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Robotic versus laparoscopic distal pancreatectomy: a French prospective single-center experience and cost-effectiveness analysis

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Abstract

Background Benefits and cost-effectiveness of robotic approach for distal pancreatectomy (DP) remain debated. In this prospective study, we aim to compare the short-term results and real costs of robotic (RDP) and laparoscopic distal pancreatectomy (LDP).

Methods From 2011 until 2016, all consecutive patients underwent minimally invasive DP were included and data were prospectively collected. Patients were assigned in two groups, RDP and LDP, according to the availability of the Da Vinci® Surgical System for our Surgical Unit.

Results A minimally invasive DP was performed in 38 patients with a median age of 61 years old (44–83 years old) and a BMI of 26 kg/m^2 (20–31 kg/m^2). RDP group ($n=15$) and LDP group ($n=23$) were comparable concerning demographic data, BMI, ASA score, comorbidities, malignant lesions, lesion size, and indication of spleen preservation. Median operative time was longer in RDP (207 min) compared to LDP (187 min) ($p=0.047$). Conversion rate, spleen preservation failure, and perioperative transfusion rates were nil in both groups. Pancreatic fistula was diagnosed in 40 and 43% ($p=0.832$) of patients and was grade A in 83 and 80% ($p=1.000$) in RDP and LDP groups, respectively. Median postoperative hospital stay was similar in both groups (RDP: 8 days vs. LDP: 9 days, $p=0.310$). Major complication occurred in 7% in RDP group and 13% in LDP group ($p=1.000$). Ninety-days mortality was nil in both groups. No difference was found concerning R0 resection rate and median number of retrieved lymph nodes. Total cost of RDP was higher than LDP (13611 vs. 12509 €, $p<0.001$). The difference between mean hospital incomes and costs was negative in RDP group contrary to LDP group (−1269 vs. 1395 €, $p=0.040$).

Conclusion Short-term results of RDP seem to be similar to LDP but the high cost of RDP makes this approach not cost-effective actually.

Keywords Distal pancreatectomy · Left pancreatectomy · Laparoscopy · Robotic surgery · Robot-assisted surgery · Costs · Pancreatic surgery

The minimally invasive approach for pancreatic surgery represents a challenging field in abdominal surgery and has been applied for benign and low-grade malignant tumors of the left pancreas in the past two decade [1]. Despite a lack of randomized clinical trials, laparoscopic distal pancreatectomy (LDP) is nowadays accepted and recommended, when feasible, over the traditional open approach because of its clinical benefits in terms of pain, lower blood loss, and reduced length of stay. Laparoscopy for malignant tumors remains controversial, although some authors have reported no difference compared to the open approach [2–5].

Robotic technology was introduced 15 years ago with the aim to overcome some of the limits of classic laparoscopy.

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The principal advantages of robotic device include reduction of natural tremors, absence of fulcrum effect, three-dimensional and high-definition vision, seven degrees of freedom compared to three (Endowrist technology), and improved ergonomics for the surgeon. All these advantages are able to facilitate challenging procedures and to reduce open conversion [6–8].

It is well known that robotic surgery increases direct operative costs. On the other hand, it is also hypothesized that the robotic technology could potentially reduce postoperative complications, hospital stay, and consequently the overall costs [9]. In the current setting of resource constraint prevailing in most countries, information about the relative costs and effectiveness of interventions is of utmost importance both for hospitals and for third party payers [10].

The aims of this prospective study were to compare the short-term outcomes of patients undergoing laparoscopic or robot-assisted distal DP and to assess the relative costs and effectiveness of both approaches.

Patients and methods

Study design and population

From November 2011 to January 2016, all patients requiring distal pancreatectomy (DP) and eligible for minimally invasive approach in our public tertiary hospital were prospectively included. Patients were assigned either to laparoscopic (LDP) or robot-assisted (RDP) distal pancreatectomy depending on the availability of the Da Vinci Surgical System. This system was acquired by our center in 2012 and shared with the Departments of Urology and gynecologic surgery. The decision on when to perform a minimally invasive DP was taken by expert senior surgeons and was discussed in the context of a multidisciplinary institutional meeting. Indications for minimally invasive approach were neoplasms < 10 cm with benign or borderline features on cross-sectional imaging or adenocarcinomas without evidence of major vessel involvement as reported by many teams [11]. The Institutional Review Board approved this study.

Surgical procedure

In average, 50 pancreatic resections are performed each year in our department. All minimally invasive DP was done by experienced pancreatic surgeons (> 40 laparoscopic procedure) as previously described [12]. The spleen preservation was planned whenever possible. Splenic vessels were conserved as described by Kimura et al. [13]. Splenic conservation while sacrificing the splenic vessels (Warshaw technique [14]) was not performed in our series. In both LDP and RDP, the pancreas was transected with an Endo-GIA™ Tri-staple™ (Covidien, Medtronic) and purple reload. The distal transected pancreas was gently lifted and a medial-to-lateral dissection started. In case of splenic conservation, the splenic vein and artery were skeletonized from the isthmus toward the hilum of the spleen. This allowed both a lymphadenectomy and a step-by-step division of all the branches coming from the splenic vessels. In case of DP with splenectomy, first the splenic artery and then the vein were divided after the transection of the pancreas. This was followed by a medial-to-lateral dissection posterior to the splenic vein along the retroperitoneal plane according to Radical Antegrade Modular PancreatoSplenectomy procedure (RAMPS) in case of suspicion of pancreatic ductal adenocarcinoma [15]. Biologic glue (IFABOND™—Péters Surgical, France) was systematically apposed on the pancreas stump. A single non-aspirative drain was placed close the pancreas at the end of the procedure.

Outcomes and data source

Demographic and clinical data were recorded prospectively using a standardized case report form. Duration of operation was defined as the time between incision and closure. After surgery, all patients were seen daily by a physician until hospital discharge. Thoracoabdominopelvic CT scan with intravenous contrast injection was performed selectively in patients with suspected abdominal or thoracic complications. Pancreatic fistula (PF) was defined and classified according to the ISGPF [16]. A fluid collection was identified through CT scan or US as the presence of fluid > 5 cm in diameter, with or without clinical relevance. Early postoperative hemorrhage was defined according to the ISGPS [17]. Postoperative complications were stratified according to the Dindo–Clavien classification which defines major complications by a score of III or more [18]. Complications, readmissions, and operative mortality were considered as those occurring within 90 days of surgery, or at any time during the postoperative hospital stay [19].

Economic analysis

Economic analysis was performed from the hospital perspective according to French and international reporting guidelines evaluating direct medical costs during a 90-day period starting from the initial intervention [20]. For this purpose, hospital analytical accounting system was used to value each recorded hospital stay that has occurred during a 90-day period starting from the initial intervention. Analytical accounting was also used to retrieve the operating room (OR) use cost, which was the expected key expenditure item. Incomes and expenditures were indexed to the consumer price index. Costs were analyzed in Euros. Intraoperative

costs included OR use costs (OR staff were paid a fixed salary), anesthesiology costs, and surgical instrumentation including Da Vinci system costs. Since postoperative care was the same in both groups, extraoperative costs were calculated on the basis of a standard surgical hospital day according and by adding imaging costs, intensive care unit costs when required. Overall costs were calculated by adding intraoperative cost, extraoperative costs, and personnel costs. Cost of initial stay alone and total cost (initial hospitalization plus eventual rehospitalizations) were calculated for each patient.

Statistical analysis

Baseline characteristics, clinical outcomes, direct medical costs, and lengths of stay were compared between both periods using standard univariate statistical tests taking into account distributions. The mean with range or interquartile range (IQR) is reported for continuous variables, and absolute and relative frequencies are reported for categorical variables. Continuous variables were compared with non-parametric test (Mann–Whitney *U*). Categorical data were compared with Chi-square test or Fisher's exact test depending on size. A p value <0.05 was considered as statistically significant. Statistical analyses were performed using SPSS Statistics, Version 20.0, for Macintosh (IBM Corp, Armonk, NY) and the SAS software (SAS Institute, Cary, North Carolina).

Results

Patient and surgical data

A minimally invasive DP was performed in 38 patients (F: 26/M: 12). In particular, 15 patients underwent an RDP, and 23 patients an LDP. RDP group and LDP group were comparable concerning demographic data, BMI, ASA score, comorbidities, the rate of malignant lesions (65 vs. 66%, $p=0.9$), the mean lesion size (28 vs. 35 mm, $p=0.250$) and the indication of spleen conservation (86 vs. 52%, $p=0.065$). Table 1 summarizes the demographic data of the two groups.

Specific instrumentation used for RDP and LDP is detailed in Table 2 including estimation of total device costs for one patient (RDP: 968 € vs. LDP: 658 €). The mean length of surgery was 207 min for RDP and 187 min for LDP ($p=0.047$). RDP was associated with an increased operative time with a mean docking time of 20 min (±5). No difference was found concerning operative time after removing docking time for each patient (RDP 191 min vs. LDP 187 min; $p=0.127$) and after DP with or without spleen preservation whatever the approach. The general trends in length of surgery for RDP and LDP over the study period are detailed in Figs. 1 and 2, respectively. Length of surgery for RDP progressively decreased after five cases with stabilization around 200 min. No conversion to open procedure occurred in both groups. Planned spleen preservation was feasible in 13/13 patients (100%) and 12/13 patients (91%) in RDP and LDP groups, respectively ($p=1.000$). This unplanned splenectomy in LDP group was justified by strong adhesions between the tumor and splenic vessels in a patient with a benign mucinous cystic neoplasm. Mean intraoperative blood loss was 130 ml ± 43 in RDP group and 110 ml ± 80 in LDP group ($p=0.485$). Intraoperative transfusion was not necessary in both groups. Surgical data are detailed in Table 3.

Postoperative outcomes

Table 4 details postoperative results in both groups. A complicated postoperative course occurred in 5 patients in RDP group (33%) and 11 patients in LDP group (48%) ($p=0.505$). A PF was diagnosed in 40 and 43% of patients ($p=0.839$) and had more often a low clinical relevance (grade A) in 83 and 80% ($p=1.000$) in RDP and LDP groups, respectively. No postoperative hemorrhage occurred in 38 studied patients. Mean postoperative hospital stay was not different in both groups (RDP: 8 days vs. LDP: 9 days, $p=0.310$). A 90-day complication Dindo–Clavien (D–C) grade ≥ III was present in 1 patient (7%) in RDP group vs. 3 patients (13%) in LDP group ($p=1.000$) and was systematically associated with severe PF (grade C).

The only patient in RDP group with a grade ≥ III complication presented a severe sepsis due to a peripancreatic fluid collection requiring surgical drainage. The three patients in the LDP group with grade D–C ≥ III complication presented acute pancreatitis with multiple peripancreatic fluid collection requiring endoscopic and surgical drainage.

Readmission in the LDP group ($n=2$) was due to fever with peripancreatic fluid collection treated successfully by antibiotics. Ninety-day mortality was nil in both groups.

Histopathologic data are resumed in Table 1. No difference was found between two groups concerning R0 resection rates (RDP: 100% vs. LDP: 93%, $p=1.000$), overall mean number of resected lymph nodes (RDP: 6 vs. LDP: 7, $p=0.922$) and mean number after DP with splenectomy (RDP: 12 vs. LDP: 11, $p=0.863$).

Cost analysis

The economic analysis is presented in Table 5. Mean intraoperative costs were significantly higher after RDP (7070 vs. 3174 €, $p<0.001$). Extraoperative and personnel costs were lower in RDP group without statistical significance. The total 90-day cost including initial hospitalization and rehospitalization remained significantly

Table 1 Patient characteristics and histopathological data

	RDP, *n* (%)	LDP, *n* (%)	*p* Value
Sex			
Male	3 (20)	9 (39)	0.292
Female	12 (80)	14 (61)	
Age, years, mean (range)	57 (34–72)	66 (44–83)	0.070
ASA score			
I	8 (57)	5 (21)	0.072
II	7 (43)	18 (79)	
III	0 (0)	0 (0)	
IV	0 (0)	0 (0)	
BMI, kg/m^2, mean (range)	23 (19–31)	25 (20–34)	0.111
Previous abdominal surgery	2 (13)	5 (21)	0.680
Comorbidities			
Diabetes mellitus	1 (7)	3 (13)	0.632
Arterial hypertension	4 (27)	9 (39)	0.494
Dyslipidemia	1 (7)	5 (22)	0.362
Cardiovascular diseases	1 (7)	5 (22)	0.361
Obstructive lung disease	1 (7)	2 (8)	1.000
Renal insufficiency	1 (7)	1 (4)	1.000
Tabagism	4 (27)	5 (22)	1.000
Histopathologic data			
Endocrine tumor	8	8	0.321
Adenocarcinoma/on IPMN	2 (2)	7 (3)	0.275
Mucinous cystic neoplasm/malignant	2/0	3/0	1.000
Serous cystic neoplasm	1	1	1.000
Solid pseudopapillary neoplasm	1	0	1.000
Ectopic spleen	0	1	1.000
Acinar cells neoplasm	0	1	1.000
Others	1	2	1.000
Number of lymph nodes, mean (range)	6 (2–12)	7 (2–13)	0.922
Spleen-preserving DP	5 (0–8)	6 (0–7)	0.795
DP with splenectomy	12 (7–12)	11 (6–13)	0.863
Tumor size, mm, mean (range)	28 (5–60)	35 (18–80)	0.250
R0 resection	15 (100)	22 (96)	1.000

IPMN intraductal papillary mucinous neoplasms, *DP* distal pancreatectomy

Table 2 Details of specific instrumentation used for RDP and LDP including costs/patient

Instrumentation	Type of device	RDP	LDP
Cautery hook	Reusable[a]	102 €	–
Bipolar forceps	Reusable[a]	322 €	–
Large needle driver	Reusable[a]	263 €	–
Ultrasonic scalpel (Harmonic™, Ethicon Endo-Surgery, Cincinnati, OH)	Non-reusable	Not used	380 €
Linear staple (Endo-GIA™ Tristaple™, Covidien, Medtronic) +	Non-reusable	235 €	
Hem-o-lok™ clip (×6) and device (TFX Medical Ltd, RTP Durham, NC)	Reusable	18 €	
Aspiration	Non-reusable	25 €	
Total		965 €	658 €

[a]Reusable robotic instrumentation is restricted to 10 uses and 15 sterilizations

–, Standard reusable laparoscopic instruments

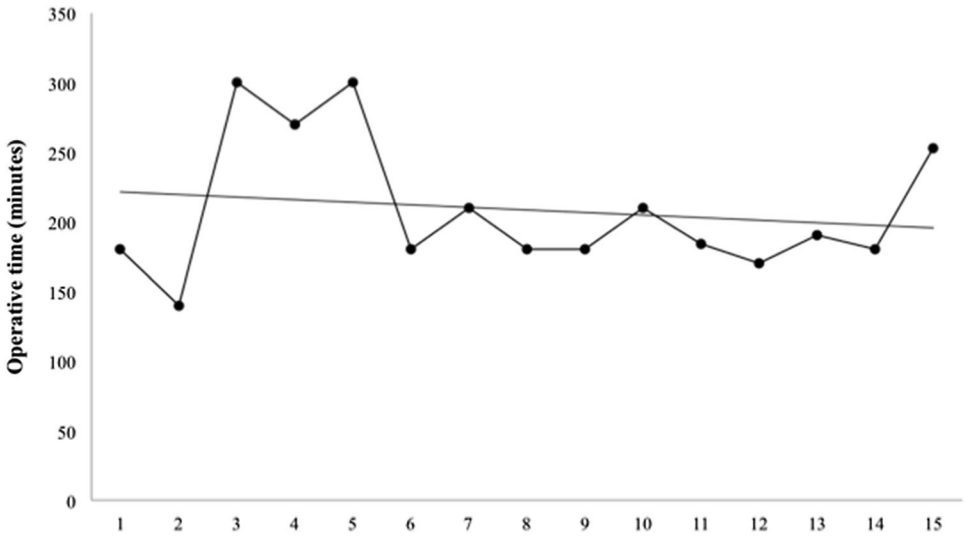

Fig. 1 Operative time for RDP over the study period

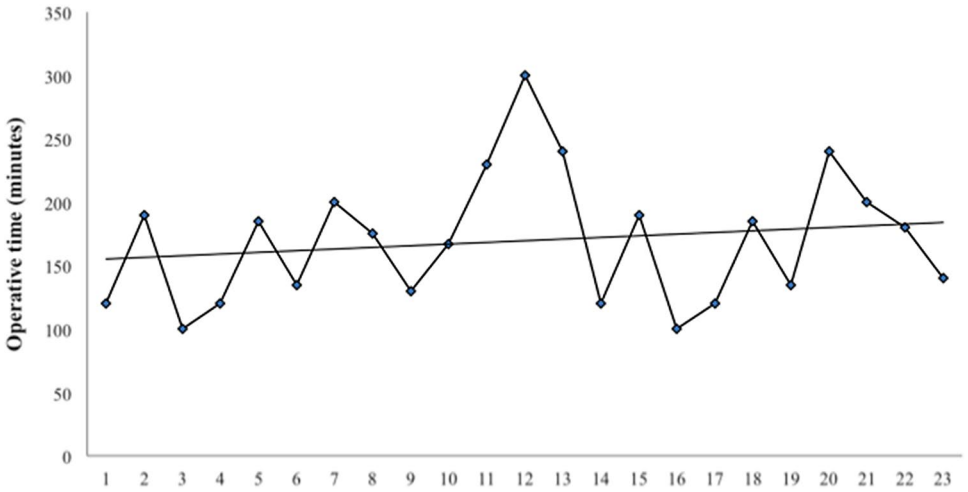

Fig. 2 Operative time for LDP over the study period

Table 3 Surgical data

	RDP, *n* (%)	LDP, *n* (%)	*p* Value
Length of surgery, min, mean (range)	207 (140–300)	187 (100–305)	0.047
DP without spleen preservation	276[a] (253–300)	210 (140–300)	0.090
DP with spleen preservation	198[a] (140–300)	151 (100–240)	0.257
Conversion to open procedure	0 (0)	0 (0)	0.245
Splenic preservation	13 (86)	12 (52)	0.065
Associated procedure	1 (7)	1 (4)	1.000
Blood loss, ml, mean (range)	130 (80–200)	110 (60–400)	0.485
Blood transfusion	0 (0)	0 (0)	1.000

[a]Including docking time

higher in RDP group (13,611 vs. 12,509 €, $p < 0.001$). Knowing that the hospital income was similar after RDP or LDP (different disease-related group but same procedure-based payments for both approaches), the ration between mean hospital income and costs was negative in RDP group contrary to LDP group (− 1269 vs. 1395 €, $p = 0.040$).

Table 4 Postoperative outcomes

	RDP, *n* (%)	LDP, *n* (%)	*p* Value
Length of stay, days, mean (range)	8 (6–15)	9 (6–18)	0.310
Postoperative complications	5 (33)	11 (48)	0.505
Complications Dindo–Clavien ≥ 3	1 (7)	3 (13)	1.000
Pancreatic fistula	6 (40)	10 (43)	0.832
Grade A	5 (83)	8 (80)	1.000
Grade B	0 (0)	1 (10)	1.000
Grade C	1 (17)	1 (10)	1.000
Peripancreatic fluid collection	2 (16)	6 (26)	1.000
Postoperative hemorrhage	0 (0)	0 (0)	1.000
Postoperative blood transfusion	0 (0)	0 (0)	1.000
Discharged with drain	1 (7)	3 (13)	1.000
Length of drainage, days, mean (range)	5 (4–21)	6 (5–60)	0.970
Pulmonary complications	1 (7)	3 (13)	0.632
Reoperation within 90 days	1 (7)	1 (4)	0.540
Readmission within 90 days	0 (0)	2 (9)	0.509
Postoperative mortality	0 (0)	0 (0)	1.000

Table 5 Economic analysis

Characteristics Median (± IQR)	RDP ($n=15$)	LDP ($n=23$)	*p* Value
Intraoperative costs (€)	6756 (± 537)	3089 (± 311)	< 0.001
Extraoperative costs (€)	4225 (± 1060)	5024 (± 2303)	0.090
Overall cost during initial stay (€)	13,119 (± 1462)	10,108 (± 1501)	< 0.001
Rehospitalization costs (€)	1785 (± 4985)	1739 (± 5337)	0.865
Overall cost (€)	13,998 (± 1987)	10,371 (± 2154)	< 0.001
Hospital income[a] (€)	11,388 (± 4228)	11,602 (± 5363)	0.984
Hospital income—costs (€)	− 1254 (± 3888)	1382 (± 3245)	0.040

[a]Disease-, procedure-related group and hospital stay-based payments

Discussion

The program of laparoscopic pancreatic surgery has begun in our department in 1998. Until now and for the all series 116 out of 569 procedures (20%) were carried out laparoscopically including DP, Whipple procedure, central pancreatectomy and enucleations. After passing the learning curve period, we routinely proposed the laparoscopic approach for DP firstly in selected benign or low-malignancy cases and later also for primary ductal adenocarcinoma. Consequently, 82 of 181 patients have had a LDP (45%) and 62 of 78 (80%) a spleen-preserving LDP. Our first case of robotic-assisted lap DP started in 2012. This prospective study aimed to compare LDP and RDP in a series of 38 consecutive and recent patients in order to provide high-quality cost data, given that previous published results are controversial and cost-effectiveness analysis are lacking [11, 21].

The LDP and RDP groups were comparable for mean age, lesion size on imaging, pathologic lesion size, final histopathologic diagnosis and prior history of upper abdominal surgery, which can potentially influence the level of operative difficulty and outcome. We did not find any significant difference with regard to blood-loss, the rate of conversion and splenic preservation. Nevertheless, patient with benign or borderline distal pancreatic lesion was more common in RDP group explaining the higher rate of DP with spleen preservation.

As previously reported, the mean operative time was longer of 30 min in the RDP group but was similar to LDP after removing the docking time of the robot suggesting that learning curve could be short for experimented laparoscopic surgeons [11, 22]. With respect to postoperative parameters, we also noted no significant difference between the two groups particularly for the rate and the severity of PF. These overall rates of PF (including grade A) are in the high range of available data in literature probably due to our systematic drain placement policy and the prospective study design [23]. Finally, the mean length of stay was slightly reduced by 1 day in the RDP group. These results translated that both

approaches were safe with no mortality when performed in a high-volume center. Furthermore, our results are in accordance with those from the first meta-analysis published by Gavriilidis et al. including 637 patients (246 robotic and 391 laparoscopic) which found that RDP had a significant shorter hospital LOS by 1 day, whereas all the other intra- and postoperative criteria were comparable [23].

As for LDP, we started RDP for benign and low-grade tumor, amenable to a spleen-preserving DP as described by Kimura. In that case, the mean number of lymph node harvested is significantly lower than RAMPS procedure. Nevertheless oncological parameters in terms of negative margin, lymph node harvested and R0 resection were also similar between groups, which confirmed that the two procedures did not compromised the quality of the resection and prognosis.

The main strength of the present study is its prospective cost analysis performed in collaboration with medico-economic experts at our medical information department. We found that intraoperative cost and total cost of RDP was more expensive than LDP (7070 vs. 3174 €, $p < 0.001$ and 13,611 vs. 12,509 €, $p < 0.001$; respectively) with a trend in lower hospital incomes in RDP group. We detailed specific instrumentation used for RDP that was inevitably more expansive than standardized instrumentation for LDP. Despite the length of surgery that has a strong impact on occupancy of operative room, surgical volume, and overall hospital incomes, OR staff were paid a fixed salary and this higher intraoperative cost is not to be related to the increased operative time of RDP. Postoperative protocols after RDP and LDP were similar and extraoperative costs were not different. The 1 day reduction of LOS and the absence of rehospitalization in the RDP group did not compensate the extra charges related to specific single use robotic devices [23]. Finally, the balance between hospital incomes (disease-, procedure-related groups and hospital stay based payments) and hospital costs was negative for RDP group compared to LDP group (− 1269 vs. 1395 €, $p = 0.040$) in our experience. The economic impact of the robotic approach is still under debate with controversial published studies [9, 11, 24]. Waters et al. found that robotics is associated with a shorter LOS (4 vs. 8 vs. 6 days) and lower overall costs (10.588 vs. 12.986 $), despite the more expensive equipment, when compared to laparoscopic approach [9]. At the contrary, Kang et al. analyzed a total of 45 patients (25 laparoscopic and 20 robotic) undergoing DP and showing that the RDP has higher intraoperative costs (8304 vs. 3861 USD) without significant difference concerning LOS (7.1 vs. 7.3 days) [24].

This higher cost of RDP could be explained by higher intraoperative cost and a higher rate of benign/borderline lesions justifying DP with spleen preservation in RDP group that led to lower hospital incomes (lower disease-, procedure-related group-based payment) even if we did not find significant difference on incomes. This key point makes us suggest that use of RDP should be enlarged to malignant pancreatic lesions to be cost-effective in our center actually. The development of LDP and RDP in surgery for malignant pancreatic ductal adenocarcinoma should lead to further costs analysis comparing both techniques in homogeneous cohort of patients requiring DP with splenectomy (higher disease, procedure-related group-based payment and hospital incomes).

This prospective medico-economic study has some limitations. The indications to minimally invasive approach for distal pancreatic lesions are not standardized and often purposed for easily resectable lesions. Maybe, the superiority of RDP over LDP will be more effective in case of complex pancreatic resection justifying further multicentric prospective studies. Although the criterion of the availability of the Da Vinci system for our unit reduced selection bias and gave us comparable groups, this method did not substitute a randomized study.

These findings may not be generalizable to all patients and centers performing LDP or RDP, especially in center with a low volume of pancreatic resection, a factor which is known to increase perioperative morbidity and mortality. In addition, our population was too small to permit a cumulative sum analysis on length of surgery and to identify inflexion points corresponding to the learning curve of RDP. Finally, the medico-economic data, especially hospital incomes, are specific of or own country and are not generalizable to other parts of the world.

To conclude, the feasibility and safety of RDP are established for routine pancreatic resection with no difference on operative time compared to LDP. Despite its limitations, this study shows that short-term results are similar to LDP and highlights the problem of the higher cost of RDP in the beginning stage of our robotic program. We agree with previous reports since it seems difficult to demonstrate a real superiority of one technique over the other in case of benign or borderline lesions. However, in view of promising oncologic results of minimally invasive pancreatic surgery, we do not think that robotic approach should be abandoned in response to its higher cost. Minimally invasive DP remains a challenging procedure and further prospective studies are required to compare learning curve of robotic vs. laparoscopic approach for young surgeons, especially when spleen preservation is indicated. Expecting an easier access and a cost reduction of this technology in the future, the advantages of robotic assistance could favor the minimally invasive DP by a larger cohort of pancreatic surgeons and expand the field of this approach to more complex corporeal or distal pancreatic lesions, so far treated by open surgery.

Compliance with ethical standards

Disclosures Drs. Regis Souche, Astrid Herrero, Guillaume Bourel, John Chauvat, Isabelle Pirlet, Françoise Guillon, David Nocca, Frederic Borie, Gregoire Mercier, and Jean-Michel Fabre have no conflicts of interest or financial ties to disclose.

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