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ORIGINAL ARTICLE

Cost comparison analysis of open versus laparoscopic distal pancreatectomy

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Abstract

Background: In comparison with open distal pancreatectomy (ODP), laparoscopic distal pancreatectomy (LDP) is associated with fewer complications and shorter hospital stays, but comparative cost data for the two approaches are limited.

Methods: Records of all distal pancreatectomies carried out from January 2009 to June 2013 were reviewed and stratified according to operative complexity. Patient factors and outcomes were recorded. Total variable costs (TVCs) were tabulated for each patient, and stratified by category [e.g. 'floor', 'operating room' (OR), 'radiology']. Costs for index admissions and 30-day readmissions were compared between LDP and ODP groups.

Results: Of 153 procedures, 115 (70 LDP, 45 ODP) were selected for analysis. The TVC of the index admission was US$3420 less per patient in the LDP group (US$10 480 versus US$13 900; $P = 0.06$). Although OR costs were significantly greater in the LDP cohort (US$5756 versus US$4900; $P = 0.02$), the shorter average hospitalization in the LDP group (5.2 days versus 7.7 days; $P = 0.01$) resulted in a lower overall cost. The total cost of index hospitalization combined with readmission was significantly lower in the LDP cohort (US$11 106 versus US$14 803; $P = 0.05$).

Conclusions: In appropriately selected patients, LDP is more cost-effective than ODP. The increased OR cost associated with LDP is offset by the shorter hospitalization. These data clarify targets for further cost reductions.

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Introduction

Since the first laparoscopic cholecystectomy was performed in 1985, minimally invasive techniques have gradually been adopted in many abdominal surgical procedures.[1] By using smaller incisions, the laparoscopic approach results in improved cosmesis, reduced postoperative pain, and quicker recovery for many patients.[2] Laparoscopic distal pancreatectomy (LDP) is the most commonly performed minimally invasive resection involving the pancreas.[3] Although it typically requires no anastomosis and is usually less technically demanding than laparoscopic pancreaticoduodenectomy, LDP still requires complex retroperitoneal access, careful dissection and the avoidance of injury to critical surrounding structures. The complexity of this operation varies tremendously according to the patient's body habitus, tumour type, and tumour location within the gland.

Recent literature comparing the safety and efficacy of LDP with those of open distal pancreatectomy (ODP) has demonstrated, in well-selected patients, lower intraoperative blood loss, reduced hospital length of stay (LoS) and decreased overall morbidity in LDP cohorts.[3–6] Although no randomized controlled trials comparing the two approaches have been conducted, retrospective

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comparisons suggest favourable postoperative outcomes in LDP patients, including reduced times to first flatus, oral intake, ambulation and weaning from i.v. pain medication, a decrease in the number of 30-day hospital readmissions, and no increase in the occurrence of postoperative pancreatic fistula (POPF).[3,4,7] Large, multicentre analyses of oncologic parameters in LDP and ODP have shown no significant differences in lymph node retrieval, numbers of positive nodes, or margin positivity.[8–10]

The question of the cost-effectiveness of LDP versus ODP has been investigated in a few small reports.[2,7,11–14] The data from these studies are mixed: there is a general consensus that the increased operative costs of LDP outweigh the benefit derived from the decreased hospital stay costs associated with the minimally invasive procedure. Furthermore, much of these data come from centres outside the USA, which makes extrapolation to domestic practice difficult. In this era of increased awareness of the costs of health care, issues not only of surgical safety and efficacy, but also of associated expenditure, must be considered with prudence. To explore this latter issue, a retrospective comparison of operative and hospital costs for both LDP and ODP was conducted at the Winship Cancer Institute, Emory University (Atlanta, GA, USA) to determine if LDP is indeed cost-effective in comparison with ODP.

Methods and materials

This study was compliant with Health Insurance Portability and Accountability Act requirements and was approved by the Emory University Institutional Review Board.

Patients

Records for all patients who underwent distal pancreatectomy (DP) from January 2009 to June 2013 at Emory University Hospital were retrospectively evaluated. Five experienced surgeons competent in minimally invasive techniques performed all open and laparoscopic resections. Cases were entered into a prospectively managed electronic database and matched with hospital 'encounter numbers', which are unique identifiers that correspond to each patient's entire hospital stay, allowing for compilation of cost information. Patients with both benign and malignant disease of the pancreas were included in the study. Routine blood tests and preoperative imaging, where appropriate, were performed. Prior to surgery, cases were presented to a multidisciplinary gastrointestinal tumour board consisting of surgeons, radiologists, medical oncologists, radiation oncologists and gastroenterologists. Patients were assessed for operative indications and feasibility, probability of operative success, and likelihood of recovery, prior to proceeding to surgery.

Definitions

Distal pancreatectomy was defined as a head-preserving formal pancreatic resection, with or without splenectomy. Both LDP and ODP were defined according to the surgical technique employed. In some LDP cases, a hand-assisted method was used according to surgeon preference. Patients in this study were further stratified by operative complexity as determined independently by two of the authors. 'Standard' complexity cases included resections of the distal pancreas with or without splenectomy, and with or without cholecystectomy. 'High' complexity cases involved additional organ resection beyond the gallbladder (stomach, colon, kidney, etc.) and were excluded from this analysis. More extensive resections of the pancreas (subtotal pancreatectomy or total pancreatectomy) or partial resections (enucleations) were also excluded. Conversions to an open procedure in which only the distal pancreas, spleen or gallbladder were removed were considered to represent cases of 'standard' complexity in keeping with an intent-to-treat analysis, but cases in which other organs were removed were excluded. Postoperative complications were classified using the previously described Clavien–Dindo scoring system.[15] The Charlson comorbidity index for each patient was calculated retrospectively to quantify comorbid conditions for analysis.[16] The presence of POPF was defined using the 2005 International Study Group on Pancreatic Fistula (ISGPF) criteria of drain output of any measurable volume on or after postoperative day 3 with an amylase level of more than three times the upper normal serum value.[17] All POPF were further classified as Grade A, B or C; fistulae of Grade B or C were denoted by the authors as 'clinically relevant'.

Operative technique

Detailed descriptions of the operative techniques used in LDP and ODP have been described elsewhere.[18,19]

Data analysed

Demographic, operative and perioperative data were collected for clinical comparison. Type of resection, intraoperative blood loss, operative time, hospital LoS, postoperative morbidity, and 30-day readmission rates were recorded.

Cost analysis

Cost data were acquired using unique 'encounter numbers' which corresponded to each patient's hospital stay. Total variable costs (TVCs) were compared between the two approaches as this cost metric provides the most accurate representation of direct hospital costs. For each patient, cost data were assessed by tabulating the costs of care for the hospital stay [e.g. floor, intensive care unit (ICU), operating room (OR), pharmaceutical, post-anaesthesia care unit, laboratory and pathology, and radiology costs]. Floor costs included nightly room expenses, food, wages and benefits for nurses, allied health professionals (physiotherapists, occupational therapists, rehabilitation services), and administrative staff, as well as building operational expenses (for heating, water supply and facilities management). Operating room costs included the costs of operative time (calculated per minute) and supplies as recorded using a computerized dispensing cabinet that corresponded to each patient's procedure (Pyxis ProcedureStation System; Cardi-

Table 1 Patient demographics and clinicopathologic characteristics of standard complexity laparoscopic and open distal pancreatectomies

Variable	LDP (n = 70)	ODP (n = 45)	P-value
Age, years, mean ± SD	58.6 ± 13.5	56.3 ± 16.1	0.40
Male gender, n (%)	24 (34%)	21 (47%)	0.26
Body mass index, kg/m^2, mean ± SD	27.9 ± 7.0	27.7 ± 5.9	0.84
Charlson comorbidity index, mean ± SD	1.79 ± 2.02	1.37 ± 1.67	0.26
ASA class, mean ± SD	2.57 ± 0.63	2.69 ± 0.51	0.36
Final pathology, n (%)			
Adenocarcinoma	11 (16%)	8 (18%)	0.97
Neuroendocrine tumour	18 (26%)	11 (24%)	1.00
Serous/mucinous cystadenoma	22 (31%)	8 (18%)	0.16
Intraductal mucinous	8 (11%)	3 (7%)	0.52
Chronic pancreatitis	8 (11%)	7 (16%)	0.72
Other (pseudopapillary tumour, pseudocyst)	3 (4%)	8 (18%)	0.02

LDP, laparoscopic distal pancreatectomy; ODP, open distal pancreatectomy; SD, standard deviation; ASA, American Society of Anesthesiologists.

nal Health, Inc., Dublin, OH, USA). Costs of operative equipment were also analysed, focusing on the usage of surgical staplers and energy devices. Laboratory and pharmaceutical costs were collected on a per-order basis. Similar data collection occurred for other categories. Costs were not adjusted for inflation. The TVCs for both the index admission and any 30-day hospital readmissions were considered for analysis.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows Version 21 (IBM Corp., Armonk, NY, USA). Differences in means between groups were compared using an independent-samples t-test. Categorical variables were analysed using the chi-squared test. Statistical significance was defined by a P-value of <0.05.

Results

Demographics and clinical outcomes

During the period from January 2009 to June 2013, of a total of 153 cases, 115 'standard complexity' DP procedures were performed at the study institution; 70 of these were laparoscopic resections. Demographic and clinicopathologic characteristics of the patient population are presented in Table 1. There were no significant differences between the LDP and ODP cohorts in patient age, gender, body mass index, Charlson comorbidity score, American Society of Anesthesiologists (ASA) class or preoperative laboratory values. The percentages of resections performed for malignancy and for chronic pancreatitis were similar in both groups.

Table 2 Intraoperative and postoperative results in standard complexity laparoscopic and open distal pancreatectomies

	LDP (n = 70)	ODP (n = 45)	P-value
Estimated blood loss, ml, mean ± SD	113 ± 155	210 ± 274	**0.03**
Length of surgery, min, mean ± SD	145 ± 61	136 ± 60	0.44
Intraoperative transfusion	1 (1%)	1 (2%)	0.75
Drains placed, n (%)	63 (90%)	40 (89%)	0.85
Hand assistance, n (%)	21 (30%)	NA	NA
Conversions to open, n (%)	5 (7%)	NA	NA
Tumour size, cm, mean ± SD	3.73 ± 2.82	4.71 ± 4.63	0.26
Length of pancreas removed, cm, mean ± SD	9.80 ± 3.09	10.56 ± 4.04	0.29
Number of nodes dissected, mean ± SD	7.54 ± 7.91	9.02 ± 9.21	0.36
Number of positive nodes (malignant cases only), mean ± SD	0.33 ± 1.30	0.22 ± 0.74	0.62
Morbidity, n (%)	34 (49%)	27 (60%)	0.31
Severe morbidity (Clavien score 3–5), n (%)	8 (11%)	8 (18%)	0.49
Clavien score for worst complication, mean ± SD	1.73 ± 0.83	2.00 ± 1.11	0.29
Pancreatic fistula (all grades), n (%)	25 (36%)	16 (36%)	0.99
Grade B/C fistula, n (%)	10 (14%)	6 (13%)	0.89
Hospital LoS, days, mean ± SD	5.2 ± 2.4	7.7 ± 5.8	**0.01**
Hospital LoS, days, median (range)	5 (1–18)	6 (2–30)	NA
30-day readmission, n (%)	9 (13%)	8 (18%)-	0.29

P-values in bold indicate differences of statistical significance (P < 0.05). LDP, laparoscopic distal pancreatectomy; ODP, open distal pancreatectomy; SD, standard deviation; LoS, length of stay; NA, not applicable.

Operating room

The average operative time was 9 min longer in the LDP group (145 min versus 136 min; P = 0.44) and average blood loss was significantly lower (113 ml versus 210 ml; P = 0.03) in the LDP cohort (Table 2). Intraoperative blood transfusion was required in only two patients, including one in each of the LDP and ODP cohorts. Closed suction drains were placed intraoperatively in a majority of patients in both the LDP and ODP groups. Average tumour size was smaller in patients undergoing LDP, but the difference was not significant (3.7 cm versus 4.7 cm; P = 0.26). The length of pancreas resected did not differ between the two groups. Nodal retrieval was similar among LDP and ODP patients.

Table 3 Cost comparison of standard complexity laparoscopic and open distal pancreatectomies

	Cost, US$, mean ± SD		
	LDP (n = 70)	ODP (n = 45)	P-value
TVC for index hospital stay	10 480 ± 2970	13 900 ± 11 600	0.06
Floor TVC	2590 ± 1250	3780 ± 2230	**<0.01**
Operating room TVC	5760 ± 1890	4900 ± 190	**0.02**
Laboratory/pathology TVC	790 ± 430	1170 ± 1000	**0.02**
Pharmacology TVC	720 ± 380	1660 ± 2550	**0.02**
Radiology TVC	120 ± 390	670 ± 2060	0.08
Intensive care unit TVC	170 ± 770	1310 ± 5160	0.15
TVC for index + readmission: all patients	11 110 ± 4220	14 800 ± 11 920	**0.05**

P-values in bold indicate differences of statistical significance ($P < 0.05$). SD, standard deviation; LDP, laparoscopic distal pancreatectomy; ODP, open distal pancreatectomy; TVC, total variable costs.

Table 4 Cost comparison for use of operative equipment in laparoscopic and open distal pancreatectomies

	LDP (n = 70)	ODP (n = 45)	P-value
Operating room equipment TVC, US$, mean ± SD	3370 ± 1720	2540 ± 1320	**<0.01**
Energy device use, n (%)	70 (100%)	22 (49%)	**<0.01**
Energy devices TVC, US$, mean ± SD	850 ± 360	330 ± 370	**<0.01**
Surgical stapler use, n (%)	69 (99%)	44 (98%)	1.00
Surgical staplers TVC, US$, mean ± SD	520 ± 280	780 ± 480	**<0.01**
Staple reload TVC, US$, mean ± SD	740 ± 450	1300 ± 940	**<0.01**
Surgical stapler + reloads TVC, US$, mean ± SD	1270 ± 590	2080 ± 1180	**<0.01**
Devices + surgical staplers (including reloads) TVC, US$, mean ± SD	2120 ± 760	2410 ± 1210	0.15
Operating room time TVC, US$, mean ± SD	1310 ± 490	1190 ± 540	0.22
Operating room, TVC, US$, mean ± SD	5760 ± 1890	4900 ± 1790	**0.02**

P-values in bold indicate differences of statistical significance ($P < 0.05$). LDP, laparoscopic distal pancreatectomy; ODP, open distal pancreatectomy; TVC, total variable costs; SD, standard deviation.

Postoperative outcomes

Rates of postoperative morbidity were similar among LDP and ODP patients (49% versus 60%; $P = 0.31$). Rates of major complications (Clavien–Dindo Grades III–V) were similar between the cohorts (11% versus 17%; $P = 0.49$). Most complications were minor and included prolonged nausea and vomiting, fever, and electrolyte imbalance. The mean Clavien–Dindo score for worst complication did not differ significantly between the groups (1.7 versus 2.0; $P = 0.29$). Rates of any POPF (36% versus 36%; $P = 0.99$) and clinically significant Grade B or C POPF (14% versus 13%; $P = 0.89$) were similar between the LDP and ODP cohorts. Of patients with POPF, nine (five in the LDP and four in the ODP cohort) required interventional radiology procedures to drain fluid collections. There were no mortalities in the 30-day postoperative period.

Hospital LoS was significantly shorter in the LDP group by 2.5 days (5.2 days versus 7.7 days; $P = 0.01$). Thirty-day readmission rates were similar between the LDP and ODP cohorts (13% versus 18%; $P = 0.29$).

Cost analysis

The TVC for the entire index hospital stay was lower in the LDP group than the ODP group by US$3420 (US$10 480 versus US$13 900; $P = 0.06$) per patient. Cost analysis (Table 3) demonstrated that although the operative costs of laparoscopic cases were significantly higher (US$5760 ± 1890 versus US$4900 ± 1790; $P = 0.02$), these increased costs were offset by decreased floor (US$2590 ± 1250 versus US$3780 ± 2230; $P < 0.01$), laboratory and pathology ($P = 0.02$), pharmacology ($P = 0.02$), radiology ($P = 0.08$) and ICU costs ($P = 0.15$). When total costs of index hospital admissions and readmissions were taken into account, LDP was found to be associated with significantly lower TVCs than ODP (US$11 110 ± 4220 versus US$14 800 ± 11 920; $P = 0.05$).

A detailed analysis of OR-related costs revealed that operative time-related TVCs were similar between the two cohorts (US$1310 ± 490 versus US$1190 ± 540; $P = 0.22$). In the present series, energy devices [the Harmonic Scalpel (Ethicon Endo-Surgery, Inc., Cincinnati, OH, USA) and the Autosonix Ultrasonic Surgical System (Covidien, Inc., Mansfield, MA, USA)] were used in 100% of LDP procedures but in only 49% of ODP procedures ($P < 0.01$) (Table 4). The cost of using these devices in LDP in comparison with ODP (US$850 ± 363 versus US$330 ± 360; $P < 0.01$) contributed to the significantly greater total OR costs accrued in the LDP cohort. Compared with LDP, ODP procedures made more frequent use of surgical staplers ($P = 0.001$) and employed a higher number of stapler reloads ($P < 0.01$). Despite the lower overall TVC, the use of staplers and their reloads represented the principle contributor to ODP TVC (US$2080 ± 1180 versus US$1270 ± 590; $P < 0.01$).

Laparoscopic hand assistance

In 21 (30%) laparoscopic procedures a hand-assist approach was utilized. Intraoperative, postoperative and cost outcomes were compared between pure LDP and LDP with hand assistance (LHDP) (Table 5). Intraoperatively, LDP was associated with significantly less blood loss (76 ml versus 197 ml; $P = 0.04$) and resection of smaller tumours (3.07 cm versus 5.15 cm; $P < 0.01$) compared with LHDP. The remaining operative and postoperative

Table 5 Intraoperative and postoperative results of laparoscopic and laparoscopic hand-assisted distal pancreatectomies

	LDP (n = 49)	LHDP (n = 21)	P-value
Estimated blood loss, ml, mean ± SD	76 ± 71	197 ± 244	**0.04**
Length of surgery, min, mean ± SD	138.40 ± 62.8	160.2 ± 55.8	0.19
Intraoperative transfusion, n (%)	0	1 (5%)	0.66
Drains placed, n (%)	44 (90%)	19 (90%)	1.00
Tumour size, cm, mean ± SD	3.07 ± 2.34	5.15 ± 3.30	**<0.01**
Size of pancreas removed, cm, mean ± SD	9.84 ± 3.21	9.70 ± 2.89	0.85
Number of LNs recovered, mean ± SD	7.3 ± 7.75	8.14 ± 8.45	0.69
Morbidity, n (%)	22 (41%)	12 (58%)	0.50
Severe morbidity (Clavien score 3–5), n (%)	6 (12%)	2 (10%)	1.00
Pancreatic fistula (all grades), n (%)	15 (31%)	10 (48%)	0.28
Grade B/C fistula, n (%)	6 (12%)	4 (19%)	0.71
Hospital LoS, days, mean ± SD	5.1 ± 2.1	5.6 ± 3.1	0.42
Hospital LoS, days, median (range)	5 (1–14)	5 (3–18)	NA
30-day readmissions, n (%)	6 (12%)	3 (14%)	1.00

P-values in bold indicate differences of statistical significance ($P < 0.05$). LDP, laparoscopic distal pancreatectomy; LHDP, laparoscopic hand-assisted distal pancreatectomy; SD, standard deviation; LN, lymph nodes; LoS, length of stay; NA, not applicable.

Table 6 Cost comparisons for laparoscopic and laparoscopic hand-assisted distal pancreatectomies

	Total variable cost, US$, mean ± SD		
	LDP (n = 49)	LHDP (n = 21)	P-value
Index hospital stay	10 030 ± 2610	11 540 ± 3500	**0.05**
Floor	2540 ± 1280	2690 ± 1580	0.65
Operating room	5510 ± 1300	6340 ± 2790	0.09
Laboratory/pathology	730 ± 330	940 ± 590	0.06
Pharmacology	690 ± 350	780 ± 460	0.42
Radiology	70 ± 150	230 ± 670	0.11
Intensive care unit	140 ± 800	230 ± 730	0.66
Index + readmission: all patients	10 840 ± 4490	11 730 ± 3540	0.42
Readmissions only	6590 ± 7770	1990 ± 490	0.46

P-values in bold indicate differences of statistical significance ($P < 0.05$). SD, standard deviation; LDP, laparoscopic distal pancreatectomy; LHDP, laparoscopic hand-assisted distal pancreatectomy.

factors, including morbidity, fistula incidence, hospital LoS and 30-day readmission rate, were similar across LDP and LHDP. For each of the cost categories examined, LDP was less costly than LHDP, although the differences were not significant (Table 6). However, the TVC for the entire index hospital stay for LDP was US$1510 lower than that for LHDP, demonstrating a statistically significant difference (US$10 030 versus US$11 540; $P = 0.048$). Furthermore, when the TVCs of the 49 LDP cases (excluding the 21 hand-assisted cases) were compared with those of the 45 ODP cases, the total cost of the index hospital admission was found to be statistically significantly lower in LDP than in ODP (US$10 030 versus US$13 900; $P = 0.03$).

Discussion

As a result of improvements in technology and growing surgeon experience, the performance of LDP continues to increase. The present study sought to establish a comprehensive cost comparison analysis between open and laparoscopic DP in well-matched patients at a high-volume academic centre.

The current results demonstrate that in well-selected patient populations, LDP can be performed safely with complication rates similar to those observed after open procedures. Although it is associated with higher operative costs than ODP, LDP has a lower overall cost as a result of the decreased hospital LoS. The increases in OR costs in laparoscopic cases were largely accounted for by the use of expensive energy dissection equipment that was not routinely utilized in open cases.

In order to strengthen the clinical applicability of the present analysis, left-sided pancreatic resections, both open and laparoscopic, were stratified according to operative complexity. This allowed for more effective matching of surgical complexity, and the validity of this approach was supported by results demonstrating comparable patient demographics, preoperative laboratory values, and comorbidity indices across the LDP and ODP cohorts.

Recent meta-analyses of comparisons of operative times for LDP and ODP in the published literature have not demonstrated statistically significant differences.[3–6,20] In one such meta-analysis of 18 studies involving 1814 patients, the laparoscopic approach added an additional 19.71 min to the time required for the open technique.[3] The present results support these conclusions as LDP procedures required an additional 9 min of operative time on average. Surgeon expertise and careful patient selection are likely to contribute to this comparability of operative times. Other operative results demonstrated equivalence between the two cohorts. Traditionally, LDP has been used for smaller, benign tumours or indolent malignancies. In an analysis of 360 DPs, DiNorcia *et al.* reported a shorter mean ± standard deviation average length of pancreas resected (7.7 ± 3.2 cm versus 10.0 ± 3.6 cm; $P < 0.01$) and a smaller median tumour size of 2.5 cm [interquartile range (IQR) 1.5–4.0 cm] versus 3.6 cm (IQR 2.0–6.0 cm) ($P < 0.01$) in patients operated by LDP compared with those submitted to ODP.[21] In that series, the laparoscopic approach was used significantly less often in patients with adeno-

carcinoma (4% versus 30%; $P < 0.01$).[21] In the current series, average tumour size and the percentage of resections performed for adenocarcinoma did not differ significantly between the LDP and ODP cohorts.

Postoperatively, the LDP and ODP cohorts exhibited similar rates of complications and comparable severity of morbidity, a pattern reflected in previous publications.[3,5,8,21,22] In their meta-analysis of 18 studies comparing LDP versus ODP, Venkat *et al.* reported an average rate of postoperative morbidity in the LDP group ($n = 780$) of 33%, compared with 44% in the ODP cohort ($n = 1034$).[3] Notably, rates of POPF were nearly identical between the LDP and ODP cohorts in the present study, including those of clinically significant (Grades B and C) fistulae.

Consistent with previous studies, the present study showed a significant decrease in hospital LoS in the LDP group. This can probably be attributed to earlier weaning from i.v. pain medication, earlier return of bowel function, and earlier ambulation. In a multicentre analysis of 637 DPs, which included 159 laparoscopic procedures, the Central Pancreas Consortium (CPC) demonstrated a significantly shorter hospital LoS in the LDP group compared with the ODP group (5.9 days versus 9.0 days; $P < 0.01$).[8] An important aspect of this earlier work is that five of the eight participating centres in this study did not use a laparoscopic approach and thus the comparison is more likely to be valid. Other authors have shown similar trends, with decreases of 2.7–5.0 days in hospital LoS for LDP compared with ODP.[3,5,23]

The decrease in the average hospital stay in the LDP cohort appears to be the driving factor in the cost disparity between LDP and ODP in the present series. In the current analysis, the costs of perioperative care for patients in the LDP cohort were lower in each of the defined cost categories. Decreased hospital LoS appears to uniformly drive down all costs associated with the postoperative management of LDP patients. In a detailed cost analysis of LDP versus ODP at a high-volume Canadian centre, Fox *et al.* reported similar findings with regard to the contribution made by a decrease in hospital LoS to the lowering of the total costs of LDP.[12] The results of that study demonstrated a linear relationship between hospital LoS and total cost, in concordance with the present findings. The implication is that factors traditionally associated with laparoscopic surgery, such as decreased postoperative pain and early ambulation, also promote a lower cost of care by earlier patient discharge. Although the cost difference per patient between LDP and ODP in the index hospital admission did not reach statistical significance, when the total costs of index and 30-day readmissions are factored into the analysis, LDP emerges as significantly less costly. As both cohorts had similar rates of 30-day readmission, the explanation for this cost differential may lie in the nature of postoperative complications or reasons for readmission. Readmission after pancreatic surgery has been subject to previous investigation. In a multi-institution study of 1302 patients submitted to pancreaticoduodenectomy, Ahmad *et al.* examined factors influencing readmission rates for that procedure.[24] They found that higher readmission rates were associated with a preoperative diagnosis of chronic pancreatitis, higher transfusion requirements, and postoperative complications including intra-abdominal abscess and pancreatic fistula (all: $P < 0.02$).[24] In their conclusion, the authors noted that factors related to infection, delayed gastric emptying, and the optimization of nutrition were the most common reasons for readmission in the 30- and 90-day periods.[24] In the present series, the most common cause for readmission within 30 days of surgery in both the ODP and LDP cohorts was infection-related ($n = 4$ in the ODP group; $n = 5$ in the LDP group). A more detailed analysis of readmission was beyond the scope of the current analysis, but is an area of ongoing investigation.

The present analysis of LHDP versus LDP showed that intraoperative blood loss and tumour resection size were decreased in purely laparoscopic cases. Although the subcategories of costs did not differ significantly between LDP and LHDP, LDP showed an overall cost advantage because the total cost of care for an LDP patient was US$1500 lower than that for an LHDP patent. As hospital LoS was similar in both groups, this cost disparity reflects small differences that are likely to relate to the increased complexity of hand-assisted cases. When the hand-assist procedures were removed from analysis and data for the 49 LDP procedures were compared directly with data for the 45 ODP procedures, the TVC for the index hospitalization was found to be significantly (US$3900) lower in LDP ($P = 0.03$). Other retrospective series and one case–control study have examined the cost-effectiveness of LDP and most studies have demonstrated no significant difference in the total cost of care in LDP compared with ODP (Table 7). In a Canadian series, the authors excluded multiple organ resections (stomach, colon, kidney) and focused on DP with or without splenectomy in a manner similar to the stratification used in the present study.[12] Their perioperative and cost findings were similar to those of the present study, although their analysis did not include readmissions. Limongelli *et al.* similarly excluded complicated procedures but found the two surgical approaches to be cost neutral overall.[7] A Korean case–control study reported a significantly higher total cost of care associated with LDP.[13] These data should be interpreted with caution, however, as the hospital LoS for patients in both the LDP and ODP cohorts was significantly longer than in any other published report (11.5 ± 4.1 days for LDP, 13.5 ± 4.9 days for ODP).[13] Additionally, no breakdown of operative and postoperative costs was included in the Korean analysis.[13]

Other recent cost analyses comparing laparoscopic and open surgical procedures have supported the cost-effectiveness of laparoscopic procedures. An extensive literature review by Park *et al.* comparing the costs of 949 laparoscopic partial nephrectomies (LPNs) with those of 574 open partial nephrectomies found that minimally invasive procedures accrued greater costs in the OR as a result of the use of equipment such as trocars and shears, and haemostasis agents.[25] However, the overall cost of care for LPN was offset by a significantly shorter hospital

Table 7 Summary of data in the literature on cost analyses for laparoscopic and open distal pancreatectomies

Study	Patients, *n*		Study design	Currency	Operative cost			Total cost of index hospital stay		
	LDP	ODP			LDP	ODP	*P*-value	LDP	ODP	*P*-value
Current series	70	45	RA	US$	5760 ± 1890	4900 ± 1790	**0.02**	10 480 ± 2970	13 900 ± 11 600	0.06
Fox *et al*. (2012)[12]	42	76	RA	Can$	4660 (4330–5510)[a]	4510 (3750–5420)[a]	0.44	10 840 (9350–12 840)[a]	13 660 (11 470–16 640)[a]	**<0.01**
Abu Hilal *et al*. (2012)[11]	35	18	RA	GBP	6040 (4276–9500)	5230 (3409–9330)	**0.03**	10 590 (6510–20 300)	15 320 (7210–47 480)	0.20
Limongelli *et al*. (2011)[7]	16	29	RA	€	2890 ± 100	1990 ± 300	**<0.01**	9600 ± 1600	10 990 ± 3020	0.20
Waters *et al*. (2010)[14]	28	32	RA	US$	3070	3510	NS	12 900	15 520	0.26
Kim *et al*. (2008)[27]	93	35	RA	10 000 won	NR	NR	NA	530 ± 160[a]	550 ± 320[a]	0.58
Eom *et al*. (2008)[13]	31	62	Case–control	US$	NR	NR	NA	4880 ± 1850	3400 ± 1250	**<0.01**

[a]Median values.
P-values in bold indicate differences of statistical significance ($P < 0.05$).
LDP, laparoscopic distal pancreatectomy; ODP, open distal pancreatectomy; NA, not applicable; NR, not reported; NS, not significant; RA, retrospective analysis.

LoS (2.9 days versus 5.7 days; $P < 0.01$), which led the authors to conclude that LPN is a more cost-effective approach.[25] Nguyen *et al*. reported similar findings in their analysis of 79 laparoscopic gastric bypasses and 76 open bypass procedures conducted within the UK health care system.[26] Patients in the laparoscopic group experienced lower operative blood loss and a shorter hospital LoS, and accrued lower overall hospital costs despite higher OR costs.[26]

The present detailed analysis of equipment expenditures showed that the use of energy devices (the Harmonic Scalpel and the Autosonix Ultrasonic Surgical System) was universal in the laparoscopic cohort and that the average number of devices used in LDP totalled three times that employed in open procedures. These devices cost on average an additional US$500 per case and represent the principal factors contributing to the higher costs of laparoscopic cases. However, surgical stapler use was higher in the ODP group, in which high numbers of stapler reloads represented the major cost burden. The increased use of staplers in open cases may possibly reflect larger pancreatic specimen resections that require more firings to adequately seal the remnant. Increased surgeon awareness of the contributions to costs made by the use of these energy devices and multiple staple reloads may represent a strategy for reducing OR costs.

The limitations of the present study include its retrospective nature and the potential for selection bias. The system used to stratify DP cases as being of 'standard' versus 'high' complexity based on technical difficulty was subjective and was based on the analysis of operative notes. Similar classification schemes have been employed previously and all cases were reviewed independently by two authors to standardize stratification. Another inherent limitation of this analysis, as with all other published series on LDP and ODP, is the lack of randomization; some patient selection bias may have occurred as some of the comparison ODP cases may not have been suitable for a laparoscopic approach. The present study encompassed several surgeons with different OR techniques and equipment preferences, which may have contributed to the variability seen in the cost analysis of OR device use.

The present study did not include a robust analysis of indirect costs such as surgeons' professional fees. These were difficult to ascertain and were excluded. The authors instead relied on direct costs and itemized expense reports for each patient's admission, sourced from hospital departments, in order to assemble cost data. Personnel fees were included in some of the cost data (e.g. ward fees included nursing fees, and occupational therapy included professional fees), but this was not universal (e.g. laboratory worker fees were not included in laboratory costs).

Conclusions

Laparoscopic DP is best suited to patients in whom tumours are contained in the body and tail of the pancreas, and appears to provide outcomes similar to those of open resection, with no increase in complications, lower blood loss, and shorter hospital stays for cases of similar difficulty. For appropriately selected patients, the laparoscopic approach to DP appears to be more cost-effective than the open approach and was associated with lower costs for index hospital admissions and readmissions. The increased OR cost associated with LDP is offset by the shorter hospitalization and lower overall cost of care. These data provide guidelines for further cost reduction strategies.

Conflicts of interest

None declared.

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