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ORIGINAL ARTICLE

Robotic versus open pancreaticoduodenectomy in elderly patients: a propensity score–matched analysis

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Abstract

Background: Pancreaticoduodenectomy (PD) is complex procedure with high morbidity in the elderly. This retrospective study aimed to compare post-operative outcomes in patients ≥75 years of age who underwent robot-assisted (RA)PD and open PD.

Methods: We analyzed 2502 patients ≥75 years of age who underwent PD from 2015 to 2018 in the National Surgical Quality Improvement Program (NSQIP) database. RAPD and open PD patients were propensity score matched 1:5 to assess the 30-day outcomes of interest: postoperative complications, length of stay, discharge destination, and readmissions.

Results: Of 725 matched patients, 110 underwent RAPD, 615 OPD, and 12 were converted to an open operation. Post-operative outcomes were largely similar between cohorts. RAPD was associated a shorter length of stay (median 8 days, interquartile range [IQR] 6 to 11) than OPD (median 8 days, IQR 7 to 13) (p = 0.003). However, RAPD was associated with more readmissions (28.1% vs. 17.7%; p = 0.02).

Conclusions: RAPD in patients ≥75 years of age appears to be safe and has a similar complication profile to open PD. Randomized or well-designed prospective matched studies are needed to confirm these findings.

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Introduction

The elderly population is the fastest growing age group in the United States and represents an increasing percentage of surgical patients.[1] The prevalence of comorbid conditions, such as diabetes, hypertension, cardiovascular disease, and cancer, is disproportionately higher in this group, which portends worse perioperative outcomes.[2] With the growing number of elderly patients, understanding the perioperative risks in this population and identifying techniques that ameliorate surgical morbidity becomes essential.

Pancreaticoduodenectomy (PD) is associated with increased peri-operative mortality and morbidity in elderly patients compared with younger patients.[3,4] The most common indication for PD is pancreatic adenocarcinoma. The median age at diagnosis is 71, and nearly 40% of patients are older than 75 years of age.[5] Although the majority of studies comparing PD in the elderly focuses on malignant disease, 20–30% of PDs are performed for benign disease, such as non-invasive intraductal papillary mucinous neoplasm (IPMN) and adenoma.[6,7] Characteristics of benign disease, mainly soft pancreatic gland texture and small duct size, contribute to pancreatic fistula, which can lead to serious complications that may impact elderly patients more severely.[7,8]

Minimally invasive and robot-assisted surgery have become increasingly common for pancreas resections and is associated with decreased morbidity and shorter hospital stay.[9,10] Previous studies have compared RAPD in older and younger patient cohorts.[11–13] While the majority of PDs are still done using an open approach,[14] there is a paucity of data exploring the utility and safety of RAPD in elderly patients. This study aimed to examine the effect RAPD has on peri-operative outcomes compared with open PD in patients 75 years of age or older.

Methods

Study design and population

The American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) is an outcomes-based quality improvement initiative that prospectively collects 30-day perioperative data from hundreds of hospitals across the country. Additionally, NSQIP provides a pancreatectomy-targeted database with 42 data points and outcomes related to pancreas surgery. The pancreas-targeted database was queried to identify patients who underwent PD (CPT 48150, 48152–48154) from 2015 to 2018. The variables from the standard NSQIP database were then merged for each patient. Patients who underwent an open or robot-assisted PD were included in the analysis. Patient exclusion criteria included emergency surgery, laparoscopic and/or hybrid approaches, vascular resection/reconstruction, pre-operative sepsis, and multi-visceral resection (i.e., hepatectomy, colectomy, enterectomy, nephrectomy, and adrenalectomy). Patients ≥75 years of age were classified as elderly in accordance with the NSQIP Geriatric Collaborative. The primary outcome of interest was perioperative morbidity. Secondary outcomes were duration of hospitalization and discharge destination. The University of California, Los Angeles Institutional Review Board deemed this study exempt from review because the data were obtained from a publicly available, deidentified database.

Definitions

Pathology reported as duodenal carcinoma, ampullary carcinoma, distal cholangiocarcinoma, pancreatic ductal adenocarcinoma (PDAC), and invasive IPMN were classified as peri-ampullary adenocarcinoma. Conversely, non-invasive cystic lesions, neuroendocrine tumors, and chronic pancreatitis were classified as non-adenocarcinoma. In 2016, the International Study Group on Pancreatic Surgery (ISGPS) revised the grading and definitions of POPF.[5] Grade A POPF is now termed "biochemical leak" and not considered clinically relevant.[15] In an attempt to standardize the definition of a clinically-relevant POPF (CR-POPF) in the NSQIP database, the fistula outcome variable was recoded to include patients with at least one of the following: POPF already classified as grade B or C by NSQIP, pancreatic drain continued longer than 21 days, percutaneous drainage of fluid collection(s) with amylase-rich fluid, nil per os (NPO) status and support with enteral nutrition or total parenteral nutrition, or reoperation related to POPF. Delayed gastric emptying (DGE) was defined as no oral intake by post-operative day 14 and/or re-insertion of a nasogastric tube. DGE grade per the ISGPS guidelines could not be determined given database limitations (e.g., day of nasogastric tube reinsertion).

Analysis of aggregate cohort

First, we compared perioperative morbidity between patients <75 and those ≥75 years of age. The remaining analysis was performed in the elderly patients only. Demographics, intra-operative findings, and perioperative outcomes were compared between the RAPD and OPD cohorts. A hospital length of stay less than 3 days was considered to be unlikely. Therefore, patients with a reported hospital length of stay less than 3 days or who died during the index admission were excluded from the hospital duration/discharge analysis. Because NSQIP only reports outcomes up to 30 days, patients with a hospital length of stay longer than 14 days were excluded from the readmission analysis to provide adequate time to capture readmissions and overcome immortal time bias in the database's documentation of this variable.[16]

Propensity score matching

To better compare patients in the open PD and RAPD cohorts, propensity scores were generated based on age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) score, diabetes, pre-operative chemotherapy, pre-operative radiation, and surgery for disease that was not adenocarcinoma. Matching was achieved in a 1-to-5 ratio using nearest neighbor matching with a caliper width equal to 0.2. Propensity score generation and matching were performed using the MatchIt package in RStudio (version 1.2.5033).

Statistical analysis

Continuous variables were reported as mean (standard deviation [SD]) or median (interquartile range [IQR]), and categorical variables are presented as absolute numbers and percentages. Univariable comparisons between cohorts were performed using χ^2 analysis or Fisher's exact tests for categorical variables. Continuous variables were analyzed using Student's t test and Mann–Whitney U test for normally and non-normally distributed data, respectively. Logistic regression was used for univariable and multivariable models. Variables found to have p values less than 0.2 on univariable analysis and/or deemed clinically relevant to the outcome were included in the multivariable analysis to provide a more comprehensive model. To account for important variables with missing data on multivariable analysis, the study population with and without the missing data were compared for differences in baseline and intra-operative characteristics. Any significant differences were included in the multivariable model to account for possible bias that was induced when removing patients with missing data. All statistical tests were 2-sided, and differences were considered significant when $p \leq 0.05$. All statistical analyses were performed with SPSS statistical software (version 26.0; IBM Corp).

Results

After exclusion criteria were applied, 11,923 patients who underwent OPD or RAPD were identified (Fig. 1). There were 2502 patients (21%) who were 75 or older. This elderly cohort had higher ASA scores and higher rates of comorbid conditions in general. Of the elderly patients, 98.2% were functionally independent pre-operatively compared to 99.4% in the younger cohort ($p < 0.001$) (Table 1). Younger patients were more likely to have PD for non-adenocarcinoma pathology (28.3% vs. 15.9%; $p < 0.001$), and PDAC was more prevalent in older patients (61.1% vs. 52.3%; $p < 0.001$). Elderly patients had a higher rate of complications, namely cardiovascular events, renal failure, and infectious complications. Younger patients were discharged to home more frequently than older patients (92.4% vs. 73%; $p < 0.001$). The 30-day mortality rate was 1% and 2.3% for the younger and older cohorts, respectively ($p < 0.001$). RAPD was performed in 5% of patients in both age groups ($p = 0.895$) (Table 1).

Unmatched elderly cohort

The unmatched cohorts comparing RAPD and OPD in patients 75 and older had similar baseline characteristics, except patients in the RAPD cohort were more likely to have non-adenocarcinoma disease (22.8% vs. 15.6%; $p = 0.034$) and to have received neoadjuvant chemotherapy (22.6% vs 11.9%; $p < 0.001$) (Table 2a). The proportion of PDs that were

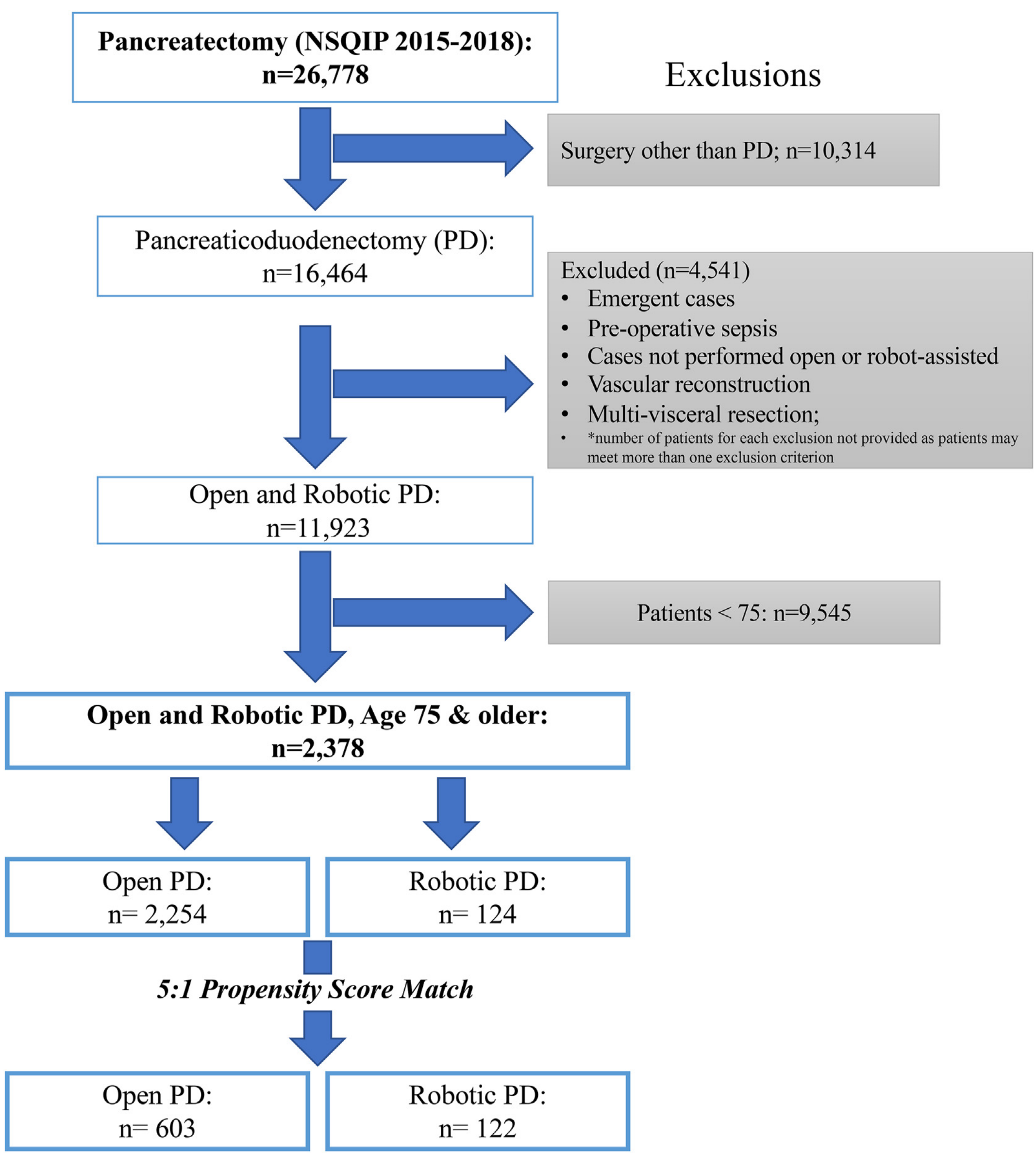

Figure 1 Flow diagram of patient selection

Table 1 Patient characteristics and perioperative outcomes for patients <75 and ≥75

Total: 11,923	Age <75 (9421)	Age ≥75 (2502)	p-value*
Female	4281 (45.4)	1191 (47.6)	0.054
Age (median, IQR)	63 (56–72)	78 (76–81)	**< 0.001**
Race			**< 0.001**
White	7113 (75.5)	1938 (77.5)	
Black	790 (8.4)	141 (5.6)	
Asian	379 (4)	115 (4.6)	
American Indian	27 (0.3)	7 (0.3)	
Hawaiian/Pacific Islander	16 (0.2)	1 (0)	
Unknown/not reported	1096 (11.6)	300 (12)	
BMI (median, IQR)	27.1 (23.6–31.1)	25.7 (23.0–28.7)	**< 0.001**[a]
ASA			**< 0.001**
1	51 (0.5)	0 (0)	
2	2280 (24.2)	328 (13.1)	
3	6568 (69.7)	1946 (77.8)	
4	521 (5.5)	228 (9.1)	
5	1 (0)	0 (0)	
Year of operation			
2015	2137 (80.6)	516 (20.6)	
2016	2419 (78.8)	652 (21.2)	
2017	2454 (79.2)	646 (20.8)	
2018	2411 (77.8)	688 (22.2)	
Functional status			**< 0.001**
Independent	9355 (99.4)	2454 (98.2)	
Partially dependent	46 (0.5)	42 (1.7)	
Totally dependent	6 (0.1)	2 (0.1)	
Diabetes	2406 (25.5)	671 (26.8)	0.193
Smoking	1942 (20.6)	153 (6.1)	**< 0.001**
Dyspnea	439 (4.7)	162 (6.5)	**< 0.001**
COPD	365 (3.9)	100 (4)	0.778
Hypertension	4587 (48.7)	1750 (69.9)	**< 0.001**
Congestive heart failure	22 (0.2)	11 (0.4)	0.081
Dialysis	20 (0.2)	8 (0.3)	0.324
Weight loss	1331 (14.1)	385 (15.4)	0.111
Bleeding disorder	216 (2.3)	69 (2.8)	0.176
Chronic steroids	244 (2.6)	64 (2.6)	0.93
Pre-operative transfusion	36 (0.4)	22 (0.9)	**0.001**
Pre-operative chemotherapy	1623 (17.2)	310 (12.4)	**< 0.001**
Pre-operative radiation	630 (6.7)	107 (4.3)	**< 0.001**
Pre-operative biliary drainage	4695 (51.9)	1347 (56.1)	**< 0.001**
Robotic approach	473 (5)	124 (5)	0.895
Non-adenocarcinoma	2627 (28.3)	395 (15.9)	**< 0.001**
PDAC	4931 (52.3)	1528 (61.1)	**< 0.001**
Pathologic findings			
Duct size			
Small	2522 (32.8)	546 (26.3)	**< 0.001**
Medium	4024 (52.3)	1105 (53.3)	0.413
Large	1153 (15)	423 (20.4)	**< 0.001**
Gland texture			
Soft	3627 (49)	970 (49.1)	0.896
Intermediate	844 (11.4)	251 (12.7)	0.105
Hard	2935 (39.6)	753 (38.1)	0.23
Post-operative outcomes			
Length of stay (med, IQR)	8 (6–11)	8 (7–13)	**< 0.001**[a]
Discharge to home	8554 (92.4)	1769 (73)	**< 0.001**
Death	98 (1)	58 (2.3)	**< 0.001**
Complications			
Fistula	1837 (19.6)	442 (17.8)	**0.039**
Delayed gastric emptying	1478 (15.7)	488 (19.6)	**< 0.001**
Cardiac arrest	92 (1)	35 (1.4)	0.067
Myocardial infarction	89 (0.9)	54 (2.2)	**< 0.001**
Cerebrovascular accident	17 (0.2)	10 (0.4)	**0.04**
Peri-operative transfusion	1128 (12)	429 (17.1)	**< 0.001**
Deep vein thrombosis	198 (2.1)	74 (3)	**0.011**
Pulmonary embolism	97 (1)	25 (1)	0.893
Progressive renal insufficiency	62 (0.7)	13 (0.5)	0.436
Acute renal failure	71 (0.8)	35 (1.4)	**0.002**
Sepsis	848 (9)	225 (9)	0.990
Septic shock	230 (2.4)	91 (3.6)	**0.001**
Pneumonia	297 (3.2)	109 (4.4)	**0.003**
Superficial surgical site infection	718 (7.6)	164 (6.6)	0.07
Deep incisional infection	120 (1.3)	23 (0.9)	0.148
Organ space infection	1539 (16.3)	385 (15.4)	0.252
Urinary tract infection	211 (2.2)	84 (3.4)	**0.001**

Abbreviations: IQR – interquartile range; BMI – body mass index; ASA – American Society of Anesthesia physical status classification; COPD – chronic obstructive pulmonary disease; PDAC – pancreatic ductal adenocarcinoma.
*All p-values are derived from Chi Square unless otherwise indicated.
[a] Mann-Whitney U.

Table 2 Pre-operative patient characteristics and post-operative outcomes for the unmatched cohort

A	Pre-Operative Patient Characteristics		
	Robot (124)	**Open (2,378)**	**p-value***
Female	61 (49.2)	1130 (47.5)	0.72
Age (median, IQR)	78 (76–82)	78 (76–81)	0.98[a]
Race			0.13
White	109 (87.9)	1829 (76.9)	
Black	4 (3.2)	137 (5.8)	
Asian	2 (1.6)	113 (4.8)	
American Indian	0 (0)	7 (0.3)	
Hawaiian/ Pacific Islander	0 (0)	1 (0)	
Unknown/not reported	9 (7.3)	291 (12.2)	
BMI (median, IQR)	25.8 (22.9–28.0)	25.6 (23.0–28.7)	0.65[b]
ASA			0.36
2	11 (8.9)	317 (13.3)	
3	101 (81.5)	1845 (77.6)	
4	12 (9.7)	218 (9.1)	
Year of operation			
2015	15 (2.9)	501 (97.1)	
2016	26 (4)	626 (96)	
2017	38 (5.9)	608 (94.1)	
2018	45 (6.5)	643 (93.5)	
Functional status			0.95
Independent	122 (98.4)	2332 (98.2)	
Partially dependent	2 (1.6)	40 (1.7)	
Totally dependent	0 (0)	2 (0.1)	
Diabetes	36 (29)	635 (26.7)	0.57
Smoking	9 (7.3)	144 (6.1)	0.59
Dyspnea	8 (6.5)	154 (6.5)	0.99
COPD	5 (4)	95 (4)	0.98
Hypertension	86 (69.4)	1664 (70)	0.88
Congestive heart failure	0 (0)	11 (0.5)	1[c]
Dialysis	0 (0)	8 (0.3)	1[c]
Weight loss	14 (11.3)	371 (15.6)	0.20
Bleeding disorder	1 (0.8)	68 (2.9)	0.26[c]
Chronic steroids	2 (1.6)	62 (2.6)	0.77[c]
Pre-operative transfusion	0 (0)	22 (0.9)	0.62[c]
Pre-operative chemotherapy	28 (22.6)	282 (11.9)	**< 0.001**

(*continued on next column*)

Table 2 (*continued*)

A	Pre-Operative Patient Characteristics		
	Robot (124)	**Open (2,378)**	**p-value***
Pre-operative radiation	3 (2.4)	104 (4.4)	0.49[c]
Pre-operative biliary drainage	66 (54.5)	1281 (56.1)	0.73
Non-adeno carcinoma	28 (22.8)	367 (15.6)	**0.034**
PDAC	77 (62.1)	1451 (61)	0.81
B	**Intra-Operative and Post-Operative Outcomes**		
	Robot (110)[e]	**Open (2,392)**	**p-value[d]**
Intra-operative findings			
Duct size			
Small	28 (25.5)	518 (21.7)	0.84
Medium	53 (48.2)	1052 (44.0)	0.70
Large	22 (20.0)	401 (16.8)	0.80
Gland texture			
Soft	57 (57.0)	913 (49.7)	0.11
Intermediate	10 (10.0)	241 (12.9)	0.40
Hard	33 (33.0)	720 (38.4)	0.28
Pancreatic Reconstruction			0.243
Pancreaticojejunal duct-to-mucosa	100 (90.9)	1985 (83)	
Pancreaticojejunal invagination	4 (3.6)	210 (8.8)	
Pancreaticogastrostomy	1 (0.9)	43 (1.8)	
Not performed	4 (3.6)	100 (4.2)	
Unknown	1 (0.9)	54 (2.3)	
Post-operative outcomes			
Length of stay (med, IQR)	8 (6–11)	8 (7–13)	**0.001**[a]
Discharge to home	86 (78.2)	1700 (71.1)	0.11
Death	3 (2.7)	55 (2.3)	0.74[c]
Readmission	27 (24.5)	379 (15.8)	**0.02**
Pancreatic fistula	12 (10.9)	430 (18.1)	0.06
Delayed gastric emptying	29 (26.4)	459 (19.2)	0.07
Cardiac arrest	1 (0.9)	34 (1.4)	1[c]
MI	2 (1.8)	52 (2.2)	1[c]
CVA	2 (1.8)	8 (0.3)	0.07[c]
Peri-operative transfusion	11 (10.0)	418 (17.5)	**0.04**
DVT	6 (5.5)	68 (2.8)	0.11
PE	0 (0.0)	25 (1.0)	0.63[c]
Progressive renal insufficiency	0 (0.0)	13 (0.5)	1[c]
Acute renal failure	4 (3.6)	31 (1.3)	0.07[c]
Sepsis	3 (2.7)	222 (9.3)	**0.02**
Septic shock	8 (7.3)	83 (3.5)	**0.04**

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Table 2 (*continued*)

B	Intra-Operative and Post-Operative Outcomes		
	Robot (110)[e]	Open (2,392)	p-value[d]
Pneumonia	2 (1.8)	107 (4.5)	0.24[c]
Superficial surgical site infection	3 (2.7)	161 (6.7)	0.10
Deep incisional infection	0 (0.0)	23 (1.0)	0.62[c]
Organ space infection	15 (13.6)	370 (15.5)	0.60
Urinary tract infection	2 (1.8)	82 (3.4)	0.58[c]

[a] Mann–Whitney U.
[b] Student's T test.
[c] Fisher's exact test.
[d] All p-values are derived from Chi Square unless otherwise indicated.
[e] fourteen patients that were converted from a robotic to open operation were included in the open cohort for post-operative outcomes.

attempted with robot assistance increased from 2.9% in 2015 to 6.5% in 2018. The conversion rate to an open procedure during the study period was 11.3%. Patients who were converted to an open procedure were included in the OPD arm for post-operative analysis (Table 2b). RAPD and OPD had a median LOS of 8 days, but this was significantly longer for OPD due to right skewness (IQR 6–11 days vs. 7–13 days; p = 0.001). Readmission rates were higher in the RAPD cohort compared to the OPD cohort (24.5% vs. 15.8%). Peri-operative transfusions occurred less frequently in RAPD patients (10.0% vs. 17.5%, p = 0.04). The rate of sepsis was lower in the RAPD cohort (2.7% vs. 9.7%, p = 0.02), but the rate of septic shock was higher (7.3% vs. 3.5%, p = 0.04). The rates of all other complications were similar (Table 2b).

Propensity-matched elderly cohort

After 1-to-5 propensity score matching, there were 122 patients in the RAPD and 603 patients in the OPD cohorts. The differences in neoadjuvant chemotherapy and surgery for non-adenocarcinoma disease in the unmatched cohort were corrected after matching (Table 3a). Twelve patients in the RAPD cohort were converted to open PD (9.8%); these patients were transferred to the OPD cohort arm for all post-operative analyses (Table 3b). OPD was associated with a higher rate of sepsis compared to RAPD (9.3% vs. 2.7%, p = 0.022). All other post-operative complications and 30-day mortality were similar between the cohorts. Twenty patients (2.8%) were excluded from the LOS analysis due to missing data, reported LOS less than 3 days, or death during the index admission. Again, RAPD and OPD had a median LOS of 8 days, but this was significantly longer for OPD due to right skewness (p = 0.003). For the readmission analysis, 574 patients (79.2%) of patients were included. RAPD had a higher rate of readmission compared to OPD (28.1% vs. 17.7%, p = 0.02).

Logistic regression analyzing factors that predicted POPF for the entire cohort revealed BMI, sex, PDAC, neoadjuvant chemotherapy, small duct size, and soft pancreatic gland texture

Table 3 Pre-operative patient characteristics and post-operative outcomes for the propensity-matched cohort

A	1:5 Propensity Matched		
	Robot (122)	Open (603)	p-value*
Female	60 (49.2)	290 (48.1)	0.83
Age (median, IQR)	78 (76–82)	79 (76–82)	0.68
Race			0.12
White	107 (87.7)	464 (76.9)	
Black	4 (3.3)	39 (6.5)	
Asian	2 (1.6)	26 (4.3)	
American Indian	0 (0)	1 (0.2)	
Hawaiian/Pacific Islander	9 (7.4)	73 (12.1)	
BMI (median, IQR)	25.9 (22.8–28.1)	25.4 (22.5–28.9)	0.92[b]
ASA			0.95
2	11 (9)	60 (10)	
3	99 (81.1)	485 (80.4)	
4	12 (9.8)	58 (9.6)	
Year of operation			
2015	15 (10.8)	124 (89.2)	
2016	26 (15.3)	144 (84.7)	
2017	38 (19.4)	158 (80.6)	
2018	43 (19.5)	177 (80.5)	
Functional status			0.53
Independent	120 (98.4)	597 (99)	
Partially dependent	2 (1.6)	6 (1)	
Totally dependent	–	–	–
Diabetes	36 (29.5)	158 (26.2)	0.45
Smoking	9 (7.4)	26 (4.3)	0.15
Dyspnea	8 (6.6)	36 (6)	0.80
COPD	5 (4.1)	23 (3.8)	0.88
Hypertension	85 (69.7)	431 (71.5)	0.69
Congestive heart failure	0 (0)	3 (0.5)	1[c]
Dialysis	0 (0)	1 (0.2)	1[c]
Weight loss	13 (10.7)	91 (15.1)	0.20
Bleeding disorder	1 (0.8)	19 (3.2)	0.23[c]
Chronic steroids	2 (1.6)	12 (2)	1[c]
Pre-operative transfusion	0 (0)	4 (0.7)	1[c]
Pre-operative chemotherapy	27 (22.1)	145 (24)	0.65
Pre-operative radiation	3 (2.5)	21 (3.5)	0.78[c]
Pre-operative biliary drainage	66 (55.5)	301 (52)	0.49
Non-adenocarcinoma	27 (22.1)	119 (19.7)	0.55
PDAC	77 (63.1)	366 (60.7)	0.62

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Table 3 (*continued*)

B	Intra-Operative and Post-Operative Outcomes		
	Robot (110)[e]	Open (615)	p-value[d]
Intra-operative findings			
Duct size			
Small	28 (25.5)	132 (21.5)	0.76
Medium	53 (48.2)	278 (45.2)	0.61
Large	22 (20.0)	103 (16.7)	0.77
Gland texture			
Soft	57 (57.0)	238 (38.7)	0.12
Intermediate	10 (10.0)	67 (10.9)	0.32
Hard	33 (33.0)	186 (30.2)	0.36
Pancreatic Reconstruction			0.24
Pancreaticojejunal duct-to-mucosa	100 (90.9)	506 (82.3)	
Pancreaticojejunal invagination	4 (3.6)	51 (8.3)	
Pancreaticogastrostomy	1 (0.9)	13 (2.1)	
Not performed	4 (3.6)	30 (4.9)	
Unknown	1 (0.9)	15 (2.4)	
Post-operative outcomes			
Length of stay (med, IQR)	8 (6–11)	8 (7–13)	**0.003**[a]
Discharge to home	86 (78.2)	424 (68.9)	0.051
Death	3 (2.7)	13 (2.1)	0.722[c]
Readmission	25 (28.1)	86 (17.7)	**0.02**
Pancreatic fistula	12 (10.9)	110 (18)	0.069
Delayed gastric emptying	29 (26.4)	113 (18.4)	0.054
Cardiac arrest	1 (0.9)	9 (1.5)	1[c]
MI	2 (1.8)	16 (2.6)	1[c]
CVA	2 (1.8)	3 (0.5)	0.167[c]
Peri-operative transfusion	11 (10)	103 (16.7)	0.073
DVT	6 (5.5)	17.(2.8)	0.138
PE	0 (0)	6 (1)	0.598[c]
Progressive renal insufficiency	0 (0)	4 (0.7)	1[c]
Acute renal failure	4 (3.6)	6 (1)	0.051[c]
Sepsis	3 (2.7)	57 (9.3)	**0.022**
Septic shock	8 (7.3)	25 (4.1)	0.137
Pneumonia	2 (1.8)	38 (6.2)	0.07[c]
Superficial surgical site infection	3 (2.7)	38 (6.2)	0.182[c]
Deep incisional infection	0 (0)	7 (1.1)	0.602[c]
Organ space infection	15 (13.6)	92 (15)	0.719
Urinary tract infection	2 (1.8)	28 (4.6)	0.295[c]

[a] Mann–Whitney U.
[b] Student's T test.
[c] Fisher's exact test.
[d] All p-values are derived from Chi Square unless otherwise indicated.
[e] Twelve patients that were converted from a robotic to open operation were included in the open cohort for post-operative outcomes.

were significant in the univariable analysis (Supplemental Table 1). The method of pancreatic reconstruction (e.g., pancreaticojejunal duct-to-mucosa) was not associated with POPF (data not shown). There were 170 patients (23.4%) with missing data for pancreas gland texture and/or duct size and were excluded from the multivariable analysis as detailed in the methods. Soft pancreas gland texture (OR 2.89; 95% CI 2.16–3.88) and BMI (OR 1.05, 95% CI 1.02–1.08), and male sex (OR 2.19; 95% CI 1.33 to 3.6) were independent predictors of POPF. Female sex (OR 0.48–0.80; 95% CI 0.62) and PDAC (OR 0.71; 95% CI 0.55–0.93) were associated with decreased odds of developing POPF. RAPD was also associated with decreased odds of developing POPF but did not reach statistical significance (OR 0.57; 95% CI 0.29–1.09) (Supplemental Table 1).

For the discharge to home analysis, age, ASA >2, non-adenocarcinoma disease, functional status, COPD, and dyspnea were significant on univariable analysis (Supplemental Table 4). On multivariable analysis, non-adenocarcinoma (OR 1.40; 95% CI 1.07–1.83) and independent functional status (OR 4.65; 95% CI 2.52–8.60) were independent predictors of discharge to home following PD. Conversely, age, ASA >2, COPD, dyspnea, and non-independent functional status were negative predictors of a home discharge after PD (Supplemental Table 2). Robotic approach was associated with increased odds of being discharged to home but did not reach statistical significance (OR 1.46; 95% CI 0.91–2.35). Intra-operative factors, such as small duct, soft gland texture, and jejunostomy tube placement, were evaluated as well, but they did not reach the threshold for inclusion in the model (data not shown).

Discussion

As the population ages, older individuals account for an increasing proportion of surgical patients and have an inherently higher risk for peri-operative complications. Age is an independent risk factor for morbidity and mortality and is useful for risk stratification. We demonstrated that elderly patients undergoing PD have more comorbid conditions, postoperative complications, and mortality. The primary focus of this study was to compare peri-operative morbidity in elderly patients who underwent a robot-assisted or open PD. RAPD was associated with a shorter LOS but a higher readmission rate than OPD. Previous studies have established that RAPD can be safely performed in elderly patients.[11,12,17] Though, to our knowledge, this is the first study comparing outcomes in open and robotic approaches to PD in elderly patients.

Pancreatic fistula is a major cause of post-operative morbidity following PD.[15,18,19] The rate of POPF was lower in the RAPD cohort, but a significant difference could not be detected with our sample size and the relative infrequency of this outcome. Previous studies have demonstrated an associated of RAPD with decreased POPF, however. One study comparing RAPD with open PD in obese patients found that the robotic approach was associated with fewer clinically-relevant POPF (OR 0.34; $p < 0.001$).[20] A recent NSQIP study also found that the robotic approach was associated with a lower rate of clinically-relevant POPF (11.9% vs. 15.6%; p = 0.026).[21]

Delayed gastric emptying is an important, although less severe complication than POPF. It is associated with prolonged hospitalization, patient discomfort, and readmission.[22] DGE mainly develops secondarily to intra-abdominal complications, such as POPF and abscess.[23–26] In our analysis, the RAPD arm in the matched cohort had a higher, but not significant, rate of DGE compared with open PD. Certain technical variables have also been identified as risk factors for DGE when creating the gastrojejunostomy during RAPD. These include a flow angle within 30 degrees of vertical between the stomach and efferent jejunal limb, greater length of the gastrojejunal anastomosis, and a robotic-sewn anastomosis (vs. stapled anastomosis).[23] The rate of DGE between open PD and RAPD are conflicting. For example, one systematic review found that RAPD was associated with lower rates of DGE compared with open PD in 4 studies.[27] Yet a more recent propensity-matched study demonstrated that the rate of DGE was significantly higher for RAPD compared with open PD (9.4% vs. 23.5%; p = 0.006).[28] Our findings of increased DGE with RAPD are presumed to be technique-related as the RAPD patients did not have higher rates of known secondary causes of DGE (intra-abdominal infection, POPF). In a recent NSQIP study evaluating risk factors of DGE in the absence of POPF or intra-abdominal infection found that minimally invasive PD (laparoscopic- and robot-assisted) and open PD had similar rates of DGE on bivariate analysis (11.1% vs. 11.7%; p = 0.159). However, age $\geq$75 was identified as a statistically significant, but modest, risk factor for DGE on multivariable analysis (OR 1.22; p = 0.003). Minimally invasive techniques were not included in the multivariable model.[29]

Hospital LOS and readmissions are important outcome measures used to evaluate quality of care in surgical patients.[30–32] Shortening the post-operative LOS has been identified as a way to reduce costs as well as decrease the risk of nosocomial infection.[31] Patients undergoing robot-assisted surgery and other minimally-invasive techniques are thought to recover more quickly and have less post-operative pain.[33,34] Our finding that RAPD is associated with a shorter LOS is consistent with previous studies.[28,35] A recent propensity-matched NSQIP study evaluating patients who underwent an open PD suggested that LOS was not directly associated with readmission.[36] A separate NSQIP study associated certain complications, such as DGE and POPF, with higher rates of short-term readmission.[32] Jiang et al. found that each 1-day increase in LOS decreased the odds of readmission in patients with clinically-relevant POPF and DGE by a factor of 0.78 and 0.70, respectively.[36] The readmission rates were not statistically different between study arms in our analysis. However, nearly 10% more patients in the RAPD cohort than the OPD cohort had a readmission.

Discharge destination following surgery has several implications. Predicting which patients are likely to be discharged to a facility is an important aspect of pre-operative counseling and metric/surrogate for recovery after surgery. In our matched cohort, nearly 10% more patients who underwent RAPD were discharged home compared to OPD. Increasing age, ASA >2, non-independent functional status prior to surgery, COPD, and dyspnea were independent predictors of a non-home discharge. However, surgical approach was not an independent predictor for discharge to home in this analysis. These findings are similar to another NSQIP study that found similar predictors of home discharge but also found that the open approach was a predictor of non-home discharge.[37]

There are limitations to this study that should be noted. The data were obtained from a retrospective database that is prone to selection bias due to unmeasured confounders, inexact coding, reporting error, or missing data. In an attempt to account for possible confounders, patients in this study were propensity-matched on pre-operative factors that were likely to affect post-operative outcomes. Additionally, this study is limited to 30-day outcomes, which renders it difficult to capture the full extent of complications and readmissions for a complex surgical procedure like PD. Further, we were unable to determine the surgeon PD volume, hospital practice setting, or which operations were performed at high-volume pancreatic centers. The importance of the surgeon and institutional learning curve for both open PD and RPD has been demonstrated in several studies.[38,39] Newer evidence also suggests that a proficiency-based curriculum coupled with mentorship may reduce the learning curve for RPD without compromising adverse events.[40] However, our study was unable to capture these surgeon and training metrics.

Lastly, the NSQIP database used for this study does not capture certain outcomes of interest for the geriatric population, such as post-operative delirium, pre-operative living situation, cognitive decline, or use of mobility aids.

In conclusion, RAPD in patients $\geq$75 years of age appears to be safe and is associated similar complication rates to open PD. RAPD is associated with a shorter hospitalization but may be associated with more readmissions. These results suggest the potential benefit of minimally invasive robotic PD in the elderly population, which could broaden the therapeutic options for a population sometimes considered too at-risk for poor outcomes. Randomized or well-designed prospective matched studies are needed to confirm these findings.

Conflict of interest/Disclosures

The authors reported no biomedical financial interests or potential conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.hpb.2022.11.011.