	Overall, $N = 9863$	OS, $N = 8663$	LS, $N = 593$	RS, $N = 607$	*P* Value	Overall, $N = 5195$	OS, $N = 2678$	LS, $N = 1347$	RS, $N = 1170$	*P* Value
Bed size					<0.001					<0.001
0–299	859 (8.7)	768 (8.9)	71 (12.0)	20 (3.3)		527 (10.1)	299 (11.2)	137 (10.2)	91 (7.8)	
300–399	1416 (14.4)	1298 (15.0)	91 (15.3)	27 (4.4)		690 (13.3)	394 (14.7)	190 (14.1)	106 (9.1)	
400–499	1302 (13.2)	1145 (13.2)	95 (16.0)	62 (10.2)		664 (12.8)	365 (13.6)	151 (11.2)	148 (12.6)	
500+	6286 (63.7)	5452 (62.9)	336 (56.7)	498 (82.0)		3314 (63.8)	1620 (60.5)	869 (64.5)	825 (70.5)	

Abbreviations: BMI, body mass index; CCI, Charlson comorbidity index; LS, laparoscopic surgery; OS, open surgery; PD, pancreaticoduodenectomy; RS, robotic-assisted surgery.

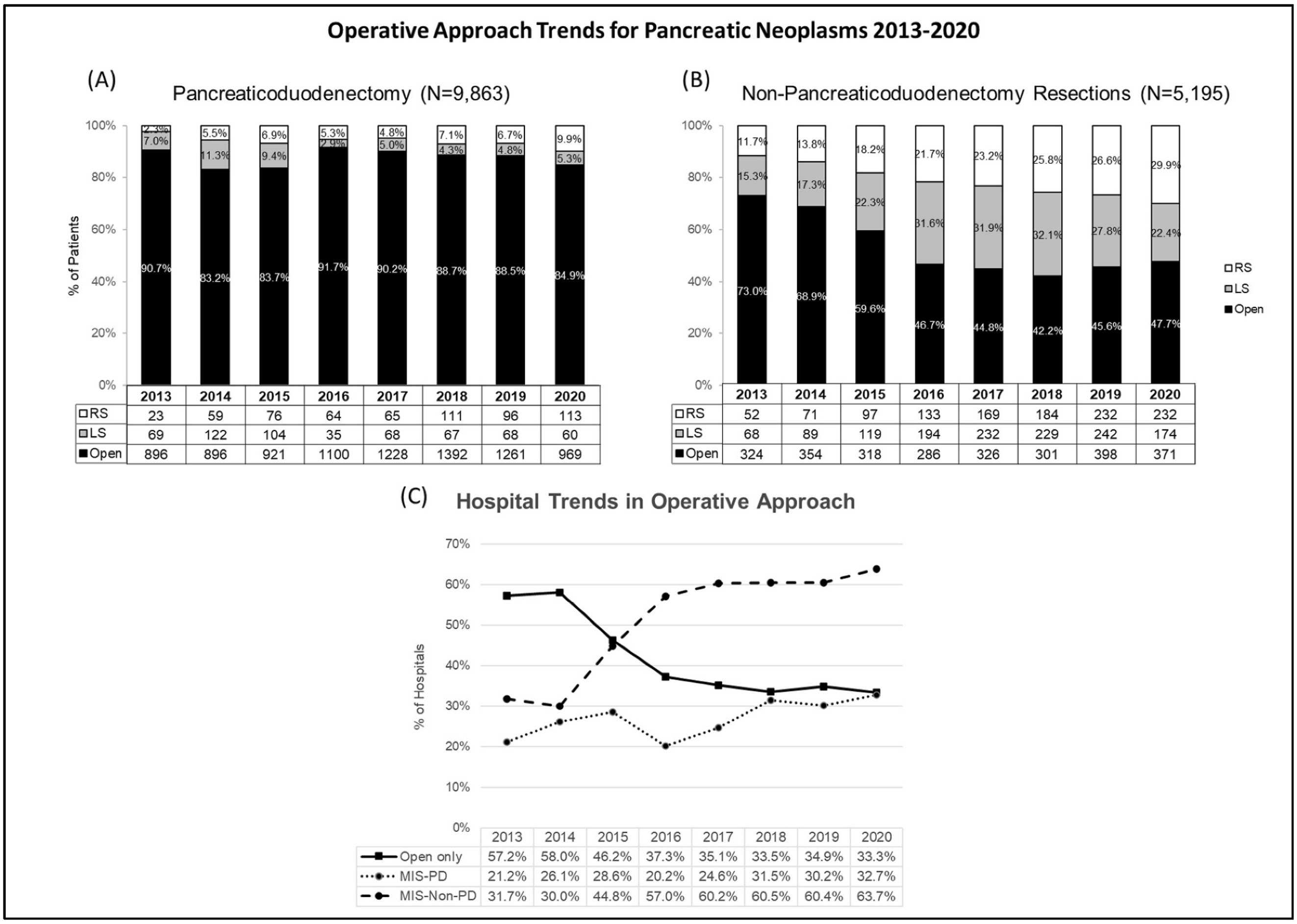

FIGURE 2 Trend utilization of an operative approach for pancreatectomy patients with pancreatic neoplasms (A) pancreaticoduodenectomy, (B) non-pancreaticoduodenectomy resections, and (C) utilization of open and minimally invasive pancreatectomy among hospitals. MIS non-PD, minimally invasive non-pancreaticoduodenectomy; MIS-PD, minimally invasive pancreaticoduodenectomy; LS, laparoscopic; RS, robotic.

higher risk for intraoperative complications (OR 2.11 [1.03–4.29] and $p < 0.039$) and transfusion (OR 1.43 [1.07–1.91] and $p < 0.017$) (Supplementary Table 5 in Supporting Information S1). On the other hand, the MIP non-PD conversion group had higher risk for splenectomy (OR 3.24 [2.46–4.32] and $p < 0.001$), in-hospital complications including transfusion (OR 2.94 [2.11–4.06] and $p < 0.001$), ICU admission (OR 2.47 [1.94–

TABLE 2 Multivariable analysis of association of surgical approach and postoperative outcomes for pancreaticoduodenectomy (PD).

Variable	Type of procedure OS, *N* = 8663	LS, *N* = 593	RS, *N* = 607	*P* Value	LS versus Open Diff/OR (95% CI)	*P* Value	RS versus Open Diff/OR (95% CI)	*P* Value
LOS				<0.001				
Mean (SD)	11.3 (9.5)	11.2 (9.2)	10.2 (10.9)		0.09 (−0.63 to 0.88)	0.810	−0.86 (−1.5 to −0.16)	0.012
Median (Q1, Q3)	8 (6, 13)	8 (6, 13)	7 (5, 11)					
LOS ≥14 days	2032 (23.5%)	141 (23.8%)	100 (16.5%)	<0.001	1.01 (0.82 to 1.23)	0.940	0.66 (0.53 to 0.82)	<0.001
OR time				<0.001				
Mean (SD)	440.0 (350.0)	479.6 (170.2)	530.4 (199.9)		41 (19 to 65)	<0.001	107 (81 to 134)	<0.001
Median (Q1, Q3)	407 (330, 510)	465 (360, 555)	480 (405, 594)					
ICU admission	5499 (63.5%)	357 (60.2%)	371 (61.1%)	0.16	0.88 (0.74 to 1.05)	0.160	0.88 (0.74 to 1.05)	0.151
In-hospital mortality	248 (2.9%)	21 (3.5%)	18 (3.0%)	0.63	1.19 (0.73 to 1.84)	0.456	1.02 (0.60 to 1.63)	0.932
Discharge home	6994 (80.7%)	470 (79.3%)	482 (79.4%)	0.52	0.92 (0.74 to 1.14)	0.431	0.93 (0.75 to 1.16)	0.508
Index reoperation	457 (5.3%)	39 (6.6%)	40 (6.6%)	0.17	1.23 (0.86 to 1.71)	0.227	1.34 (0.94 to 1.87)	0.091
In-hospital complication	3999 (46.2%)	296 (49.9%)	285 (47.0%)	0.20	1.16 (0.98 to 1.37)	0.093	1.00 (0.85 to 1.19)	0.972
Intraoperative	182 (2.1%)	20 (3.4%)	15 (2.5%)	0.11	1.54 (0.93 to 2.41)	0.073	1.26 (0.70 to 2.09)	0.411
Pulmonary	1123 (13.0%)	83 (14.0%)	99 (16.3%)	0.054	1.08 (0.84 to 1.37)	0.540	1.27 (1.00 to 1.59)	0.045
Mechanical ventilation	638 (7.4%)	57 (9.6%)	50 (8.2%)	0.11	1.31 (0.97 to 1.74)	0.068	1.16 (0.84 to 1.56)	0.362
Transfusion	1674 (19.3%)	149 (25.1%)	136 (22.4%)	<0.001	1.36 (1.11 to 1.65)	0.002	1.26 (1.02 to 1.54)	0.026
Bleeding	2284 (26.4%)	172 (29.0%)	174 (28.7%)	0.19	1.17 (0.97 to 1.40)	0.107	1.05 (0.87 to 1.27)	0.597
Infections	1243 (14.3%)	90 (15.2%)	86 (14.2%)	0.85	1.06 (0.83 to 1.33)	0.634	1.00 (0.78 to 1.26)	0.989
Venous thromboembolism	180 (2.1%)	13 (2.2%)	14 (2.3%)	0.92	1.01 (0.54 to 1.73)	0.964	1.12 (0.61 to 1.90)	0.680
30-day readmission	1592 (18.4%)	103 (17.4%)	123 (20.3%)	0.40	0.96 (0.76 to 1.19)	0.689	1.09 (0.88 to 1.34)	0.434
30-day perioperative cost				<0.001				
Mean (SD)	48,039 (40,936)	51,063 (47,613)	54,381 (44,067)		4186 (987 to 7654)	0.015	8877 (5492 to 12,541)	<0.001
Median (Q1, Q3)	37,330 (27,847, 53,371)	38,061 (29,192, 55,651)	43,083 (32,760, 58,189)					

Abbreviations: CI, confidence interval; Diff, mean difference; ICU, intensive care unit; LOS, length of stay; LS, laparoscopic surgery; OR, odds ratio; OR time, operative room time; OS, open surgery; RS, robotic-assisted surgery.

3.14] and $p < 0.001$), and increased LOS (mean difference 1.3 [0.71–1.9) and $p < 0.001$) compared to the nonconversion group (Supplementary Table 6 in Supporting Information S1). Perioperative costs between conversion and nonconversion groups were not significantly different in the MIPD group but were higher

TABLE 3 Multivariable analysis of association of surgical approach and postoperative outcomes for non-pancreaticoduodenectomy resections (Non-PD).

Variable	Type of procedure				LS versus Open		RS versus Open	
	OS, *N* = 2678	LS, *N* = 1347	RS, *N* = 1170	*P* Value	OR/Diff (95% CI)	*P* Value	OR/Diff (95% CI)	*P* Value
LOS				<0.001				
Mean (SD)	7.4 (5.7)	6.2 (5.1)	6.1 (5.2)		−1.1 (−1.4 to −0.79)	<0.001	−1.2 (−1.5 to −0.86)	<0.001
Median (Q1, Q3)	6 (5, 8)	5 (4, 7)	5 (4, 7)					
LOS ≥10 days	435 (16.2%)	162 (12.0%)	111 (9.5%)	<0.001	0.71 (0.58 to 0.87)	<0.001	0.56 (0.44 to 0.70)	<0.001
OR time								
Mean (SD)	294.8 (195.1)	298.4 (155.2)	384.2 (188.9)	<0.001	6.2 (−4.4 to 17)	0.254	88 (74 to 102)	<0.001
Median (Q1, Q3)	267 (210, 345)	270 (210, 360)	339 (261, 450)					
Splenectomy	1816 (67.8%)	907 (67.3%)	691 (59.1%)	<0.001	0.98 (0.85 to 1.13)	0.764	0.66 (0.57 to 0.76)	<0.001
ICU Admission	1089 (40.7%)	353 (26.2%)	280 (23.9%)	<0.001	0.52 (0.44 to 0.60)	<0.001	0.45 (0.38 to 0.52)	<0.001
In-hospital mortality	34 (1.3%)	10 (0.7%)	12 (1.0%)	0.31	0.59 (0.27 to 1.16)	0.146	0.80 (0.39 to 1.52)	0.508
Discharge home	2397 (89.5%)	1230 (91.3%)	1062 (90.8%)	0.15	1.29 (1.02 to 1.64)	0.035	1.16 (0.91 to 1.48)	0.250
Index reoperation	79 (2.9%)	30 (2.2%)	31 (2.6%)	0.41	0.75 (0.48 to 1.14)	0.191	0.97 (0.62 to 1.48)	0.887
In-hospital complication	855 (31.9%)	320 (23.8%)	294 (25.1%)	<0.001	0.67 (0.58 to 0.79)	<0.001	0.72 (0.61 to 0.84)	<0.001
Intraoperative	48 (1.8%)	22 (1.6%)	16 (1.4%)	0.63	0.90 (0.53 to 1.49)	0.689	0.82 (0.44 to 1.43)	0.501
Pulmonary	234 (8.7%)	87 (6.5%)	85 (7.3%)	0.029	0.73 (0.56 to 0.95)	0.020	0.84 (0.64 to 1.10)	0.211
Mechanical ventilation	113 (4.2%)	44 (3.3%)	46 (3.9%)	0.34	0.77 (0.53 to 1.10)	0.157	0.95 (0.65 to 1.35)	0.760
Transfusion	333 (12.4%)	112 (8.3%)	92 (7.9%)	<0.001	0.63 (0.50 to 0.79)	<0.001	0.62 (0.48 to 0.79)	<0.001
Bleeding	473 (17.7%)	165 (12.2%)	173 (14.8%)	<0.001	0.67 (0.55 to 0.81)	<0.001	0.81 (0.67 to 0.99)	0.039
Infections	185 (6.9%)	72 (5.3%)	61 (5.2%)	0.050	0.78 (0.58 to 1.03)	0.088	0.73 (0.54 to 0.99)	0.045
Venous thromboembolism	32 (1.2%)	6 (0.4%)	11 (0.9%)	0.068	0.36 (0.13 to 0.81)	0.023	0.83 (0.40 to 1.63)	0.613
30-day readmission	455 (17.0%)	216 (16.0%)	206 (17.6%)	0.56	0.93 (0.77 to 1.11)	0.403	1.04 (0.86 to 1.25)	0.676
30-day perioperative cost				<0.001				
Mean (SD)	32,291 (26,240)	30,078 (23,585)	36,519 (33,743)		−2066 (−3493 to −611)	0.005	5286 (3547 to 7082)	<0.001
Median (Q1, Q3)	25,481 (18,793, 36,360)	23,819 (17,214, 33,571)	28,940 (21,633, 40,200)					

Abbreviations: CI, confidence interval; Diff, mean difference; ICU, intensive care unit; LOS, length of stay; LS, laparoscopic surgery; OR, odds ratio; OR time, operative room time; OS, open surgery; RS, robotic-assisted surgery.

in the non-PD group (mean difference $4946 (2061–8080) and $p = 0.001$).

4 | DISCUSSION

This retrospective cohort study evaluated the recent trends in adopting minimally invasive pancreatectomy for pancreatic neoplasms in the United States from 2013 to 2020 in a large representative dataset of US hospitals. Since 2013, there has been an overall increase in MIP and the number of hospitals performing these cases. Both MIPD and non-PD resections have seen increased adoption but at unequal rates. Non-PD cases account for the greatest proportion of MIP procedures and are performed in two-thirds of low pancreatectomy volume hospitals, which may be influenced by the fact that non-PDs are technically more approachable for surgeons.[26–28] Conversely, MIPD represents a more technically complex dissection coupled with multiple reconstructions. This could explain why 87.8% of PDs in this study are open and why MIPD has a slower adoption rate and is performed in fewer hospitals (~25%).

The laparoscopic PD rate has been stagnant compared to robotic PD, which has seen a 4-fold increase, even though the LS approach was first developed and had a reported easier learning curve.[26,29] In addition, the laparoscopic non-PD rate has been diminishing compared to robotic non-PD and there has been an almost 3-fold increase in the number of robotic non-PDs performed. Robotic pancreatectomy became the most common minimally invasive approach for both non-PD (2016) and PD (2020), which could be due to surgeon-perceived advantages of robotics, such as three-dimensional visualization and increased dexterity, which facilitate dissection and reconstruction.[25]

Our study shows few advantages of MIPD over open approach. This reflects the literature where similar results include improved outcomes such as decreased LOS.[9,10,30] However, a multi-institutional study of eight centers showed open PD associated with improved outcomes, such as blood loss and major complications, compared to robotic PD.[31] One possible explanation for this difference could be that this dataset more widely represents the current state of practice across the US instead of data from a small number of specialized centers. Our study showed no difference in mortality, which is consistent with other reports in the literature, but mortality results are mixed.[7,32–34] There is less data comparing robotic and laparoscopic approaches, but available data confirm that the approaches are similar except for the lower conversion rates with RS approach.[11,35,36] We observed that the robotic PD group had a significantly lower incidence of conversion to open than LS. This is similar to the findings from the LAELAPS trials, which showed a robotic PD conversion of 6.5% (LAELAPS-2) versus 11% for laparoscopic PD (LAELAPS-3).[29,35,37] Our study is in line with other studies that demonstrate longer OR times for LS than open surgery. This may be due to longer setup times and a steep learning curve of 39 cases for the robotic approach.[38]

In contrast to PD, MIP in non-PD patients is associated with improved outcomes compared to OS including LOS, transfusions, ICU admission, and splenic preservation. The improved outcomes of the MIP non-PD approach are likely multifactorial.[2,3,8,12,39,40] Despite longer OR times and costs, robotic non-PD is advantageous and non-inferior compared to OS and LS, respectively, consistent with other studies.[41,42] Additionally, robotic non-PD had a lower conversion to open rate than laparoscopy 1:10 versus 1:5. This could be resultant of selection bias where surgeons choose patients with favorable anatomy such as small localized neoplasms for the robotic approach. The observation that robotic surgery displaces laparoscopy as the predominant MIS approach for non-PD has accelerated in 2020 as more hospitals have robotic capabilities. If the observed trends continue, robotic surgery will overtake laparoscopy as the approach of choice despite increased OR times and costs.[41,43]

Limitations of this study are related to the administrative dataset. PHD accounts for 25% of inpatient admissions and this could limit the generalizability of the results as some patient and surgeon populations may be underrepresented or overrepresented. When comparing the PHD to the American Hospital Association Dataset (AHAD), which includes all US hospitals, the rural–urban ratio is comparable (AHAD 76% vs. PHD 70%). PHD has a relatively similar representation of teaching hospitals (~30% PHD vs. 40% AHAD).

In the USA, payer information can be used as a surrogate for demographic information. PHD is relatively similar to AHAD for Medicare/Medicaid (PHD 52% vs. AHAD 48%), private insurance (PHD 35% vs. AHAD 43%), and out-of-pocket (PHD 7% vs. AHAD 9%).[44,45] This study adjusted for various baseline patient and hospital characteristics in multivariable analysis to minimize selection bias. Unfortunately, in the USA, there is no uniform database for all healthcare encounters. PHD does not track patients across the entire health system and can only report data from hospital inpatient and outpatient facilities. Therefore, readmissions to non-index facilities would not be captured. There is no data on surgeon experience or tumor and treatment-specific information, which may influence the surgeon's choice of procedure and outcomes. This is still observational data; a randomized controlled trial would minimize bias and elucidate the differences among the three approaches.

5 | CONCLUSIONS

MIP for non-PD has become the most common operative approach with improved outcomes compared to OS. MIPD has flat adoption with similar outcomes to OS. Robotics facilitates completion of both PD and non-PD minimally invasively through fewer conversions to OS. Robotic PD should be increasingly considered given non-inferior outcomes to open surgery. Currently, there are ongoing randomized trials looking at minimally invasive pancreatectomy, which will offer high-quality evidence and data. An unsolved challenge is that the USA observational cohort data may not represent results from European data because pancreatic surgery is not regionalized to designated centers, allowing individual hospitals and surgeons to choose the operative approach even when the pancreatectomy operative volume may be low. Regionalization of care in the USA might be necessary to ensure better and more uniform outcomes for complex procedures.

AUTHOR CONTRIBUTIONS

Rejoice F. Ngongoni: Conceptualization, investigation, methodology, project administration, writing—original draft preparation, writing—review and editing. **Busisiwe Mlambo**: Conceptualization, writing—original draft, writing—review and editing. **I-Fan Shih**: Formal analysis, methodology, writing—original draft, writing—review and editing. **Yanli Li**: Formal analysis, writing—review and editing. **Sherry M. Wren**: Conceptualization, investigation, methodology, supervision, writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

Rejoice Ngongoni declares that she has no conflicts of interest. Busisiwe Mlambo is employed by and has stock ownership and stock options with Intuitive Surgical. I-Fan Shih is employed by and has stock ownership and stock options with Intuitive Surgical. YanLi Li is employed by and has stock ownership and stock options with Intuitive Surgical. Sherry Wren is a consultant of and has stock ownership of Intuitive Surgical.

DATA AVAILABILITY STATEMENT

Research data are not shared.

ETHICS STATEMENT

Not needed.

CONSENT FOR PUBLICATION

Not applicable. The manuscript does not contain data from any person.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.