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Objective: To assess feasibility and safety of a multicenter training program in robotic pancreatoduodenectomy (RPD) adhering to the IDEAL framework for implementation of surgical innovation.

Background: Good results for RPD have been reported from single center studies. However, data on feasibility and safety of implementation through a multicenter training program in RPD are lacking.

Methods: A multicenter training program in RPD was designed together with the University of Pittsburgh Medical Center, including an online video bank, robot simulation exercises, biotissue drills, and on-site proctoring. Benchmark patients were based on the criteria of Clavien. Outcomes were collected prospectively (March 2016-October 2019). Cumulative sum analysis of operative time was performed to distinguish the first and second phase of the learning curve. Outcomes were compared between both phases of the learning curve. Trends in nationwide use of robotic and laparoscopic PD were assessed in the Dutch Pancreatic Cancer Audit.

Results: Overall, 275 RPD procedures were performed in seven centers by 15 trained surgeons. The recent benchmark criteria for low-risk PD were met by 125 (45.5%) patients. The conversion rate was 6.5% (n = 18) and median blood loss 250ml [interquartile range (IQR) 150–500]. The rate of Clavien-Dindo grade ≥III complications was 44.4% (n = 122), postoperative pancreatic fistula (grade B/C) rate 23.6% (n = 65), 90-day complication-related mortality 2.5% (n = 7) and 90-day cancer-related mortality 2.2.% (n = 6). Median postoperative hospital stay was 12 days (IQR 8–20). In the subgroup of patients with pancreatic cancer (n = 80), the major complication rate was 31.3% and POPF rate was 10%. Cumulative sum analysis for operative time found a learning curve inflection point at 22 RPDs (IQR 10–35) with similar rates of Clavien-Dindo grade ≥III complications in the first and second phase (43.4% vs 43.8%, $P = 0.956$, respectively). During the study period the nationwide use of laparoscopic PD reduced from 15% to 1%, whereas the use of RPD increased from 0% to 25%.

Conclusions: This multicenter RPD training program in centers with sufficient surgical volume was found to be feasible without a negative impact of the learning curve on clinical outcomes.

Keywords: complication, learning curve, operative time, robotic pancreatoduodectomy, robotic surgery

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Minimally invasive pancreatoduodenectomy can be performed using the laparoscopic approach, first reported in 1994,[1] and by the robotic approach, first reported in 2000.[2] In recent years, 3 randomized trials have compared laparoscopic pancreatoduodenectomy (LPD) to open pancreatoduodenectomy (OPD).[3–5] The Indian PLOT and the Spanish PADULAP monocenter trials reported improved or similar complication rates and shorter hospital stay with LPD, as compared to OPD.[4,5] The multicenter Dutch LEOPARD-2 trial, however, was prematurely stopped because of an (nonsignificant) increase in mortality after LPD, as compared to OPD.[3]

Several high-volume centers have reported good outcomes with robotic pancreatoduodenectomy (RPD).[6–13] Hereafter, the Dutch Pancreatic Cancer Group decided to advice against the use of LPD in the Netherlands and started a training program for RPD in selected high-volume centers.

In 2016 and 2019, the Dutch Pancreatic Cancer Group reported on the LAELAPS-1[14] and LAELAPS-2[15] training programs for laparoscopic distal pancreatectomy and LPD, respectively. The multicenter LAELAPS-3 training program in RPD was developed in close collaboration with the highly experienced University of Pittsburgh Medical Center (UPMC) group, who previously pioneered training strategies for RPD.[16–18] Prospective multicenter training programs for RPD were not available in the literature.[19]

The present study aims to assess safety and feasibility of a multicenter training program in RPD in the Dutch healthcare setting including the trends in the use of LPD and RPD in the Netherlands during the same period.

METHODS

This prospective multicenter study investigated the outcomes of the LEALAPS-3 multicenter training program in RPD which was designed in collaboration with the UPMC group (MH, HZ, AZ).[16–18] Data of all consecutive RPDs were collected from March 2016 to October 2019, including the first procedure in every participating center. This study followed the guidelines for Strengthening the Reporting of Observational Studies in Epidemiology (STROBE).[20] The medical ethics review committee of Amsterdam UMC, location Academic Medical Center, waived the need for informed consent due to the observational nature of this study. This study was registered at the Netherlands Trial Register (NTR8073).

Patients

The following selection criteria were used: body mass index (BMI) ≤35kg/m^2 without signs of vascular involvement on a pancreatic CT scan not older than 4 weeks at the time of surgery. With increasing experience, a few patients were included with a BMI above 35 or with some vascular abutment. The final decision to select a patient for RPD was left at the discretion of the surgical team.

Centers

The training program was only offered to centers with sufficient surgical volume to perform at least 20 RPDs annually as recommended by the recent international evidence-based Miami guidelines[21] and the University Pittsburgh Medical Center (UPMC) group.[3,16,21] The Miami guidelines and others also recommend participation in structured training programs for surgeons undertaking RPD, including virtual reality simulation, biotissue models, surgical video review, and on-site proctoring.[21,22] All patients received at least 1 postoperative surgical drain. Drains were generally removed once amylase levels were low (less than 3 times the upper limit of normal serum amylase). The primary management of clinically relevant postoperative pancreatic fistula was by minimally invasive catheter drainage.[23,24] Patients could be discharged in case of a good clinical condition with the surgical or other drains in situ. Drains were subsequently removed at the outpatient clinic.

Training Program

The steps of the LAELAPS-3 program are shown in Figure 1, and remained unchanged throughout the study period. First, simulation training required ≥95% scores on 22 predefined da Vinci Skills Simulator exercises (Supplemental table 1, http://links.lww.com/SLA/C948).[17] Second, biotissue training comprised of basic suturing and anastomoses training on artificial organs, according to the UPMC training model; 2 suture drills; 4 or more hepaticojejunos-tomies; and 4 or more pancreaticojejunostomies.[18] Third, video training was accessible through an online, private video database (VIMEO, New York, NY) containing >100 edited videos with content ranging from biotissue drill, essential steps during RPD, and entire RPD procedures (courtesy of MH).[25] Fourth, on-site proctoring was

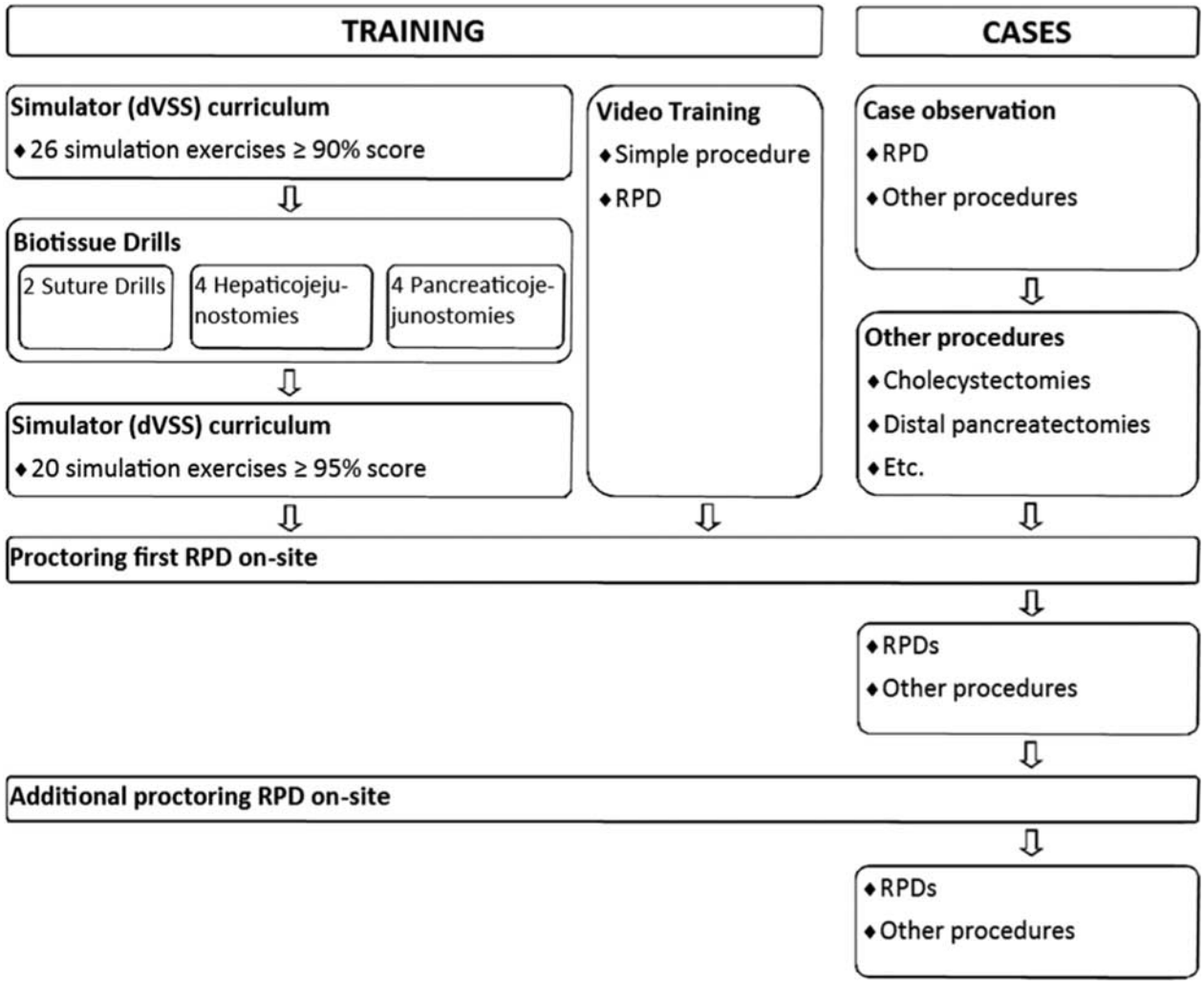

FIGURE 1. Overview of a multicenter training program for robotic pancreatoduodenectomy. Vertical: Step-wise completion of training elements. Horizontal: Combined training elements during each time frame. dVSS indicates da Vinci Skills Simulator.

performed by an international experts (HZ, MH, AZ, and OM). At the start of the program, all participating surgeons had at least 5 years of experience with open pancreatic surgery. Surgeons at 3 participating centers had experience with LPD.

Surgical Technique

The Intuitive (Sunnyvale, CA) da Vinci surgical system was used for all RPD procedures. In all centers each procedure was performed by teams of at least 1 console surgeon and at least 1 bedside surgeon. These 2 surgeons were present during the entire RPD procedure. Based on their preferences in open surgery, minor alterations to the standard RPD technique were allowed, such as the sequence of steps or type of pancreatic anastomosis (6 centers used the modified Blumgart anastomosis as described by UPMC,[26] and 1 center used pancreaticogastrostomy). See supplemental text 1, http://links.lww.com/SLA/C949 for a detailed description of the surgical procedure. In one center the bed-side surgeon was replaced by a dedicated nurse specialist.

Definitions

Conversion was defined as a laparotomy to perform part of the resection or reconstruction, either reactive/urgent or conditional/ nonurgent.[27] Complications were scored according to the Clavien-Dindo classification.[28] Postoperative pancreatic fistula, delayed gastric emptying, postpancreatectomy hemorrhage, and chyle leakage were scored according to International Study Group on Pancreatic Surgery definitions. Only grade B/C complications were recorded as being clinically important.[29–32] Bile leak was scored according to the International Study Group on Liver Surgery definition.[33] Surgical site infections were scored according to the Centers for Disease Control and Prevention definition.[34] Oncologic radicality was assessed according to the guidelines of both the Royal College of Pathologists (>1 mm margin free for a R0 resection; RCP-R0) and the College of American Pathologists (0 mm margin free for a R0 resection' CAP-R0).[35,36] Lymph node count was performed in compliance the American Joint Committee on Cancer.[37]

Operative time was defined as the time between first incision until full closure of incisions and usually included a short break between the resection and anastomotic phase.

Resection time was defined as start of the mobilization phase until the entire specimen was resected. Reconstruction time was defined as start of positioning the bowel for the first anastomosis until the last stitch of the last anastomosis. Other operative time was defined as operative time minus the reconstruction- and resection time. Extended resection was defined as resections other than pancreatic head, duodenum, pylorus, distal stomach, gallbladder, or regional lymph-node stations. Venous resection was defined as a partial- or segmental resection of the porto-mesenteric vein. Benchmark patients, that is, patients without significant comorbidities and major vascular resection, were identified based on the 2019 criteria of Clavien et al.[38]

Data Collection

Data were prospectively collected during hospital stay and after discharge up to 90 days postoperatively. Collected baseline characteristics were sex, age, BMI, comorbidity and medical history, American Society of Anesthesiologist physical status (ASA score), pancreatic duct diameter, and pancreatic textures (soft or firm). Collected operative outcomes were conversion, perioperative use of somatostatin analogue, operative time, measured intraoperative blood loss (mL, including both blood in suction canister and in gauzes), histopathological diagnosis, tumor size, resection margins and lymph node retrieval.

Collected postoperative outcomes were postoperative pancreatic fistula, bile leakage, delayed gastric emptying, post-pancreatectomy hemorrhage, chyle leakage, incisional surgical site complication, intensive care unit admission, complications according to Clavien-Dino classification, length of hospital stay, readmission, neoadjuvant chemo (radio)therapy, in-hospital, 30-day, and 90-day mortality. In addition, nationwide trends on the use of LPD and RPD were obtained via the Dutch Pancreatic Cancer Audit to assess potential practice shifts over time.[39]

Statistical Analysis

Data were analyzed using IBM SPSS statistics for Windows version 26 (IBM Corp, Armonk, NY). Normally distributed continuous data were presented as means and standard deviations (SDs). Non-normally distributed continuous data were presented as medians and interquartile ranges (IQRs). Categorical data were presented as frequencies and percentages. Pearson Correlation (r) was used to test trends in continuous data. A two-tailed P value <0.05 was considered statistically significant. Subgroup analyses included low vs high risk patients and patients with and without pancreatic ductal adenocarcinoma. Three sensitivity analyses were performed; first by excluding endoscopic feeding tube placement as Clavien-Dindo grade III complication; second by excluding centers who performed less than 60 RPDs altogether; third by excluding the first 20 RPDs for each center.

The cumulative sum method (CUSUM) was used to determine the learning curve for operative time per center. CUSUM divided the study population per center in 2 groups; the first and second phase of the learning curve for operative time.[40–43] Validity of CUSUM analysis improves along with the size of the cohort. Therefore, data of 4 centers who had performed at least 20 consecutive RPDs until the end of the study period were included in the learning curve analyses (Centers A-D). The CUSUM for operative time was the running total of differences between the individual data points and the mean of all data points for each center. The total operative time was used to identify the overall learning curve per center. See supplemental text 2, http://links.lww.com/SLA/C950 for the essentials of the CUSUM.

Analyses were performed according to intention-to-treat principles, meaning that RPD procedures that were converted to OPD remained in the RPD group for analyses.

RESULTS

Training Program

A total of 275 RPD procedures were performed by 15 trained surgeons from 7 centers who had completed the training program. One center had performed 5 RPDs before the start of the training program. The other 6 centers performed their first RPD after the biotissue exercises within the training program. The mean annual RPD center volume was 21 (SD 9). Two of the 7 centers performed less than 20 RPDs annually (actual annual volume in these centers calculated for a 12 months period was 16 and 8 RPDs). The 15 robot console surgeons had performed at least 26 simulation exercises individually, a total of 58 biotissue pancreaticojejunostomy and 55 biotissue hepaticojejunostomy anastomoses. The training program comprised approximately 26 hours during a period up to 3 months until the first proctored RPD. The additional time spent on educational videos was not monitored. Per center, median 3 surgeons were trained (IQR 2–4). A total of 16 on-site RPD proctoring sessions were organized in which all surgeons were proctored. The RPD proctoring procedures took place throughout the study period: March 2016 [center A], September 2016 [center B], January 2017 and September 2017 [both times centers B and C], December 2018 [centers D, E, F], and May 2019 [center D, E, F, G] (See supplemental table 2, http://links.lww.com/SLA/C951 for more details on inclusion rates and start of enrollment). The median number of proctoring sessions per surgeon was 2 (IQR 1–3). During proctoring, most RPD procedures were performed by teams of 2 surgeons. Finally, of the 7 teams, 15 surgeons were trained to perform RPD on the da Vinci Surgeon Console, the other surgeons were trained as bed-side surgeons, providing laparoscopic assistance. Console surgeons had > 8 years of experience performing open pancreatic surgery. Experience with the robotic platform ranged from 1 to 4 years. Seven surgeons from 3 centers had previous experience with 30 to 55 LPDs per center in the LAELAPS-2 training program (2014–2016) and the LEOPARD-2 trial (2016–2017). All surgeons had performed several robotic pancreatic procedures such as pancreatic distal pancreatectomy, robotic lateral pancreaticojejunostomies, and pancreatic enucleations (see Fig. 1).

Baseline Characteristics

Overall, 53.1% of patients were male (n = 146) and the median age was 68 years (IQR 61–74). Of all patients, 23.3% (n = 64) were ≥75 years, 13.1% (n = 36) had a BMI ≥ 30kg/m^2,27.6% (n = 76) were American Society of Anesthesiologist 3, and 37.1% (n = 102) had previous abdominal surgery. Fifteen patients (5.5%) received preoperative chemo (radio)therapy. All procedures were performed using da Vinci surgical systems: 55.6% Xi (n = 153), 25.1% Si (n = 69), 12.4% S (n = 34), and 6.9% X (n = 19). Overall, 45.5% (n = 125) of patients could be categorized as low-risk patients based on the recent benchmark criteria of Clavien et al. Baseline characteristics are shown in Table 1.

Perioperative Outcomes

The overall conversion rate was 6.5% (n = 18), which was urgent in 3.3% of patients (n = 9). The urgent conversions were due to venous bleeding during mobilization of the mesenteric

TABLE 1. Baseline Characteristics

Characteristic	n = 275
Age, yr, median (IQR)	68 (61–74)
Age ≥75 yr, n (%)	64 (23.3)
BMI, kg/m^2, median (IQR)	25 (23–27)
BMI ≥30 kg/m^2, n (%)	36 (13.1)
Male, n (%)	146 (53.1)
Comorbidity and medical history, n (%)	244 (88.7
Cardiovascular disease	138 (50.2)
Pulmonary disease	99 (36.0)
Gastrointestinal disease	120 (43.6)
Pancreatitis	48 (17.5)
Endocrine disease	23 (8.4)
Diabetes	46 (16.7)
Oncologic disease <5 years prior	53 (19.3)
Neurologic disease	53 (19.3)
Other past medical history	140 (50.9)
ASA physical status, n (%)	
1	22 (8.0)
2	177 (64.4)
3	76 (27.6)
Previous abdominal surgery, n (%)	102 (37.1)
Neoadjuvant chemo (radio)therapy, n (%)	15 (5.5)
Suspected malignant disease, n (%)	172 (62.5)
Benchmark classification*, n (%)	125 (45.5)

*Benchmark patients were identified based on the 2019 criteria of Clavien et al.[28].
ASA indicates American Society of Anesthesiologist.

TABLE 2. Operative and Pathology Outcomes

Operative Outcome	n = 275
Extended resection, n (%)	10 (3.6)
Total operative time, min., (IQR)	420 (382–486)
Operative times < 400 min, n (%)	99 (36.0)
Resection phase*	203 (169–244)
Reconstruction phase*	155 (132–183)
Other time	73 (46–105)
Blood loss, mL, median (IQR)	250 (150–500)
Conversion, n (%)	18 (6.5)
Urgent conversion	9 (3.3)
Venous resection, n (%)	17 (6.2)
Segmental	3 (1.1)
Soft pancreatic gland texture, n (%)	141 (51.3)
Pancreatic duct diameter, mm, median (IQR)	3 (2–5)
Pancreatic duct diameter < 3 mm, (%)	80 (29.1)
Perioperative use of somatostatin analogue, n (%)	134 (48.7)
Malignant disease, n (%)	207 (75.3)
Pancreatic ductal adenocarcinoma	80 (29.1)
Distal cholangiocarcinoma	37 (13.4)
Ampullary cancer	47 (17.1)
pNET	12 (4.4)
Other	31 (11.3)
Premalignant or benign disease, n (%)	68 (24.7)
Intraductal papillary mucinous neoplasm	29 (10.5)
Low-/intermediate-grade dysplasia	25 (9.1)
High-grade dysplasia	4 (1.5)
Ampullary adenoma	12 (4.4)
Auto-immune pancreatitis or cholangitis	10 (3.6)
Chronic pancreatitis	7 (2.5)
Other	10 (3.6)
Tumor size, mm (IQR)	24 (15–34)
Lymph node harvest, # (IQR)	15 (12–19)
RCP-R0 resection in all patients#, n (%)	109 (52.7)
CAP-R0-resection in all patients^, n (%)	196 (94.7)

#RCP-R0 reseciton = 1 mm free margin.
^CAP-R0 = 0 mm free margin.
*pNET indicates Pancreatic neuroendocrine tumor

TABLE 3. Postoperative Outcomes

Postoperative Outcome	n = 275
Unplanned ICU admission, n (%)	47 (17.1)
Length of initial hospital stay, median days (IQR)	12 (8–20)
Initial hospital stay < 7 d, n (%)	38 (13.8)
Readmission, n (%)	39 (14.2)
Length of total hospital stay, median days (IQR)	14 (8–22)
Clavien-Dindo complication >III, n (%)	122 (44.4)
Benchmark patients only	52/125 (41.6)
Excluding endoscopic feeding tube placement*	107/275 (38.9)
Pancreatic ductal adenocarcinoma	25/80 (31.3)
Postoperative pancreatic fistula (Grade B/C), n (%)	65 (23.6)
B	55 (20.0)
C	10 (3.6)
Bile leakage (Grade B/C), n (%)	30 (10.9)
Delayed gastric emptying (Grade B/C), n (%)	91 (33.1)
Postpancreatectomy hemorrhage (Grade B/C), n (%)	31 (11.3)
Extraluminal bleeding	24 (8.7)
Intraluminal bleeding	7 (2.5)
Chyle leakage (Grade B/C), n (%)	17 (6.2)
Incisional Surgical Site Complication, n (%)	14 (5.1)
Surgical Site Infection, n (%)	39 (13.8)
Superficial incisional surgical site infection	10 (3.6)
Deep incisional surgical site infection	4 (1.5)
Organ- or space surgical site infection	24 (8.7)
Requiring drainage	12 (4.2)
Reoperation, n (%)	27 (9.8)
In-hospital mortality, n (%)	9 (3.3)
30-d mortality, n (%)	6 (2.2)
90-d all cause mortality, n (%)	13 (4.7)
90-d complication-related mortality	7 (2.5)
90-d cancer-related mortality	6 (2.2)

*Excepting Clavien–Dindo III complication limited to endoscopic feeding tube placement as only intervention.

vein (n = 3), during tunneling of the pancreas (n = 2), during resection of the uncinate process from the mesenteric vein (n = 2), due to arterial bleeding during duodenal mobilization from the uncinate process (n = 1), or a bleeding from the superior mesenteric artery after the pancreatic anstomosis had been constructed (n = 1). Six patients developed major morbidity and 2 patients died in this subgroup of urgent conversion. Overall, median operative time was 420 minutes (IQR 382–486) and median blood loss 250 mL (IQR 150–500). Median pancreatic duct diameter was 3 mm (IQR 2–5), pancreatic texture was soft in 51.3% (n = 141) of patients. Venous resections and extended resections were performed in 6.2% (n = 17) and 3.6% (n = 10) of patients, respectively.

Overall, 75.3% of patients (n = 207) had a malignant histopathological diagnosis, with 52.7% RCP-R0 (n = 103) and 94.7% CAP-R0 (n = 196) resections rates. Overall, 29.1% of patients (n = 80) had pancreatic ductal adenocarcinoma, with 43.8% RCP-R0 and 92.5% CAP-R0 resections rates. Overall, Median lymph node harvest was 15 (IQR 12–19, range 3–33, mean 15.7). Operative outcomes are shown in Table 2.

Postoperative Outcomes

Of all patients, 44.4% (95% CI: 38.4–50.5%) (n = 122) developed a Clavien-Dindo grade ≥III complication and 17.1% (n = 47) were admitted to the intensive care unit (ICU) for complications. Median length of initial hospital stay was 12 days (IQR 8–20). In total, 14.2% (n = 39) were readmitted within 90-days after initial discharge. Median length of total hospital

TABLE 4. Outcomes in the First and Second Phase of the Learning Curve as Defined by the CUSUM Inflection Point for Operative Time

Operative Outcome	Total (n = 275)	Before Inflection Point, First Phase (n = 83)	After Inflection Point, Second Phase (n = 144)	P Value
Total operative time, min, median (IQR)	420 (382–486)	467 (407–540)	415 (383–463)	0.009
Resection phase	203 (169–244)	205 (166–281)	187 (162–240)	0.009
Reconstruction phase	155 (132–183)	155 (133–180)	158 (132–183)	0.601
Other	73 (46–105)	80 (62–118)	56 (33–89)	0.002
Blood loss, mL, median (IQR)	250 (150–500)	250 (150–650)	300 (150–500)	0.613
Conversion, n (%)	18 (6.5)	6 (7.2)	8 (5.6)	0.631
Urgent conversion, n (%)	10 (3.6)	3 (3.6)	5 (3.5)	0.640
Clavien-Dindo complication > III, n (%)	122 (44.4)	36 (43.4)	63 (43.8)	0.956
Postoperative pancreatic fistula (Grade B/C), n (%)	65 (23.6)	14 (16.9)	40 (28.0)	0.123
90-day mortality, n (%)	13 (4.7)	4 (4.8)	8 (5.6)	0.811

Data of 4 centers who performed at least 20 consecutive RPDs in de study period were included in the learning curve analyses.
CUSUM indicates Cumulative sum analysis of operative time.

stay including readmission was 14 days (IQR 8–22, Range 2–84). Overall, 23.6% (n = 65) of patients developed postoperative pancreatic fistula, of whom 20.0% (n = 55) grade B and 3.6% (n = 10) grade C. Of all patients with pancreatic fistula, 61.5% (n = 40) patients were discharged with the surgical drain in place. The rate of postoperative pancreatic fistula in patients with pancreatic ductal adenocarcinoma was 10% (8 out of 80 patients). The rate of bile leakage was 10.9% (n = 30), of which 8.4% (n = 23) grade B and 2.5% (n = 7) grade C. Twelve of these 30 patients had concomitant pancreatic fistula. Overall, 33.1% (n = 91) of patients developed delayed gastric emptying, and 11.3% (n = 31) developed postpancreatectomy hemorrhage (of these, 24 involved extraluminal bleeding and 7 involved intraluminal bleeding originating from the gastrojejunal anastomosis), and 6.2% (n = 17) developed chyle leakage. Overall, 9.8% (n = 27) of patients underwent a reoperation. In-hospital mortality was 3.3% (n = 9), 30-day mortality 2.2% (n = 6). The 90-day complication-related mortality was 2.5% (n = 7) and the 90-day cancer-related mortality rate was 2.2% (n = 6). Postoperative outcomes are shown in Table 3. Underlying pathology in patients who died from progressive disease was pancreatic ductal adenocarcinoma (n = 5), and pancreatic cancer arising from intraductal papillary mucinous neoplasm (n = 1). Of the 13 patients who died within 90 days, 11 had malignant disease and 2 had benign disease.

An analysis of the subgroup of low-risk patients (n = 125) based on the recent benchmark criteria was performed. A ClavienDindo ≥ III complication developed in 41.6% of this subgroup (95% CI: 32.9–50.8%) (n = 52). A subgroup analysis compared patients with pancreatic ductal adenocarcinoma (n = 80) and other patients (n = 195). A lower rate of Clavien-Dindo > III complications was seen in patients with pancreatic ductal adenocarcinoma, 31.3% (n = 25) versus in other patients 49.7% (n = 97), $P = 0.004$.

Learning Curve Effect

From the CUSUM learning curve of operative time data of 4 centers that performed more than 20 RPDs in the entire program were included. The inflection point per center was reached after a median of 22 RPD procedures, thus defining the first and second phase of the learning curve. Except for neo-adjuvant chemo (radio)-therapy, baseline characteristics were comparable before and after the inflection point, see supplemental table 3, http://links.lww.com/SLA/C952. In the second phase of the learning curve, median total operative time was

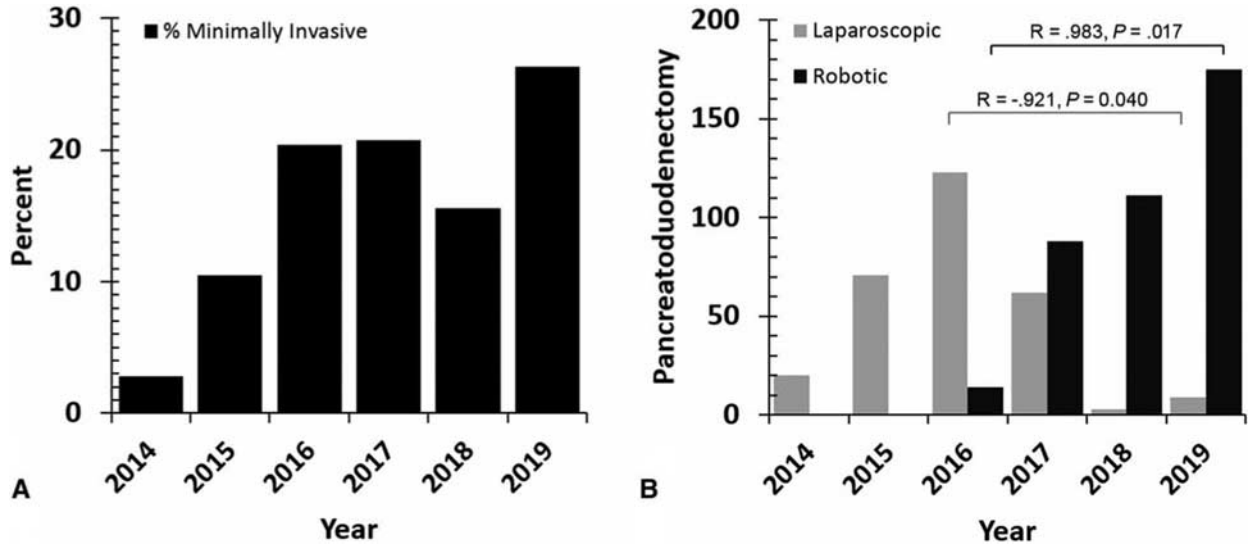

FIGURE 2. Annual use of laparoscopic and robotic pancreatoduodenectomy. A, Approach to pancreatoduodenectomy over time. B, The annual total number of patients undergoing laparoscopic and robotic pancreatoduodenectomy.

52 minutes shorter for all centers (median operative time of 467 vs 415 min, $P = 0.009$). After 60 RPD procedures (reached in 2 out of 7 centers), no further decrease in total operative time was seen, see Supplemental Figure 1, http://links.lww.com/SLA/C953. After the inflection point, the resection time was 18 minutes shorter (median 205 vs 187 minutes, $P = 0.009$), other operative time (such as trocar placement, specimen extraction, skin closure, etc) was 24 minutes shorter (median 80 vs 56 min, $P = 0.002$), whereas the reconstruction time was similar (median 155 vs 158 min, $P = 0.601$) between the first and second phase of the learning curve.

After the inflection point, no statistically significant differences were seen in conversion rates (7.2% vs 5.6%), Clavien-Dindo complication ≥III complications (43.4% vs 43.8%), postoperative pancreatic fistula (16.9% vs 28.0%), and 90-day mortality (4.8% vs 5.6%) (Table 4), for the first and second phase, respectively. Sensitivity analysis of the 2 centers which performed over 60 RPDs and sensitivity analysis excluding the first 20 RPDs per center revealed no significant changes in the findings, that is, operative time, conversion rates, postoperative hospital stay, readmission, Clavien-Dindo complication > III, postoperative pancreatic fistula, bile leakage, pospancreatectomy hemorrhage, and 90-day mortality did not differ significantly.

Nationwide Trends

Between 2016 and 2019, the nationwide proportion of LPD decreased from 15% to 1% (r = –0.921, $P = 0.040$), whereas the use of RPD increased from 0% to 25% (r = 0.983, $P = 0.017$) (see Fig. 2).

DISCUSSION

This first report of a multicenter training program in RPD demonstrated its feasibility and safety through acceptable outcomes with 44.4% Clavien-Dindo grade III or higher complications, 3.3% in-hospital mortality rate, 6.5% conversions, and 12 days median hospital stay. These outcomes include all procedures starting with the first RPDs performed in 7 centers. The CUSUM analysis identified an inflection point for operative time at 22 RPD procedures which reflects a relatively short learning curve. Outcomes in the first and second phase of the learning curve in the study period did not differ significantly which supports the safety of this training program approach.

Similar studies on multicenter RPD training programs are lacking.[19,44] Previous studies from the UPMC group and University of Heidelberg described elements of this training program such as simulation exercises, biotissue training, and proctoring.[22,45,46] In the current study, the reconstruction time was similar between both phases of the learning curve for operative time suggesting a positive impact of the training program and supporting the use of the highly standardized biotissue anastomoses training. Further qualitative analysis is ongoing to assess the anastomoses and possibilities for further improvement.[18,26,46,47]

Outcomes of the current training program were relatively comparable to the preceding LAELAPS-2 training program on LPD in 4 centers (n = 114) for Clavien-Dindo grade ≥ III complications (44.4% vs 43.0%), postoperative pancreatic fistula (23.6% vs 34.2%), complication related 90-day mortality (2.5% vs 3.5%).[15] The conversion rate in the current study was lower (6.5% vs 11%), as demonstrated by previous studies.[48] Moreover, the 4.7% mortality is similar to the overall mortality after pancreatoduodenectomy in the Netherlands before this training program (4.1% in the period 2014–2015)[49] and similar to the 6.1% mortality after pancreatic surgery in German very high volume centers (highest quintile, period 2009–2013).[50]

According to the *Assessment* phase of the IDEAL framework, the actual benefit of RPD over OPD remains to be proven by randomized controlled trials.[51] To date, several retrospective multicenter studies have directly compared RPD with OPD.[52–55] First, Zureikat et al (n = 211) found comparable safety and short term oncologic efficacy, while reducing major complications (OR 0.64, 95% CI: 0.47-0.85) for RPD (UPMC and Cleveland Clinic) versus OPD in 6 high volume centers.[52] Second, the European consortium on Minimally Invasive Pancreatic Surgery compared RPD (n = 184), LPD, and OPD.[53] They found no differences in major morbidity, mortality, and hospital stay between the approaches, but reported a lower conversion rate with RPD versus LPD (5% vs 26%).[53]

We compared the outcomes of this multicenter training program to the first 200 RPD procedures as reported by the UPMC group,[56] the proctors of the present study. Some baseline differences were seen, such as mean BMI (28 vs 25), previous abdominal surgery (52% vs 37%), and pancreatic ductal adenocarcinoma (52% vs 29%) for the UPMC study and the present study. Outcomes were largely comparable, such as operative time (483 vs 420 minutes), conversion rate (5.2% vs 6.5%), blood loss (250 vs 250 ml), and 90-day mortality (3.3% vs 4.7%), for the

TABLE 5. Reports on the Learning Curve of Robotic Pancreatoduodenectomy

RPD series	Year	Total	Mono- / Multicenter	Operative Time	(E) BL	Conversion	Hospital Stay	Major Morbidity	Fistula, %	Mortality†	Inflection $CUSUM_{OT}$, N
Chen et al.[7]	2014	60*	Monocenter	410	400	1 (1.7)	20	7 (11.7)	8.3	1 (1.7)	40
Napoli et al.[9]	2016	70*	Monocenter	522	–	1 (1.4)	23.2	12 (17.1)	35.7	2 (2.8)	33
Shyr et al.[6]	2018	61*	Monocenter	–	100	Excluded	24	6 (9.8)	11.5	0 (0.0)	20
Takahashi et al.[10]	2018	65*	Monocenter	498	155	3 (4.6)	7	20 (30.8)	3.1	0 (0.0)	15–30
Guerra et al[12]	2018	59*	Monocenter	515	1500	11 (18.6)	9	15 (25.4)	11.8	2 (3.3)	20
Zureikat et al.[8]	2019	500*	Monocenter	415	200	26 (5.2)	8 (6–11)	124 (24.8)	7.8	15 (3.0)	80
Shi et al.[11]	2019	450*	Monocenter	307	419	5 (1.1)	22	32 (7.1)	9.8	–	170
Marino et al.[13]	2020	60*	Monocenter	415	220	6 (10)	11	12 (20)	11.1	3 (5.0)	30
LAELAPS-3	2020	275	Multicenter	420	250	18 (6.5)	12 (8–20)	122 (44.4)	23.6	6 (2.2)	22

*Consecutive number of included RPDs.

†30-day complication related mortality.

(E)BL indicates (Estimated) Blood Loss; CUSUMOT, Cumulative sum analysis of operative time; Major Morbidity, Clavien-Dindo grade ≥III complication; RPDs, Robotic pancreatoduodenectomies.

UPMC study and the present study. Better outcomes were seen in the first 200 RPDs for UPMC for length of stay (median 9 vs 12 days), Clavien-Dindo grade ≥III complications (26% vs 44%), and postoperative pancreatic fistula (9% vs 24%) while the readmission rate was lower in the current study (29.2% vs 14.2%). In the first 500 RPDs of UPMC, a significant further reduction in both operative time and postoperative pancreatic fistula was seen showing that increase in experience will further improve outcomes.[8]

Outcomes were also compared with published single center studies with up to 500 consecutive RPDs, see Table 5.[6,8–13] The majority of these studies did not explicitly mention whether the first RPD per center were included in the analyses.[6,8–11] The present multicenter study largely parallels these studies.[6,8–13] The rate of Clavien-Dindo grade > III complications seems to be higher in the present study, although morbidity rates vary widely between series which could be related to registration bias and patient selection.[8,57,58] Furthermore, the current study is a prospective study which reduced the risk of bias.

Comparing outcomes or RPD across centers is hampered by differences in patient populations. The recent benchmark paper demonstrated that the percentage of benchmark patients differed from 9% to 93% across centers for OPD.[38] Only about half of the present multicenter study population qualified as low-risk cases. Outcomes of RPD for the low-risk population in the present study were acceptable in this early learning curve experience, Clavien-Dindo grade ≥ III: 41.6% (benchmark < 30%); median hospital stay: 12 days (benchmark 15 days); and 90-day mortality: 4.3% (benchmark ≤ 5%).[38] The relatively high rate of Clavien-Dindo ≥ III complications (41.6%) may be partly explained by the low percentage (29.1%) of patients with pancreatic ductal adenocarcinoma in this study. In the current study, Clavien-Dindo ≥ III complications were reduced in patients with pancreatic ductal adenocarcinoma (31.3% vs 49.7%), in line with previous reports, such as by Dokmak et al.[59] The rate of POPF (10%) was also lower in the subgroup who underwent an RPD for pancreatic ductal adenocarcinoma. Moreover, the complication rate is similar to the open group of the 3 recent randomized controlled trials: the Dutch LEOPARD-2 trial: 39%; the Spanish PADULAP trial: 34%; the Indian PLOT trial: 31%.[3–5]

The rate of bile leakage was rather high with 11% (95% CI: 7.5%–15.2%), especially when compared to the ~5% bile leakage dictated by studies on textbook outcomes.[60] Yet, this rate is not different from the 12% bile leak seen after laparoscopic PD and 10% after open PD in the LEOPARD-2 trial.[3] This could partially be explained by the low rate of pancreatic cancer (29%) as seen in both the present study and in the LEOPARD-2 trial.

It is difficult to compare length of postoperative stay between international studies. For example, in the current study, 62% of patients with postoperative pancreatic fistula were discharge from the hospital with drains in situ, whereas in a similar study by Napoli et al, national guidelines only allowed discharge from the hospital when patients fully recovered and needed no outpatient care.[9]

In the current study, the CAP-R0 (0 mm) rate in the current study (94.7%) met textbook outcomes as identified from the National Cancer Database (> 77.9%).[61] However, the RCP-R0 (> 1 mm) rate of 52.8% in the current study was lower than previously described in the Netherlands (66.4% in 1736 patients) for patients with pancreatic/bile duct cancers.[62] The mean number of lymph nodes harvested in the current study (15.7) was higher than reported in that same Dutch study[62] and is in line with the literature: 8.7 to 23.4 nodes.[63]

The results of this study should be interpreted in light of some limitations. First, some changes other than surgical experience could have contributed to the shortening of operative time during the program. For instance, 2 out of 7 centers performed their first procedures on a precursory version of the da Vinci surgical system before switching to a da Vinci Xi system, after 14 and 34 cases. Second, the current study design did not assess impact of variations in the training program. For instance, outcomes could be further improved with more extensive proctoring or with a minimal proficiency score in the biotissue drills.[45] The current design, however, reflects a pragmatic and feasible approach which could probably be translated to high-volume centers in other healthcare settings. As an example, the European consortium on Minimally Invasive Pancreatic Surgery group has recently launched the LEARNBOT (NTR8898) program to translate the current training program to a European level. Third, not all centers had performed 20 RPDs at the time of this analysis. The learning curve outcomes for 3/7 centers will still have to be determined.

Strengths of this study include the use of a dedicated training program within a multicenter setting in high-volume centers in close collaboration with the highly experienced UPMC group and the prospective data collection of this study with meticulous valuation of complications and readmissions.

In conclusion, a multicenter RPD training program was found to be feasible with acceptable outcomes during the early learning curve. No negative impact on patient outcomes of the first learning curve phase was detected. Future prospective, comparative studies should compare RPD with OPD and LPD to provide a more definitive answer with focus on the relatively high morbidity and mortality. Care should be taken, similar to LPD, to ensure safe implementation of RPD.

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REFERENCES

1. Gagner M, Pomp A. Laparoscopic pylorus-preserving pancreatoduodenec-tomy. *Surg Endosc*. 1994;8:408–410.
2. Giulianotti PC, Sbrana F, Bianco FM, et al. Robot-assisted laparoscopic pancreatic surgery: Single-surgeon experience. *Surg Endosc*. 2010;24:1646–1657.
3. van Hilst J, De Rooij T, Bosscha K, et al. Laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours (LEOP-ARD-2): a multicentre, patient-blinded, randomised controlled phase 2/3 trial. *Lancet Gastroenterol Hepatol*. 2019;4:199–207.
4. Poves I, Burdío F, Morató O, et al. Comparison of perioperative outcomes between laparoscopic and open approach for pancreatoduodenectomy: the PADULAP randomized controlled trial. *Ann Surg*. 2018;268:731–739.
5. Palanivelu C, Senthilnathan P, Sabnis SC, et al. Randomized clinical trial of laparoscopic versus open pancreatoduodenectomy for periampullary tumours. *Br J Surg*. 2017;104:1443–1450.
6. Shyr BU, Chen SC, Shyr YM, et al. Learning curves for robotic pancreatic surgery-from distal pancreatectomy to pancreaticoduodenectomy. *Medicine*. 2018;97:1–8.
7. Chen S, Chen JZ, Zhan Q, et al. Robot-assisted laparoscopic versus open pancreaticoduodenectomy: a prospective, matched, mid-term follow-up study. *Surg Endosc*. 2015;29:3698–3711.
8. Zureikat AH, Beane JD, Zenati MS, et al. 500 minimally invasive robotic pancreatoduodenectomies: one decade of optimizing performance. *Ann Surg*. 2021;273:966–972.

9. Napoli N, Kauffmann EF, Palmeri M, et al. The learning curve in robotic pancreaticoduodenectomy. *Dig Surg*. 2016;33:299–307.
10. Takahashi C, Shridhar R, Huston J, et al. Outcomes associated with robotic approach to pancreatic resections. *J Gastrointest Oncol*. 2018;9: 936–941.
11. Shi Y, Wang W, Qiu W, et al. Learning curve from 450 cases of robot-assisted pancreaticoduocectomy in a high-volume pancreatic center: optimization of operative procedure and a retrospective study. *Ann Surg*. 2021;274:e1277–e1283.
12. Guerra F, Checcacci P, Vegni A, et al. Surgical and oncological outcomes of our first 59 cases of robotic pancreaticoduodenectomy. *J Visc Surg*. 2019;156:185–190.
13. Marino MV, Podda M, Pisanu A, et al. Robotic-assisted pancreaticoduodenectomy: technique description and performance evaluation after 60 cases. *Surg Laparosc Endosc Percutaneous Tech*. 2020;30:156–163.
14. De Rooij T, Van Hilst J, Boerma D, et al. Impact of a nationwide training program in minimally invasive distal pancreatectomy (LAELAPS). *Ann Surg*. 2016;264:754–762.
15. de Rooij T, van Hilst J, Topal B, et al. Outcomes of a multicenter training program in laparoscopic pancreatoduodenectomy (LAELAPS-2). *Ann Surg*. 2019;269:344–350.
16. Nota CL, Zwart MJ, et al. Developing a robotic pancreas program: the Dutch experience. *J Vis Surg*. 2017;3:106–1106.
17. Hogg ME, Tam V, Zenati M, et al. Mastery-based virtual reality robotic simulation curriculum: the first step toward operative robotic proficiency. *J Surg Educ*. 2017;74:477–485.
18. Tam V, Zenati M, Novak S, et al. Robotic pancreatoduodenectomy biotissue curriculum has validity and improves technical performance for surgical oncology fellows. *J Surg Educ*. 2017;74:1057–1065.
19. Jones LR, Zwart MJW, Molenaar IQ, et al. Robotic pancreatoduodenectomy: patient selection, volume criteria, and training programs. *Scand J Surg*. 2020;109:29–33.
20. von Elm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Int J Surg*. 2014;12:1495–1499.
21. Asbun HJ, Moekotte AL, Vissers FL, et al. The Miami international evidence-based guidelines on minimally invasive pancreas resection. *Ann Surg*. 2020;271:1–14.
22. Vining CC, Hogg ME. How to train and evaluate minimally invasive pancreas surgery. *J Surg Oncol*. 2020;122:41–48.
23. Smits FJ, Van Santvoort HC, Besselink MG, et al. Management of severe pancreatic fistula after pancreatoduodenectomy. *JAMA Surg*. 2017;152: 540–548.
24. Bressan AK, Wahba M, Dixon E, et al. Completion pancreatectomy in the acute management of pancreatic fistula after pancreaticoduodenectomy: a systematic review and qualitative synthesis ofthe literature. *Hpb*. 2018;20:20–27.
25. Hogg ME, Besselink MG, Clavien PA, et al. Training in minimally invasive pancreatic resections: a paradigm shift away from "see one, do one, teach one" *Hpb*. 2017;19:234–245.
26. Hogg ME, Zenati M, Novak S, et al. Grading of surgeon technical performance predicts postoperative pancreatic fistula for pancreaticoduodenectomy independent of patient-related variables. *Ann Surg*. 2016;264: 482–489.
27. Montagnini AL, Røsok BI, Asbun HJ, et al. Standardizing terminology for minimally invasive pancreatic resection. *Hpb*. 2017;19:182–189.
28. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg*. 2004;240:205–213.
29. Bassi C, Marchegiani G, Dervenis C, et al. The 2016 update of the International Study Group (ISGPS) definition and grading of postoperative pancreatic fistula: 11 Years After. *Surgery (United States)*. 2017;161:584–591.
30. Wente MN, Bassi C, Dervenis C, et al. Delayed gastric emptying (DGE) after pancreatic surgery: a suggested definition by the International Study Group of Pancreatic Surgery (ISGPS). *Surgery*. 2007;142:761–768.
31. Wente MN, Veit JA, Bassi C, et al. Postpancreatectomy hemorrhage (PPH)-An International Study Group of Pancreatic Surgery (ISGPS) definition. *Surgery*. 2007;142:20–25.
32. Besselink MG, van Rijssen LB, Bassi C, et al. Definition and classification of chyle leak after pancreatic operation: a consensus statement by the International Study Group on Pancreatic Surgery. *Surg (United States)*. 2017;161:365–372.
33. Koch M, Garden OJ, Padbury R, et al. Bile leakage after hepatobiliary and pancreatic surgery: a definition and grading of severity by the International Study Group of Liver Surgery. *Surgery*. 2011;149: 680–688.
34. Mangram AJ, Horan TC, Pearson ML, et al. Guideline for prevention of surgical site infection, 1999. Hospital Infection Control Practices Advisory Committee. *Infect Control Hosp Epidemiol*. 1999;20:250–278. quiz 279–80.
35. Washington K, Berlin J, Branton P, et al. Protocol for the examination of specimens from patients with carcinoma of the pancreas. *Cancer Protoc Templates*. 2016;1:1–17.
36. Campbell F, Cairns A, Duthie F, Feakins R. The Royal College of Pathologists. Minimum datasets for the histopathological reporting of pancreatic, ampulla of Vater and bile duct carcinoma. In: *Standards and Minimum Datasets for Reporting Cancers Duct Carcinoma*. 2019.
37. Edge SB, Compton CC. The american joint committee on cancer: The 7th edition of the AJCC cancer staging manual and the future of TNM. *Ann Surg Oncol*. 2010;17:1471–1474.
38. Sánchez-Velázquez P, Muller X, Malleo G, et al. Benchmarks in pancreatic surgery: a novel tool for unbiased outcome comparisons. *Ann Surg*. 2019;270:211–218.
39. van Rijssen LB, Koerkamp BG, Zwart MJ, et al. Nationwide prospective audit of pancreatic surgery: design, accuracy, and outcomes of the Dutch Pancreatic Cancer Audit. *Hpb*. 2017;19:919–926.
40. Kim MS, Kim WJ, Hyung WJ, et al. Comprehensive learning curve of robotic surgery: discovery from a multicenter prospective trial of robotic gastrectomy. *Ann Surg*. 2021;273:949–956.
41. Van Workum F, Stenstra MHBC, Berkelmans GHK, et al. Learning curve and associated morbidity of minimally invasive esophagectomy: a retrospective multicenter study. *Ann Surg*. 2019;269:88–94.
42. Markar SR, Mackenzie H, Lagergren P, et al. Surgical proficiency gain and survival after esophagectomy for cancer. *J Clin Oncol*. 2016;34: 1528–1536.
43. Hu Y, Jolissaint JS, Ramirez A, et al. Cumulative sum: a proficiency-metric for basic endoscopic training. *J Surg Res*. 2014;192:62–67.
44. Moekotte AL, Rawashdeh A, Asbun HJ, et al. Safe implementation of minimally invasive pancreas resection: a systematic review. *Hpb* 2020;22: 637–648.
45. Rice MK, Hodges JC, Bellon J, et al. Association of Mentorship and a Formal Robotic Proficiency Skills Curriculum With Subsequent Generations' Learning Curve and Safety for Robotic Pancreaticoduodenectomy. *JAMA Surg*. 2020;155:607–615.
46. Haney CM, Karadza E, Limen EF, et al. Training and learning curves in minimally invasive pancreatic surgery: from simulation to mastery. *J Pancreatol*. 2020;3:101–110.
47. Hogg ME, Zenati M, Novak S, et al. 2016 Scientific session of the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES), Boston, Massachusetts, USA, 16-19 March 2016. *Surg Endosc*. 2016; 30:317–324.
48. Kamarajah SK, Bundred JR, Marc OS, et al. A systematic review and network meta-analysis of different surgical approaches for pancreaticoduodenectomy. *Hpb*. 2020;22:329–339.
49. van der Geest LGM, van Rijssen LB, Molenaar IQ, et al. Volume-outcome relationships in pancreatoduodenectomy for cancer. *Hpb*. 2016;18:317–324.
50. Nimptsch U, Krautz C, Weber GF, et al. Nationwide in-hospital mortality following pancreatic surgery in Germany is higher than anticipated. *Ann Surg*. 2016;264:1082–1090.
51. McCulloch P, Altman DG, Campbell WB, et al. No surgical innovation without evaluation: the IDEAL recommendations. *Lancet*. 2009;374: 1105–1112.
52. Zureikat AH, Postlewait LM, Liu Y, et al. A multi-institutional comparison of perioperative outcomes of robotic and open pancreaticoduodenectomy. *Ann Surg*. 2016;264:640–649.
53. Klompmaker S, Van Hilst J, Wellner UF, et al. Outcomes after minimally-invasive versus open pancreatoduodenectomy: a pan-european propensity score matched study. *Ann Surg*. 2020;271:356–363.
54. Nota CLMA, Robotgeassisteerde Whipple-operatie: Resultaten van de eerste 100 ingrepen in Nederland. *Ned Tijdschr Geneeskd*.;163.
55. Nassour I, Tohme S, Hoehn R, et al. Safety and oncologic efficacy of robotic compared to open pancreaticoduodenectomy after neoadjuvant chemotherapy for pancreatic cancer. *Surg Endosc*. 2021;35: 2248–2254.

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56. Boone BA, Zenati M, Hogg ME, et al. Assessment of quality outcomes for robotic pancreaticoduodenectomy: identification of the learning curve. *JAMA Surg*. 2015;150:416–422.
57. Zureikat AH, Moser AJ, Boone BA, et al. 250 robotic pancreatic resections: safety and feasibility. *Ann Surg*. 2013;258:554–559.
58. Zhang T, Zhao ZM, Gao YX, et al. The learning curve for a surgeon in robotassisted laparoscopic pancreaticoduodenectomy: a retrospective study in a high-volume pancreatic center. *Surg Endosc*. 2019;33:2927–2933.
59. Dokmak S, Ftériche FS, Aussilhou B, et al. Laparoscopic pancreaticoduodenectomy should not be routine for resection of periampullary tumors. *JAm Coll Surg*. 2015;220:831–838.
60. Van Roessel S, Mackay TM, Van Dieren S, et al. Textbook outcome: nationwide analysis of a novel quality measure in pancreatic surgery. *Ann Surg*. 2020;271:155–162.
61. Sweigert PJ, Eguia E, Baker MS, et al. Assessment of textbook oncologic outcomes following pancreaticoduodenectomy for pancreatic adenocarcinoma. *J Surg Oncol*. 2020;121:936–944.
62. Onete VG, Besselink MG, Salsbach CM, et al. Impact of centralization of pancreatoduodenectomy on reported radical resections rates in a nationwide pathology database. *Hpb*. 2015;17:736–742.
63. Zhao Z, Yin Z, Hang Z, et al. A systemic review and an updated meta-analysis: Minimally invasive vs open pancreaticoduodenectomy. *Sci Rep*. 2017;7:1–8.