Effect of Hospital Volume, Surgeon Experience, and Surgeon Volume on Patient Outcomes After Pancreaticoduodenectomy

A Single-Institution Experience

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Objective: To determine the importance of hospital volume, surgeon experience, and surgeon volume in performing pancreaticoduodenectomy (PD).

Design, Setting, and Patients: From 1980 through 2007, 1003 patients underwent PD by 19 surgeons at a university hospital.

Main Outcome Measures: Patient morbidity and mortality, quality of resection, and learning curve were examined according to hospital volume (period 1: 1980-2003 vs period 2: 2004-2007), surgeon experience (total number of PDs), and surgeon volume (number of PDs per year).

Results: Perioperative morbidity and mortality for all 1003 PDs were 41% and 3%, respectively. Differences existed between period 1 and period 2 in percentage of PDs performed in elderly patients (7% vs 17%), mortality (4% vs 2%), estimated blood loss (1817 mL vs 780 mL), length of stay (18 days vs 12 days), and proportion of International Study Group on Pancreatic Fistula grade C pancreatic fistulae (29% vs 12%). Surgeons with less experience (<50 PDs) performed PD with higher morbidity (53% vs 39%), pancreatic fistula rate (20% vs 10%), estimated blood loss (1918 mL vs 1101 mL), and operative time (458 minutes vs 335 minutes) compared with surgeons with more experience (≥50 PDs). Experienced surgeons had comparable outcomes irrespective of annual volume. Mortality, margins, and number of lymph nodes resected were not affected by surgeon experience or surgeon volume. Learning curves projected that less experienced surgeons would achieve morbidity and mortality rates equivalent to those of experienced surgeons when they reached 20 and 60 PDs, respectively.

Conclusions: Improvement in PD outcomes, including mortality, occurred with increased PD volume at a pancreatic center. Surgeon experience remained an important determinant of overall morbidity. Experienced surgeons, however, had comparable outcomes irrespective of annual volume.

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EVIDENCE SUGGESTS THAT COMplex surgical procedures can result in improved outcomes when performed in centers with high volume. Compelling data now exist to indicate that mortality, survival, and overall life expectancy are improved when pancreaticoduodenectomy (PD) is performed in high-volume centers.[1-6] This may explain in part why increasing numbers of patients undergo PD at these types of institutions.[7,8]

Despite the apparent regionalization of PD, a significant number of patients continue to undergo PD at low-volume centers.[8] In addition, although the overall outcomes of PD are improved at high-volume centers, significant differences in outcomes of PD exist among these institutions.[9] Within high-volume centers, there are also major differences in individual surgeons' experience and volume. Surgeon volume in pancreatic surgery has been linked to mortality and may explain a part of the apparent institutional volume effect.[3,10]

Despite improvements due to regionalization, PD remains a complex procedure associated with high perioperative morbidity and potential mortality. Strong evidence exists for a volume-outcome relationship in which high-volume centers have a reduced perioperative morbidity and mortality rate, although the exact mechanism (surgeon-related factors vs system-related factors) for this association remains unclear. The aim of this study was to determine the effects of hospital volume, surgeon experience, and surgeon volume on postoperative clinical outcomes in patients undergoing PD at a single academic institution performing a high volume of pancreatic surgery. The learning

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curve for individual surgeons was compared with the overall institutional experience during the same time frame in an attempt to isolate the surgeon contribution to overall outcome.

METHODS

DESIGN, SETTING, AND PATIENTS

From 1980 through December 31, 2007, 1003 PDs were performed by 19 surgeons for a variety of pancreatic pathologies at Indiana University Hospital (IUH). Data were obtained by retrospective review of a prospectively collected clinical database. For historical purposes, this database was prospectively maintained by a single experienced, high-volume pancreas surgeon (James A. Madura, MD) until 2001 and has subsequently been maintained by one of us (C.M.S.). Supplemental data for this study were obtained by office and electronic medical record reviews, the IUH/Clarian Cancer Registry, and the United States Death Index. This study was conducted in strict compliance with the Indiana University Institutional Review Board.

EXPERIENCE AND VOLUME VARIABLES

Surgeon experience was determined by counting the overall number of PDs performed at IUH during the 2 study periods. Surgeons who performed 50 or more PDs during the 2 periods were defined as experienced surgeons. Notably, 3 of these experienced surgeons had performed PD at another institution before performing more than 50 PDs at IUH. Less experienced surgeons were defined as having performed fewer than 50 PDs. None of the less experienced surgeons had performed PD at other institutions before performing PD at IUH. Surgeon volume was defined as the number of PDs performed annually by an individual surgeon. Low-volume surgeons were defined as performing a mean of fewer than 20 PDs per year. High-volume surgeons were defined as performing a mean of 20 or more PDs per year. Complexity of PD performed by individual surgeons is difficult to analyze retrospectively. As a surrogate marker, complexity of PD was assessed in this study by counting the number of PDs in which a portal vein reconstruction was performed as a function of surgeon experience and volume. Thoroughness or quality of resection in PD performed for periampullary cancer is equally difficult to analyze. As a surrogate marker, quality was assessed by counting the total number of resected lymph nodes identified by the pathologist and the margin status (positive vs negative) as a function of surgeon experience and volume.

LEARNING CURVE

We studied the learning curves of less experienced surgeons in period 2. Cut points were established empirically. Using 2-order polynomial equations in regression models (Microsoft Excel 2007; Microsoft Corp, Redmond, Washington) to investigate the effect of each successive operative experience on continuous and binary outcome variables, we calculated the incremental improvement toward various outcome measures that would be achieved by the less experienced surgeon group with the addition of each decile of PD (eg, 10 PDs, 20 PDs, or 30 PDs).[11] The goal of the analysis was to determine the number of PDs needed by less experienced surgeons in period 2 to meet or surpass the numerical mean of experienced surgeons in period 2 (note that *numerical equivalence* is not the same as *statistically significant*; ie, the achievement of numerical equivalence is a much more rigorous requirement).

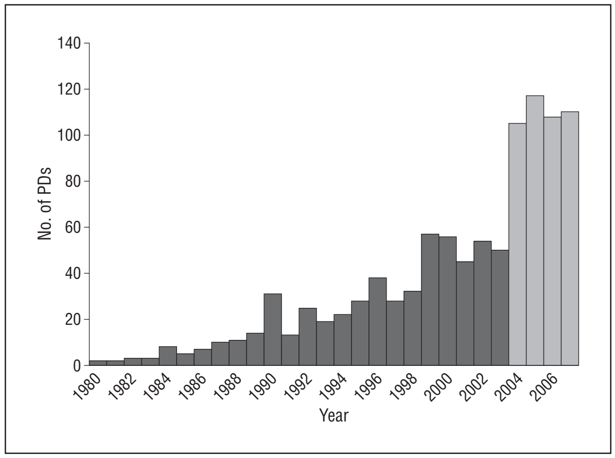

Figure 1. Annual volume of pancreaticoduodenectomy (PD) from 1980 through 2007 at Indiana University Hospital, Indianapolis.

OUTCOMES VARIABLES

We determined intraoperative blood loss, operating time (duration from incision to closure), mortality (death occurring in the hospital or within 30 days of operation), and overall morbidity (all major complications including but not limited to infectious, cardiopulmonary, and gastrointestinal complications). Pancreatic leak was categorized according to the International Study Group on Pancreatic Fistula (ISGPF) criteria.[12] Intra-abdominal abscesses were counted in pancreatic leak rates. Cardiopulmonary complications included myocardial infarction, arrhythmia, congestive heart failure, pneumonia, pulmonary embolus, and respiratory failure.

STATISTICAL ANALYSIS

Data analyses were carried out with GraphPad Prism (GraphPad Software, Inc, La Jolla, California) and Microsoft Excel 2007. Statistical associations between categorical factors were assessed using the Fisher exact test. Statistical associations between continuous variables were assessed with the *t* test for comparisons of 2 groups and analysis of variance for comparisons of multiple groups. Statistical significance was set at $P < .05$.

RESULTS

PERIOD COMPARISON

From 1980 through 2007, the annual volume of PD at IUH steadily increased, but it rapidly increased after 2003 (**Figure 1**). In light of this dramatic difference in annual PD volume, the demographics, pathologic indications for PD, and outcomes before and after this rapid increase in annual PD volume were compared (periods 1 and 2; **Table 1**).

Period 1 spanned from 1980 through 2003. During this period, 563 PDs were performed (mean, 24 per year) by 11 surgeons. Period 2 spanned from 2004 through 2007, when 440 PDs were performed (mean, 110 per year) by 8 surgeons.

An analysis of the demographics of the 2 periods revealed a significantly greater mean age of patients in period 2 compared with period 1 (63 years vs 58 years; $P < .001$). Correspondingly, elderly patients (>75 years)

Table 1. Patient Characteristics, Pathologic Findings, and Perioperative Outcomes

Characteristic[a]	Period 1 (1980-2003)	Period 2 (2004-2007)	*P* Value
Surgeons, No.	11	8	NA
PDs, No.	563	440	NA
Mean age, y (range)	58 (57-59)	63 (61-64)	<.001
Elderly patients (>75 y)	37 (7)	74 (17)	<.001
Sex ratio, M/F	1:4	1:2	.18
Diagnosis			
Periampullary adenocarcinoma	339 (65)	277 (63)	.70
Pancreatitis	123 (24)	75 (17)	.01
Cystic tumor	59 (11)	84 (19)	<.001
Other	42 (8)	4 (1)	.01
Positive margin status[b]	44 (12)	27 (10)	.30
Resected lymph nodes, No. (range)[b]	9 (7-11)	11 (9-13)	.26
Mortality, %	4	2	.04
Morbidity, %	42	40	.30
Age ≤75 y	220/526 (42)	135/366 (37)	.003
Age >75 y	15/37 (41)	53/74 (72)	<.001
Cardiopulmonary complications, overall	84/563 (15)	98/440 (22)	.003
Cardiopulmonary complications, elderly patients	15/37 (41)	53/74 (72)	<.001
Delayed gastric emptying, overall	41/563 (7)	45/440 (10)	.06
Delayed gastric emptying, elderly patients	3/37 (8)	8/74 (10)	.07
Pancreatic leak, %	10	13	.13
Grade A	27	38	.14
Grade B	45	50	.30
Grade C	29	12	.02
Intraoperative blood loss, mL (range)	1817 (1617-2018)	780 (683-877)	<.001
Operating time, min (range)	347 (334-359)	330 (322-340)	.09
Mean hospital stay, d (range)	18 (16-20)	12 (11-13)	<.001

Abbreviations: NA, not applicable; PDs, pancreaticoduodenectomies.
[a] Data are presented as number (percentage) unless otherwise indicated.
[b] Calculated only in patients with periampullary adenocarcinoma.

were proportionally more common in period 2 compared with period 1 (17% vs 7%; *P*<.001). Sex distribution was not different between the 2 periods.

An analysis of the pathologic indications for PD revealed no differences in the percentage of patients undergoing PD for periampullary cancer. In addition, no differences existed between periods when comparing type of periampullary cancer (pancreatic, biliary, ampullary, or duodenal), tumor size, lymph node status, number of resected lymph nodes, or margin status. However, when compared with period 1, period 2 had proportionally fewer patients undergoing PD for pancreatitis (17% vs 24%; *P*=.01). Also, a higher percentage of patients underwent PD for cystic neoplasms in period 2 compared with period 1 (19% vs 11%; *P*<.001).

Mortality and morbidity for all 1003 patients in the study were 3% and 41%, respectively. When divided between periods, mortality significantly improved in period 2 compared with period 1 (2% vs 4%; *P*=.04). Overall morbidity remained the same in both periods. Because more elderly patients underwent surgery in period 2, we also examined morbidity as a function of age. When patients were divided by age (ie, elderly patients [>75 years] vs nonelderly patients [≤75 years]), a significant improvement in morbidity was observed in nonelderly patients in period 2 compared with period 1 (37% vs 42%; *P*=.003). However, elderly patients counterbalanced this improvement because they had proportionally increased morbidity in period 2 compared with period 1 (72% vs 41%; *P*<.001).

Analysis of complications revealed that cardiac and pulmonary complications were significantly increased in period 2 compared with period 1 (22% vs 15%; *P*=.003). This increase in cardiac and pulmonary complications in period 2 was even more pronounced when examining elderly patients (72% vs 41%; *P*<.001). Other complications examined (eg, delayed gastric emptying, pancreatic leak, and infection) were not significantly different among elderly patients between the 2 periods. The pancreatic leak rate for all 1003 patients in the study was 11%. No difference in the percentage of pancreatic leaks was observed between periods 1 and 2 (Table 1). However, of the fistulae that did occur, fewer were ISGPF grade C in period 2 compared with period 1 (12% vs 20%; *P*=.02).

Intraoperative measures included estimated blood loss, operating time, and length of hospital stay. Mean blood loss significantly improved in period 2 compared with period 1 (780 mL vs 1817 mL; *P*<.001). Mean operating time was unchanged between periods. Mean length of hospital stay significantly improved in period 2 compared with period 1 (12 days vs 18 days; *P*<.001).

SURGEON EXPERIENCE

Surgeons who performed 50 or more PDs during the 2 periods of the study were defined as experienced surgeons (**Table 2**). Of the 1003 PDs performed in this study, 859 (86%) were performed by experienced surgeons: 482 in period 1 and 377 in period 2. Experienced surgeons performed most PDs that involved portal vein resection com-

Table 2. Perioperative Outcomes According to Surgeon Experience

Characteristic	Less Experienced Surgeons (<50 PDs)	Experienced Surgeons (≥50 PDs)	P Value
Surgeons, No.	13	6	NA
PDs, No.	144	859	NA
Mortality, %	4	3	.09
Morbidity, %	53	39	.001
Pancreatic leak, %	20	10	.03
Operating time, min (range)	458 (442-475)	335 (323-347)	.04
Intraoperative blood loss, mL (range)	1918 (2004-1832)	1101 (1056-1146)	.002
PV resection, No. (%)	3 (4)	68 (96)	<.001
Resected lymph nodes, No. (range)[a]	11 (10-12)	10 (9-11)	.40
Positive margins, %[a]	14	11	.06

Abbreviations: NA, not applicable; PDs, pancreaticoduodenectomies; PV, portal vein.
[a] Calculated only in patients with periampullary adenocarcinoma.

Table 3. Perioperative Outcomes According to Surgeon Volume

Characteristic	Low-Volume Surgeons (<20 PDs per Year)	High-Volume Surgeons (≥20 PDs per Year)	P Value
Surgeons, No.	16	3	NA
PDs, No.	461	542	NA
Mortality, %	4	2	.09
Morbidity, %	44	38	.07
Pancreatic leak, %	11	12	.60
Operating time, min (range)	442 (421-463)	317 (297-337)	.007
Intraoperative blood loss, mL (range)	1788 (1684-1892)	978 (888-1068)	<.001
Resected lymph nodes, No. (range)[a]	9 (7-11)	13 (11-14)	.04
Positive margins, %[a]	10	11	.30

Abbreviations: NA, not applicable; PDs, pancreaticoduodenectomies.
[a] Calculated only in patients with periampullary adenocarcinoma.

pared with less experienced surgeons (68 [96%] vs 3 [4%]; $P<.001$). Surgeons who performed fewer than 50 PDs during the 2 periods of the study were defined as less experienced surgeons. When compared with experienced surgeons, less experienced surgeons performed PD with comparable mortality (4% vs 3%). However, compared with less experienced surgeons, experienced surgeons had proportionally less morbidity (39% vs 53%; $P=.001$). In particular, the pancreatic leak rate was significantly lower in PDs performed by experienced compared with less experienced surgeons (10% vs 20%; $P=.03$). Intraoperative measures also were significantly different between experienced and less experienced surgeons. Mean intraoperative blood loss was significantly less in PDs performed by experienced surgeons (1101 mL vs 1918 mL; $P=.002$). In addition, mean operative time (335 minutes vs 458 minutes; $P=.04$) was significantly shorter in PDs performed by experienced surgeons. As a measure of the thoroughness or quality of resection in PD for periampullary cancer, we compared the number of lymph nodes resected,the type of cancer, and the number of positive surgical margins between experienced and less experienced surgeons. Using these outcome measures, the quality of cancer resection was comparable between both types of surgeons.

SURGEON VOLUME

Surgeon volume was defined as the number of PDs performed annually by an individual surgeon. Low-volume surgeons were defined as performing a mean of fewer than 20 PDs per year (**Table 3**). High-volume surgeons were defined as performing a mean of 20 or more PDs per year. Of the 1003 PDs performed in this study, 542 (54.0%) were performed by high-volume surgeons. Low-volume surgeons performed PD with statistically equivalent mortality and morbidity rates compared with high-volume surgeons (Table 3). In examining operative measures, however, high-volume surgeons performed PD with lower mean blood loss compared with low-volume surgeons (978 mL vs 1788 mL; $P<.001$). In addition, high-volume surgeons performed PD faster than low-volume surgeons (317 minutes vs 442 minutes; $P=.007$). In gauging quality of resection in PD for periampullary cancer, differences also existed between high- and low-volume surgeons. High-volume surgeons had a greater number of resected lymph nodes identified by the pathologist than low-volume surgeons (mean, 13 vs 9; $P=.04$). Margin status was equivalent between both types of surgeons.

EXPERIENCED SURGEONS AND ANNUAL VOLUME OF PD

In previous analyses, we have examined surgeons according to overall experience and separately according to annual volume. Some surgeons are experienced (≥50 PDs) but do not perform a high annual volume of PDs (≥20 PDs per year). Thus, we examined experienced surgeons according to whether they performed a high or low annual volume of PD (**Table 4**). Among experienced surgeons, low-volume and high-volume surgeons had equivalent mortality and morbidity rates. In addition, perioperative measures (estimated blood loss and operating time) were comparable. Finally, quality of periampullary cancer resection (as previously defined) was also the same among experienced surgeons with low and high annual volume.

LESS EXPERIENCED SURGEONS' LEARNING CURVE IN PERIOD 2

Less experienced surgeons (n=4) were studied in period 2 (**Figure 2**). The goal of this analysis was to determine the number of PDs needed to be performed by less experienced surgeons in period 2 to meet or surpass the numerical means of the experienced surgeons in this period. The number of PDs needed by less experienced surgeons to achieve the mean estimated blood loss of experienced surgeons was 0 (Figure 2A). For less experienced surgeons to achieve morbidity outcomes numerically equivalent to those of experienced surgeons, they needed 20 PDs

Table 4. Perioperative Outcomes of Experienced Surgeons According to Surgeon Volume[a]

Characteristic	Low-Volume Surgeons (<20 PDs per Year)	High-Volume Surgeons (≥20 PDs per Year)	*P* Value
Surgeons, No.	3	3	NA
PDs, No.	352	507	NA
Mortality, %	2	4	.30
Morbidity, %	38	40	.28
Pancreatic leak, %	10	7	.08
Operating time, min (range)	317 (281-343)	354 (333-378)	.09
Intraoperative blood loss, mL (range)	978 (858-1098)	1226 (1020-1432)	.10
Resected lymph nodes, No. (range)[b]	12 (11-13)	10 (8-11)	.09
Positive margins, %[b]	11	11	.60

Abbreviations: NA, not applicable; PDs, pancreaticoduodenectomies.
[a]Experienced surgeons were defined as those who had performed 50 or more PDs.
[b]Calculated only in patients with periampullary adenocarcinoma.

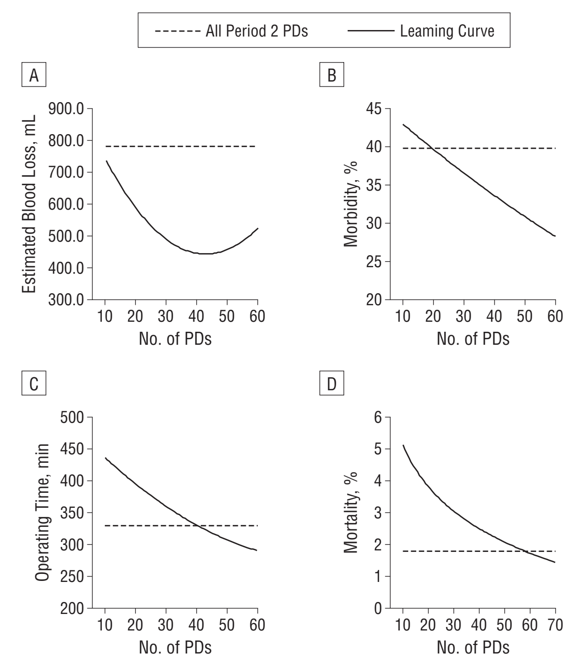

Figure 2. Learning curves of less experienced surgeons (<50 career pancreaticoduodenectomies [PDs]) in period 2 (2004-2007) compared with mean of all period 2 experienced surgeons.

(Figure 2B). To achieve operative time equivalent to that of experienced surgeons, less experienced surgeons needed 40 PDs (Figure 2C). Finally, to achieve equivalent mortality rates, less experienced surgeons needed 60 PDs (Figure 2D).

COMMENT

The aim of the present study was to determine the importance of hospital volume, surgeon experience, and surgeon volume in performing PD. To accomplish this aim, we evaluated 1003 PDs performed at a single institution, IUH (1980-2007), and 19 individual surgeons' experiences and annual volumes. In evaluating the institutional PD data, we found 2 clearly distinct periods. Pancreaticoduodenectomies performed in period 2 (2004-2007) were distinct from those in period 1 (1980-2003) owing to a 4- to 5-fold increase in annual institutional PD volume, an increased mean patient age, and an altered profile of pathologic indications, namely, increased cystic neoplasms and decreased chronic pancreatitis. Period 2 also had evidence of increased complexity of PD, with more portal vein resections.

The rapid increase in annual volume was, in large part, a result of the recruitment of a pancreatic surgeon as chair of the Department of Surgery (K.D.L.) and several additional surgeons (H.A.P., A.N., N.J.Z., and M.G.H.) with pancreatic surgery expertise to Indiana University. This strategy resulted in an influx of new patients. Although there was not a specific protocol or critical care pathway,[13] period 2 was remarkable for the establishment of a hepatopancreaticobiliary fellowship and a dedicated intensive care unit staff. These changes may partly account for improvements in outcomes that we attribute to volume-outcome relationships. Our data suggest that despite an increased proportion of groups at higher risk for morbidity and mortality (elderly patients, patients undergoing portal vein resections, and those with cystic lesions), a rapid increase in PD volume at an existing pancreatic surgery center resulted in an overall improvement in patient outcomes, including reduced intraoperative blood loss, length of hospital stay, ISGPF grade C pancreatic fistula rate, and mortality. Patients in period 2 and those operated on by experienced surgeons may have been relatively higher risk, with greater and more significant comorbid factors. Therefore, the differences between the groups compared may be underestimated by this study. Unfortunately, specific preoperative comorbid factors or general measures such as American Society of Anesthesiologists physical status classification were poorly defined or not available to us before 2004.

In evaluating individual surgeon PD experience, experienced surgeons performed PD with lower intraoperative blood loss, shorter operative time, and lower morbidity but no difference in quality of resection or mortality when compared with less experienced surgeons. Surrogate measures of quality of resection (number of lymph nodes resected and margin positivity) were used in this study. The number of lymph nodes resected likely depends on variation in the patients' anatomy, the pathologist's diligence, and only to some extent on the surgeon's experience. Similarly, positive margin status is as much an indicator of tumor stage as it is a measure of the quality of resection. Such surrogate measures of quality assume consistency of pathologic processing techniques and protocols during the time frame of the study, which is unlikely to be the case. Recognizing that these surrogate markers are suboptimal, we nonetheless used them because there were no other suitable measures of quality of resection available.

In evaluating individual surgeon annual PD volume, high-volume surgeons performed PD with the same morbidity and mortality as low-volume surgeons. However, high-volume surgeons performed PD with lower intraoperative blood loss, shorter operative times, and more resected lymph nodes (in periampullary cancer) compared with low-volume surgeons. When examining experience and volume together, we discovered that experienced surgeons had equivalent perioperative outcomes irrespective of their annual volume.

Learning curves for less experienced surgeons were examined in period 2. We used period 2 for this analysis because it was a more recent, stable, and shorter period than period 1. Our data suggest that less experienced surgeons did not need to perform any additional PDs to achieve equivalent estimated blood loss, but to achieve equivalent morbidity, operative time, and mortality required 20, 40, and 60 PDs, respectively. Interestingly, the mean intraoperative blood loss in PDs performed by less experienced surgeons in period 2 was already equivalent to that of experienced surgeons in that period. When period 1 surgeons were included, however, mean intraoperative blood loss in PDs performed by less experienced surgeons was significantly higher than that of experienced surgeons. Thus, the less experienced surgeons in period 2 began their learning curve for estimated blood loss considerably ahead of less experienced surgeons in period 1. This observation could be explained by an institutional effect (creation of a hepatopancreaticobiliary fellowship program) and/or individual effect (higher level of prior training by less experienced surgeons in period 2 vs period 1). Because there was no significant difference in the mortality rate between experienced and less experienced surgeons, the validity of such a learning curve may be called into question. Nonetheless, to achieve an equivalent percentage of mortality (a more stringent requirement than statistical significance), the learning curve predicts a 60-PD requirement.

This study was conceived because it is our impression that the contribution of surgeon PD experience vs the overall institutional PD experience and volume is not well understood. For example, an experienced surgeon working in a low-volume institution may be technically proficient at PD; however, the system support for diagnosis and treatment of postoperative complications may be inadequate. Conversely, a high-volume center with intensive care, interventional radiologic examination, and gastroentrologic expertise could provide superior support to a surgeon with lesser PD experience. Previous publications have clearly demonstrated that mortality, survival (for patients with periampullary adenocarcinoma), and overall life expectancy are improved when PD is performed in high-volume centers (>5 PDs per year).[3-6] Thus, it appears that hospital environment plays an important role in the safety and efficacy of PD. Morbidity was also shown to be increased in hospitals with low pancreas resection volume.[14] Our study findings comparing 2 periods with different volumes are consistent with these previous studies indicating improvements in mortality.

Surgeon volume, however, has been less emphasized in the literature until more recently. Surgeon volume in pancreatic surgery has been linked to mortality and may explain a significant part of an institution's volume effect.[3,10] A learning curve in pancreatic surgery has recently been hypothesized and modeled, suggesting that after 60 PDs, surgeons improved the perioperative outcomes of estimated blood loss, operative time, length of hospital stay, and margin status in patients undergoing PD for periampullary adenocarcinoma.[15] Our study findings according to individual surgeon experience and volume are consistent with these previous studies. To our knowledge, however, our study is novel because it indicates that although experience improves morbidity, annual volume for already experienced surgeons has no additional benefit regarding outcomes.

Limitations of this study include its retrospective design; use of surrogate measures for both quality (number of resected lymph nodes and margin positivity) and risk/complexity (patients who were elderly, underwent portal vein resections, or had cystic neoplasms); and an extended time frame of study analysis during which pathologic, interventional radiologic, and endoscopic studies, intensive care, and surgical techniques and technology were likely to have undergone significant changes. In light of these limitations, we do not recommend that these data be used inappropriately by payers and policy makers to draw conclusions. Use of a large, cooperative database might be more optimal than what is presented in this article to draw definitive conclusions about experience and volume-outcome relationships. Nonetheless, such databases have significant limitations on the number of fields tracked. Thus, the results of institutional reports will likely complement large cooperative database studies, particularly for more detailed analyses.

In conclusion, our data suggest that the institutional annual PD volume is important because this variable was the only measure that improved mortality. However, even within a center performing a high volume of PD, surgeon PD experience remains important because this variable resulted in improved overall morbidity. Experienced surgeons gained no additional measurable benefit of increased annual volume. This observation suggests that once surgeons in high-volume centers are experienced with PD, they need not continue to perform a high annual volume of PD to maintain superior outcomes.

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DISCUSSION

Michael Bouvet, MD, La Jolla, California: The surgeon's experience in performing PD remains highly important for patient outcomes. While this conclusion should not be surprising to anyone who operates on the pancreas, it has important implications if we are to keep complication rates low for patients who are undergoing pancreatic surgery. Your experience at Indiana University should be applauded and can serve as an example of how a center with surgeons that are focused on pancreatic cancer can make a big difference in patient outcomes.

In my own experience as an attending surgeon at UCSD [University of California, San Diego] over the last 11 years, I have realized that there are many potential pitfalls in this operation that can be avoided—but only after accumulating enough cases to see what can go wrong. For instance, recognizing aberrant hepatic arterial anatomy during the portal dissection is crucial to avoid a disastrous outcome if a replaced hepatic artery is ligated instead of the gastroduodenal artery. Likewise, the knowledge of how to deal with the soft gland with a very small pancreatic duct during the pancreaticojejunostomy is important so that the postoperative fistula can be avoided. Lastly, the pancreatic surgeon should be prepared to resect a portion of the portal vein if necessary to obtain negative margins. These scenarios are best learned in the operating room, with appropriate surgical mentorship, and this can only come with experience. It is not only the intraoperative technical aspects of this operation that are critical—it is also the preoperative patient selection and postoperative patient care that can make a big difference in outcomes. Again, this comes from experience. It certainly helps to have a high-volume center with the appropriate ancillary services such as quality pancreatic imaging, experienced endoscopic ultrasonographers, critical care units, and interventional radiologists, which can help with the management of these patients.

I have several questions for you. First of all, you noted a higher percentage of patients undergoing PD for cystic lesions in period 2. We have also seen a similar trend at our institution in recent years. Do you have any thoughts as to why this may be? Second, I was somewhat surprised that elderly patients had a proportionally increased morbidity in period 2 compared with period 1. Do you think you were taking on more difficult cases in the later period with sicker patients? Lastly, it is also interesting that you found that experienced surgeons had equivalent perioperative outcomes irrespective of their annual volume. One might infer that once the peak of the learning curve has been achieved, perhaps after 60 PDs, the necessary skills are there to keep the complications low.

Dr Howard: With regard to percentage of cystic lesions, we are seeing a lot more of these, as is the group in Boston. I believe this change comes from improved imaging, and it has become such a high-volume aspect of our referral practice that we now have a cyst group at our hospital with their own clinic. Many new patients are seen with incidental findings on computed tomographic scans, magnetic resonance images, or endoscopic ultrasounds. I think the big question is, how many of these should we be removing with PD?

The increased elderly patient morbidity in period 2 actually was a surprise to us too. Again, it was cardiopulmonary morbidity, and in reviewing the data it appears that with our increase in volume we are now operating on patients who in the past we might not have operated on, just as you suggest. For instance, the data suggest that over the last 4 years we are operating on more periampullary cancers with vascular involvement. In addition, we seem to be operating on more patients with multiple medical comorbidities. Of course, we are not unique in this; I think most surgeons are currently operating on sicker patients than they have historically owing to many factors that may or may not be related to the technical aspects of the operation. Consequently, it becomes a difficult variable to accurately quantify in a series over 27 years.

Regarding your comment on learning curves, our data suggest that once you become an experienced surgeon (≥50 PDs at our institution), you have no further improvement in your technical skills, and once you reach this skill level, you achieve comparable outcomes regardless of your annual volume. In contrast to our data, Dr Tseng and colleagues at MD Anderson looked at the acquisition of technical expertise in PD and pointed out that in their experience, improvement continues beyond 60 PDs. It seems there has to be some cutoff or plateau of outcomes, or we would ultimately approach zero morbidity and mortality. Nevertheless, her data did show that one can continue to acquire skills and technical expertise even when approaching 200 PDs.

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