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ORIGINAL ARTICLE

Assessing the perioperative complications and outcomes of robotic pancreaticoduodenectomy using the National Cancer Database: is it ready for prime time?

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Abstract

Robotic pancreaticoduodenectomy has generated significant interest in recent years. Our study aimed to evaluate the difference in surgical, oncological, and survival outcomes after pancreaticoduodenectomy (PD) by either a robotic (RPD) or open approach (OPD). Using the National Cancer Database, we identified patients from 2010 and 2017 diagnosed with pancreatic adenocarcinoma and underwent pancreaticoduodenectomy by either robotic PD or open approach. Patients who underwent robotic PD during 2010 were compared to patients receiving the same procedure in 2017. In addition, a secondary analysis was performed to assess outcomes of robotic PD to open PD for the 2017 patient cohorts. Our primary outcomes included 30-day and 90-day mortality, length of stay, as well as 30-day readmission. Secondary outcome measures were surgical margins, lymph node yield, and adjuvant chemotherapy initiation within 12 weeks of surgery. When we compared the 2017 data to 2010 data, we found that robotic pancreaticoduodenectomy had lower 30- and 90-day mortality rates in 2017 compared to 2010. Additionally, we found that the lymph node yield in robotic PD increased during the study period. When we compared robotic PD to open PD for 2017, we found no statistically significant differences in readmission rates (10.1% vs. 9.7%: *p*-0.4), lymph node yield, or negative margin between the groups. Outcomes of robotic PD have improved over the years. In 2017, outcomes of robotic PD were similar to open PD.

Keywords Robotic pancreaticoduodenectomy · Open pancreaticoduodenectomy · National Cancer Database

Introduction

There has been a paradigm shift from open to minimally invasive surgery in all surgical specialties [1–3]. Studies have shown that complex operations can be performed through a minimally invasive approach with comparable efficacy and safety to open technique, which has led to minimally invasive surgery becoming the standard of care in surgical fields such as urology, and increasingly hepatobiliary surgery [4–6]. Society guidelines have framed minimally invasive surgery as the gold standard for specific procedures such as distal pancreatectomy [7, 8].

The role of robotic surgery in pancreaticoduodenectomy (PD) has been of significant debate [9]. The operation is complex and can involve long hours without additional benefits to the patient [10]. Several groups have successfully performed robotic-assisted major pancreatic resections in the past decade, but the literature shows that they have been slow to expand [10, 11]. In 2013, Zureikat et al. demonstrated a relatively higher rate of pancreatic fistulae in patients undergoing robotic PDs than open PDs. Furthermore, they did not find any significant difference in the length of hospital stay [11]. Hence, the benefits of minimally invasive surgery seen in other surgical fields were not reproducible in pancreaticoduodenectomies. However, robotic technology has been

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improving continuously, and motion control technologies have advanced and have become more precise [12].

The goals of our study are twofold. Our first aim was to assess if perioperative outcomes after robotic pancreaticoduodenectomy are improving. The second aim was to assess if perioperative outcomes are comparable to open pancreaticoduodenectomy.

Methods

We performed a retrospective analysis of the National Cancer Database base for the years 2010 and 2017. The National Cancer Database is a joint project of the Commission on Cancer of the American College of Surgeons and the American Cancer Society containing Health Insurance Portability, and Accountability Act-compliant deidentified patient data. The database serves as a prospectively collected hospital-based registry that collects data on more than 70% of malignant diagnoses from more than 1,500 Committee on Cancer accredited institutions. We included all patients diagnosed with pancreatic cancer who underwent pancreaticoduodenectomy by either robotic or open approach.

Inclusion and exclusion criteria

We included patients of age 18–90 who underwent pancreaticoduodenectomy for adenocarcinoma of the head of the pancreas. The ICD-O-3 histology codes included in the study were: 8140/3, 8141/3, 8143/3, 8144/3, 8145/3, 8148/3, 8190/3, 8200/3, 8210/3, 8211/3, 8230/3, 8255/3, 8260/3, 8261/3, 8262/3, 8263/3, 8290/3, 8310/3, 8323/3, 8350/3, 8370/3, 8440/3, 441/3, 8450/3, 8470/3, 8471/3, 8480/3, 8481/3, 8482/3, 8490/3, 8500/3, 8503/3, 8504/3, 8510/3, 550/3, 8551/3, 8560/3, 8570/3, 8574/3, 8576/3, and 9015/3). Patients were categorized into two study groups based on the surgical approach—open vs. robotic. Extracted demographic data included: age, gender, hospital academic status, insurance status, comorbidities, and median income. Data from the years 2010 and 2017 were chosen for comparison as they represent the earliest years available in NCDB with coding for robotic pancreaticoduodenectomy, while 2017 was chosen as it is the latest year available in NCDB. Data extracted included data pertinent to the tumor: the stage of the disease, tumor grade, neoadjuvant chemotherapy, adjuvant chemotherapy, and radiotherapy.

We excluded patients ≤ 18-years-old, patients with an unknown surgical approach, or who had a laparoscopic pancreaticoduodenectomy. Additionally, patients with pathologic diagnoses other than pancreatic adenocarcinoma and those missing outcome data were excluded. Finally, patients with additional cancer diagnoses, tumors involving the celiac axis or superior mesenteric artery (T4), distant metastases, and individuals who underwent surgery with palliative intent were excluded.

Outcomes

Our Primary outcomes included 30-day and 90-day mortality, length of stay, as well as 30-day readmission. Secondary outcome measures were surgical margins, lymph node yield, and adjuvant chemotherapy initiation within 12 weeks of surgery. We also assessed for initiation of adjuvant chemotherapy within 12 weeks of surgery which is based on current National Comprehensive Cancer Network guidelines for relevant randomized controlled trials. First, we compared the perioperative outcomes of robotic pancreaticoduodenectomy in 2010 to its perioperative outcomes in 2017. Then, we compared the 2017 perioperative outcomes of robotic PD with the 2017 open PD group to see if the outcomes were similar. We hypothesized that perioperative outcomes of robotic pancreaticoduodenectomy have improved over the years and are now comparable to outcomes of open pancreaticoduodenectomy.

Propensity matching

We utilized propensity score matching in the 1:1 ratio to match the open group with the robotic group for 2017 before comparing their perioperative outcomes. We matched the two groups based on age, gender, comorbidities, race, insurance status, hospital characteristics such as facility type and volume, and tumor characteristics—tumor stage, grade, lymphovascular invasion, and use of neoadjuvant chemotherapy.

Statistical analysis

Statistical analyses were carried out using Statistical Product and Service Solutions (SPSS) version 21.0 software (SPSS Inc., IBM, Armonk, NY). All continuous data were presented as median and mean ± standard deviation (SD), and frequencies were presented when appropriate for the data type. Mean values of continuous variables were compared with a 2-tailed Student's *t* test. Nonparametric statistical tests were used if the variables did not follow the normal distribution. Categorical variables were presented as percentages. We compared categorical variables using Pearson's χ^2 test or Fisher's exact test contingency tables. For all analyses, a p value of ≤ 0.05 was established to determined significance.

Results

We analyzed a total of 4193 patients diagnosed with pancreatic cancer in the years 2010 and 2017. Based on the inclusion and exclusion criteria, 137 patients underwent robotic

PD in 2010 and 416 in 2017. There were no statistically significant differences in demographics, insurance status, or median income among patients undergoing robotic PD during the study period. Similarly, the tumor characteristics of patients undergoing robotic PD over the years have remained the same. Table 1 highlights the patient demographics across the two study periods.

Robotic surgery outcomes

When we compared the 2017 data to the 2010 data for robotic pancreaticoduodenectomy. We found that robotic PD had lower 30-day (4.4% vs. 1.2%, $p=0.02$) and 90-day (7.3% vs 4.1%, $p=0.03$) mortality rates in 2017 compared to 2010. We found that the lymph node yield increased during the study period (16 vs. 20, $p<0.001$). We found no statistically significant difference in rates of positive margins between the two groups. The median length of stay for robotic PD improved from 9 days [IQR 7–14] in 2010 to 8 days [IQR 7–13] in 2017 (p-0.01). Table 2 highlights the perioperative outcome differences between the two study periods.

Open vs. robotic PD outcomes

We then sought to compare perioperative outcomes between open PD and robotic PD for the year 2017. In 2017, 1992 patients underwent open PD, while 416 patients underwent robotic PD. Patients who underwent open PD were more likely to have more comorbidities (42.6% vs. 31.2%; p-0.001), be uninsured (4.3% vs. 1.3%; p-0.001) and were more likely to have a higher tumor stage than the robotic counterpart. After propensity score matching, we had 310 patients in both robotic and open PD groups. We found no difference in preoperative characteristics among the two groups after matching. Table 3 highlights the matched and unmatched demographics.

In terms of perioperative outcomes, we found no statistically significant difference in 30-day (1.5% vs. 1.3%, $p=0.4$) and 90-day (3.4% vs. 3.3%, $p=0.5$) mortality between the open and the robotic group for 2017. There were no differences in readmission rates (10.1% vs. 9.7%: p-0.4). The median length of stay for robotic PD was similar to the open PD group (7 days [IQR 6–9] vs. 8 days [IQR 6–11; p-0.7). There was no difference in the initiation of chemotherapy within 12 weeks of surgery (50.1% vs. 49.8%: p-0.7).

In terms of oncological outcomes, there were no differences in lymph node yield (20 [10–21] vs. 20 [13–27]; p-0.5) and negative margin rates (79.1% vs. 78.1%; p-0.4) between the two groups. Table 4 highlights the perioperative outcome differences between the two study periods. Figure 1 highlights the difference in mortality trends across the study period for Open and Robotic PD.

Table 1 Demographics of RPD

	2010 $n=137$	2017 $n=416$	p value
Patient factors	67 ± 23	67 ± 22.6	0.6
Age at diagnosis (years)			
Sex			
Male	50.5%	51.6%	0.7
Female	48.9%	47.1%	
Center			
Academic	67.3%	65.1%	
Non-academic	30.3%	32.3%	
Comorbidities			
CDCC score			
0–1	62.8%	62.4%	0.3
≥ 2	29.8%	31.2%	
Insurance status			
Uninsured	1.4%	1.3%	0.5
Private insurance	38.1%	36.5%	
Medicaid	4.6%	4.6%	
Medicare	52.1%	55.1%	
Median income			
≤ $30,000	13.2%	13.7%	0.1
30,000–34,999	21.3%	21.6%	
35,000–45,999	26.5%	26.5%	
46,000 or more	61.3%	61.7%	
Tumor factors			
Tumor grade			
Well	10.1%	11.1%	0.3
Moderate	45.4%	24.5%	
Poor	28.9%	30.4%	
Anaplastic	13.8%	13.9%	
Stage			
AJCC T stage			
Stage 1	17.9%	17.5%	0.3
Stage 2	78.8%	78.1%	
Stage 3	2.7%	3.1%	
Treatment factors			
Neoadjuvant chemotherapy			
Yes	12.1%	12.7%	0.4
Adjuvant chemotherapy			
Yes	34.5%	33.5%	0.2
Adjuvant radiotherapy			
Yes	22.1%	22.4%	0.6

Discussion

This study highlights improvements in robotic pancreatic surgery perioperative outcomes and shows comparable results to its open counterpart. First, we wanted to investigate if robotic PD outcomes have improved over the years because of the significant learning curve associated with

Table 2 Robotic outcomes

	Early (2010) $N=137$	Late (2017) $N=416$	p value
Surgical margins			
No residual tumor	80.5%	78.1%	0.64
Microscopic residual tumor	8.8%	10.3%	
Macroscopic residual tumor	4.1%	3.6%	
Lymph node yield, *n*, median [IQR]	16 [12–22]	20 [13–27]	< 0.001
Hospital length of stay, day median [IQR]	9 [7–14]	8 [7–13]	0.01
30-day readmission			
Unplanned	8.6%	8.5%	0.67
Planned	0.7%	1.2%	
Chemotherapy initiation within 12 weeks	46.8%	49.8%	0.04
30-day mortality	4.4%	1.2%	0.02
90-day mortality	7.3%	4.1%	0.03

the operation. We found significantly improved perioperative outcomes in 2017 compared to 2010 for robotic PD. Once we demonstrated that robotic PD's perioperative outcomes have improved, we wanted to compare it with the gold standard—open PD. We utilized propensity matching between the open and robotic groups due to the differences in demographics and tumor characteristics. Our study showed similar perioperative outcomes for open and robotic pancreaticoduodenectomy.

For the analyses, we used the years 2010 and 2017. 2010 was the earliest data year available to us from NCDB with granular details about the type of pancreaticoduodenectomy, while 2017 was the latest year available. Therefore, we chose these two points to assess if surgical and oncological efficacy has improved over the years. We chose not to include laparoscopic pancreaticoduodenectomy in the analysis for multiple reasons. First, laparoscopic technology has remained fairly constant, whereas robotic technology has undergone several changes since its inception. Secondly, more centers are now providing robotic technology as it is more adaptable than laparoscopy for pancreaticoduodenectomy and may provide for advantages that are not feasible in laparoscopic surgery. Furthermore, several case series have already reported oncologic outcomes comparable to OPD. [13–15]

The robotic approach's impact on more oncologic specific outcomes has also been a topic of much interest. In particular, there has been concern that a robotic approach may compromise oncologic outcomes, including margin status and the number of lymph nodes examined. Our study shows that the rates of R0 resection have remained the same, but lymph node yield has improved. We also see an improved 30 day and 90-day mortality during the study period.

As delays in adjuvant therapy initiation are associated with adverse outcomes, we sought to identify if robotic PD offers any advantage to earlier initiation of chemotherapy [16]. We found that while adjuvant therapy within 12 weeks of resection rates has improved for robotic PD during the study period, the rates are similar to the open group for 2017.

These findings are of utmost significance; it demonstrates improved robotic surgery perioperative outcomes over time and that its outcomes are currently comparable to the gold standard, open PD. This is a critical study because of previous data suggesting higher adverse events associated with robotic PD. In 2013, Zureikat et al. reported their experience with 250 robot-assisted pancreatic surgeries. In their study, 132 robotic PD cases were included, with a morbidity of nearly 62% [11]. In 2015, Chen et al. reported their first experience with robotic PD. They found the overall morbidity to be 35%, concluding that robotic PD did not have many advantages over open PD, and the main benefit of robotic PD was a less surgical burden [17].

Our study found no difference in median overall survival between RPD (21.9 months) and the open pancreatoduodenectomy group. Our findings are similar to a study by Nassour et al., which showed no difference in median overall survival between RPD and open pancreatoduodenectomy groups [18]. Their group has also shown similar results between the two approaches in patients receiving neoadjuvant therapy [19].

Robotic pancreatic surgery is expanding to a great variety of centers nationwide. These findings support the continuation of rigorous training to proliferate qualified robotic pancreatic surgeons. A recent study by Rosemurgy et al. showed that their outcomes of robotic PD were superior to predicted outcomes reported in ACS NSQIP for overall complications, serious complications, returned to the operating room, surgical site infections, deep vein thrombosis, and length of stay [20].

One of the main concerns regarding applying minimally invasive surgery to pancreatic cancer resections is the potential increase in morbidity. A European randomized trial of minimally invasive distal pancreatectomy demonstrated

Table 3 Demographics of OPD and RPD in 2017

	Unmatched			Matched		
	Open	Robotic	*p* value	Open	Robotic	*p* value
	n = 1992	*n* = 416		*n* = 310	*n* = 310	
Patient factors	68.9 ± 21.3	67 ± 22.6	0.6	68.1 ± 19.3	66 ± 21.3	0.6
Age at diagnosis (years)						
Sex						
Male	51.3%	51.6%	0.7	51.1%	50.1%	0.7
Female	47.3%	47.1%		47.9%	48.6%	
Center			0.5			0.6
Academic Centers	65.3%	65.1%		65.3%	65.1%	
Non-Academic Centers	32.3%	32.3%		32.1%	32.3%	
Comorbidities						
CDCC score						
0–1	55.1%	62.4%	0.001	60.5%	60.7%	0.7
≥ 2	42.6%	31.2%		35.2%	34.5%	
Insurance status						
Uninsured	4.3%	1.3%	0.001	3.1%	2.9%	0.6
Private insurance	35.5%	36.5%		36.1%	36.5%	
Medicaid	9.1%	4.6%		5.7%	5.3%	
Medicare	51.1%	55.1%		55.1%	55.3%	
Median income						
≤ $30,000	21.2%	13.7%	0.001	9.5%	10.4%	0.5
30,000–34,999	23.2%	21.6%		23.1%	21.4%	
35,000–45,999	24.5%	26.5%		26.3%	26.7%	
46,000 or more	31.1%	38.2%		41.1%	41.5%	
Tumor factors						
Tumor grade						
Well	21.3%	31.2%	0.3	31.6%	31.2%	0.6
Moderate	31.3%	24.5%		23.0%	24.5%	
Poor	32.3%	30.4%		31.3%	30.4%	
Anaplastic	15.1%	13.9%		14.1%	13.9%	
Stage						
Stage 1	11.3%	11.3%	< 0.01	17.7%	17.4%	0.6
Stage 2	80.8%	78.1%		74.8%	75.1%	
Stage 3	7.9%	3.1%		7.5%	7.5%	
Treatment factors						
Neoadjuvant chemotherapy						
Yes	23.1%	12.7%	0.4	16.1%	15.7%	0.5
Adjuvant chemotherapy						
Yes	45.1%	33.5%	0.2	32.3%	33.5%	0.7
Adjuvant radiotherapy						
Yes	31.3%	22.4%	0.6	23.1%	22.4%	0.6

advantages to the minimally invasive approach with reduced time to functional recovery, operative blood loss, and frequency of delayed gastric emptying compared to open distal pancreatectomy [21]. Trials of laparoscopic pancreaticoduodenectomy vs. OPD, however, have shown mixed results with two trials suggesting advantages [22]. A 2010–2011 NCDB study showed an unadjusted 30-day mortality rate was 5.1% for minimally invasive PD versus 3.1% after open surgery. They concluded that minimally invasive PD has higher 30-day mortality then open surgery [23]. However, there has been improvement in outcomes with improvements in technology, increase in volume, and understanding of the learning curves associated with robotic PD. Our study highlights there have been improvements in perioperative mortality along with lymph node yield with robotic PD since 2010. A similar study by Nassour et al. utilized the NCDB

Table 4 Outcomes OPD vs. RPD

	OPD $N=310$	RPD $N=310$	p value
Surgical margins			
No residual tumor	79.1%	78.1%	0.4
Microscopic residual tumor	9.9%	10.3%	
Macroscopic residual tumor	3.1%	3.6%	
Lymph node yield, *n*, median [IQR]	20 [10–21]	20 [13–27]	0.5
Hospital length of stay, day median [IQR]	8 [6–11]	7 [6–9]	0.7
30-day readmission			
Unplanned	8.3%	8.5%	0.4
Planned	1.8%	1.2%	
Both	10.1%	9.7%	
Chemotherapy initiation within 12 weeks	50.1%	49.8%	0.7
30-day mortality	1.5%	1.3%	0.4
90-day mortality	3.4%	3.3%	0.5

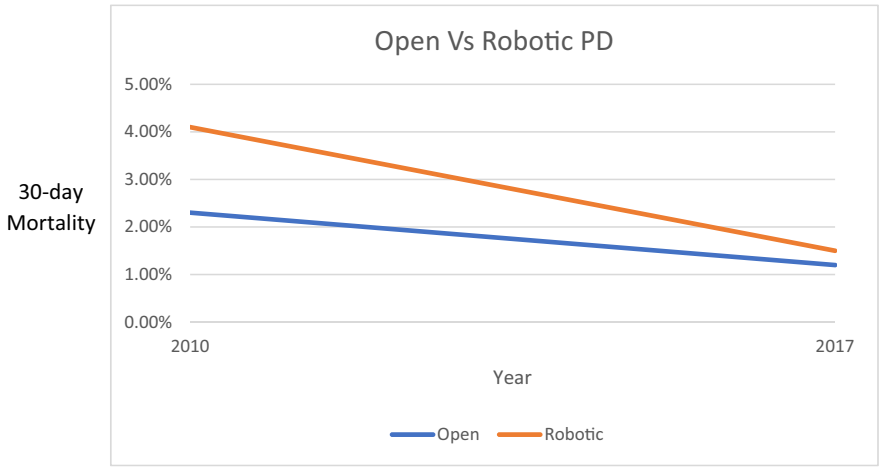

Fig. 1 Outcome comparison of Open vs. Robotic PD in a matched cohort. Outcomes between Robotic and Open PD once the groups were matched for age, gender, hospital characteristics, tumor staging and characteristics, and neoadjuvant chemotherapy. *X* axis: years, *Y* axis: 30 day mortality

Outcomes between Robotic and Open PD once the groups were matched for age, gender, hospital characteristics, tumor staging and characteristics, and neoadjuvant chemotherapy.

X Axis: Years , Y Axis : 30 day Mortality

and found that over time there have been improvements in mortality and lymphadenectomy with robotic PD with no changes in conversion to open surgery, negative margin resections, or readmissions [18].

This study's limitations include the bias associated with patient selection and the retrospective nature of the research [15]. Unmatched data showed patients with higher comorbidities and higher stages undergoing open PD; therefore, we performed propensity score matching to control biases. However, inherent biases in the data set cannot be controlled by propensity score matching [24, 25]. Lastly, the database available in NCDB in 2017 was more detailed than in 2010 [26]. Hence, we utilized only those accurately recorded variables in 2010 to have a fair comparison. Also, robotic technology has improved since 2017; the findings of this study should be interpreted in this context. As the technology continues to improve, more studies will be needed to assess its efficacy compared to the open approach. Also, details regarding systemic chemotherapy administration, especially on whether individuals were offered yet refused therapy, could not be ascertained. [27, 28] The database does not include specific post-pancreatectomy outcomes such as unplanned reoperations, pancreatic fistula, delayed gastric emptying, or post-pancreatectomy hemorrhage [29]. This does not allow to the identification of the exact etiologies for readmission. Another limitation of the database is that it does not allow for critical operative characteristics such as duration of surgery, estimated blood loss, or concomitant vascular resection and reconstruction involved in the operation [30].

Conclusion

Robotic pancreaticoduodenectomy was associated with similar positive margins and readmission rates as an open pancreaticoduodenectomy. Hence robotic pancreaticoduodenectomy may be considered as a non-inferior option. However, further randomized clinical trials should be designed to assess long-term outcomes and the cost-effectiveness of robotic pancreaticoduodenectomy.

Author contributions All the authors contributed to the study design, concept, data analysis, writing the manuscript, and final edits.

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Data availability Yes, available.

Declarations

Conflict of interest Drs. Hassan Aziz, Muhammad Khan, Sara Khan, Guillermo P. Serra, Martin D Goodman, Yuri Genyk, Mohd. Raashid Sheikh, have no conflicts of interests to declare. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

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