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Centralizing a national pancreatoduodenectomy service: striking the right balance

L. S. Nymo[1,2], D. Kleive[3,4], K. Waardal[5], E. A. Bringeland[7,8], J. A. Søreide[6,9], K. J. Labori[3,4], K. E. Mortensen[1,2], K. Søreide[6,9] and K. Lassen[2,3]

[1]Department of Gastrointestinal Surgery, University Hospital of North Norway, and [2]Institute of Clinical Medicine, Arctic University of Norway, Tromsø, [3]Department of Hepatobiliary and Pancreatic Surgery, Oslo University Hospital, and [4]Institute of Clinical Medicine, University of Oslo, Oslo, [5]Department of Gastrointestinal Surgery, Haukeland University Hospital, and [6]Department of Clinical Medicine, University of Bergen, Bergen, [7]Department of Gastrointestinal Surgery, St Olav Hospital, Trondheim University Hospital, and [8]Department of Clinical and Molecular Medicine, Norwegian University of Science and Technology, Trondheim, and [9]Department of Gastrointestinal Surgery, Stavanger University Hospital, Stavanger, Norway

Correspondence to: Dr L. S. Nymo, Department of Gastrointestinal Surgery, University Hospital of North Norway, Sykehusveien 38, 9019 Tromsø, Norway (e-mail: linnsnymo@gmail.com)

Background: **Centralization of pancreatic surgery is currently called for owing to superior outcomes in higher-volume centres. Conversely, organizational and patient concerns speak for a moderation in centralization. Consensus on the optimal balance has not yet been reached. This observational study presents a volume–outcome analysis of a complete national cohort in a health system with long-standing centralization.**

Methods: **Data for all pancreatoduodenectomies in Norway in 2015 and 2016 were identified through a national quality registry and completed through electronic patient journals. Hospitals were dichotomized (high-volume (40 or more procedures/year) or medium–low-volume).**

Results: **Some 394 procedures were performed (201 in high-volume and 193 in medium–low-volume units). Major postoperative complications occurred in 125 patients (31·7 per cent). A clinically relevant postoperative pancreatic fistula occurred in 66 patients (16·8 per cent). Some 17 patients (4·3 per cent) died within 90 days, and the failure-to-rescue rate was 13·6 per cent (17 of 125 patients). In multivariable comparison with the high-volume centre, medium–low-volume units had similar overall complication rates, lower 90-day mortality (odds ratio 0·24, 95 per cent c.i. 0·07 to 0·82) and no tendency for a higher failure-to-rescue rate.**

Conclusion: **Centralization beyond medium volume will probably not improve on 90-day mortality or failure-to-rescue rates after pancreatoduodenectomy.**

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Introduction

A volume–outcome effect on mortality after pancreatoduodenectomy (PD) has been demonstrated repeatedly, with lower short-term mortality rates in high-volume centres[1–5]. The failure to prevent death in patients suffering from major postoperative morbidity (failure-to-rescue (FTR)) has been proposed as a mechanism behind the volume–outcome effect on mortality that is more important than the occurrence of postoperative complications[6,7]. Timely recognition and optimally sequenced treatment of complications after PD is a complex matter and requires a multidisciplinary approach[8,9]. A higher unit caseload necessarily reflects greater experience in the handling of complications. Academic teaching status of the treating hospital has also been proposed to influence FTR[7].

Covering a population of just 5·3 million inhabitants over a vast geographical area, pancreatic surgery in Norway has been restricted to only five hepatopancreatobiliary (HPB) units for more than a decade[10–12]. All are academic teaching hospitals with 24-h interventional radiology and endoscopy services available, and highly resourced ICUs. Although centralized, catchment areas vary substantially between

the units, from high- to medium-volume combined HPB and upper gastrointestinal units covering 0·5–1·0 million inhabitants each, to a single very high-volume dedicated HPB unit serving an uptake population of more than 2·6 million. The government funds the universal healthcare coverage, and there are no private institutions for resectional surgery.

A previous nationwide analysis[11] using administrative data documented a low contemporary 90-day mortality rate after PD in Norway, and negligible cross-regional patient drift. There were similar regional population-based incidences of the procedure and equal mortality rates among patients treated at the respective units, but variation in relaparotomy rates and use of vascular reconstruction was demonstrated[11]. A significant proportion of relaparotomies within 30 days (1 in 5) and deaths within 90 days (4 in 10) occurred after first discharge from hospital[11]. The centralization of surgery within a single-payer health system relies on patients being transferred back to general hospitals for parts of the postoperative phase and follow-up. Although still under the auspices of the operating (index) unit, these transfers reduce the patients' organizational and geographical proximity to the index surgical unit in the subacute recovery phase, where postoperative adverse events may still develop. This is an inherent consequence of centralization in all but the most densely populated countries.

This study assessed overall and procedure-specific outcomes in a complete national cohort of patients undergoing PD, and investigated for a volume–outcome effect in a country with longstanding centralization but a large variation in unit volume. The aim of the analysis was to examine a potential benefit from further centralization.

Methods

All patients registered in the Norwegian Registry for Gastrointestinal and HPB Surgery (NoRGast) have given written informed consent[13]. In addition, the project was granted allowance from the Norwegian Directorate of Health for additional access to electronic patient journal (EPJ) data. Approval of alignment of the multicentre data was given by the Data Protection Authority of Norway (reference number 17/33320-2).

Study design

This was an observational cohort study of complete nationwide data in a universal health coverage system. The STROBE guidelines[14] for reporting observational studies were adhered to, where applicable.

Accrual of data

NoRGast is a procedure-driven national quality registry with prospective gathering of core data for case mix and postoperative complications[13]. All five Norwegian HPB units contribute data to NoRGast. Data for all registered pancreatoduodenectomies performed between January 2015 and December 2016 were retrieved from the NoRGast database. Data from NoRGast were cross-checked at a patient level by performing an identical search for the same procedure codes in the local EPJs for each HPB unit, and data for missing patients were included. In addition, procedure-specific variables and complications not available in NoRGast (preoperative biliary drainage, duration of procedure, intraoperative haemorrhage, grade of postoperative pancreatic fistula (POPF), grade of postpancreatectomy haemorrhage (PPH) and histopathology data) were registered manually from the EPJ for all patients by a local HPB surgeon. Three of the four healthcare regions have a shared regional EPJ, allowing direct access to patient data for any transfer stays or readmissions outside the index unit; this ensures data quality for complications occurring after the index stay. In the one region where regional EPJ access was not available, discharge reports from transfer stays or readmissions were collected and evaluated. Date of death is available automatically in the EPJ via a direct coupling with the National Registry of Norway (Folkeregisteret).

Definitions

Co-morbidity

Severe cardiac disease (New York Heart Association class above 2 or severe arrhythmia) and pulmonary disease (forced expiratory volume in 1 s less than 50 per cent and/or vital capacity below 60 per cent) were defined in accordance with the modified form of the Estimation of Physiologic Ability and Surgical Stress (E-PASS) system[15]. Diabetes mellitus was defined by preoperative use of any antidiabetic medication, administered either subcutaneously or orally.

Procedure details and postoperative complications

Any complication graded as 3 or above in the Accordion system[16] was considered a major complication. Briefly, Accordion grade 3 refers to percutaneous or endoscopic reintervention with or without general anaesthesia; Accordion 4 refers to relaparotomy or single-organ failure (SOF); Accordion 5 refers to relaparotomy and SOF, or multiple organ failure alone; and Accordion 6 refers to death. POPF[17], PPH[18] and venous resection[19] were scored in accordance with proposed guidelines from the International Study Group of Pancreatic Surgery.

Table 1 Patient demographics

	Total (n = 394)	High volume (n = 201)	Medium–low volume (n = 193)	Unit range#	P††
Age (years)*	67·5 (60–73)	68 (61·5–74)	67 (58–72)	66–67·5	0·364‡‡
BMI (kg/m^2)*	24·5 (21·9–26·9)	24·1 (21·7–26·7)	24·6 (22·0–27·1)	24·2–25·5	0·271‡‡
Albumin (g/l)*	40·0 (36·0–43·0)	40·0 (35·5–43·0)	40·0 (36·0–43·0)	36·0–43·0	0·584‡‡
Weight loss†	n = 315	n = 149	n = 166		
Any	231 (73·3)	117 (78·5)	114 (68·7)	(62·5–71·7)	0·064
> 5%	185 (58·7)	101 (67·8)	84 (50·6)		
> 10%	90 (28·6)	62 (41·6)	28 (16·9)		
Diabetes mellitus‡	68 (17·3)	36 (17·9)	32 (16·6)	(6·3–22·6)	0·829
Neoadjuvant chemotherapy	22 (5·6)	11 (5·5)	11 (5·7)	(0–12·9)	0·922
Severe pulmonary disease§	15 (3·8)	3 (1·5)	12 (6·2)	(0–18·8)	0·014
Severe cardiac disease¶	23 (5·8)	11 (5·5)	12 (6·2)	(0–11·3)	0·753
Preoperative drainage	150 (38·1)	88 (43·8)	62 (32·1)	(25·8–37·1)	0·017
ERCP	134 (34·0)	88 (43·8)	46 (23·8)	(17·8–31·3)	
PTC	16 (4·1)	0 (0)	16 (8·3)	(0–15·6)	
ECOG score					0·083
0	288 (73·1)	157 (78·1)	131 (67·9)	(62·2–71·4)	
1	95 (24·1)	39 (19·4)	56 (29·0)	(25·7–37·5)	
> 1	11 (2·8)	5 (2·5)	6 (3·1)	(0–4·4)	
ASA grade					0·487
I–II	216 (55·0)	106 (53·0)	110 (57·0)	(46·8–75·0)	
≥ III	177 (45·0)	94 (47·0)	83 (43·0)	(25·0–53·2)	
Histopathology (extracted specimens)	n = 393	n = 201	n = 192**		0·072
Any malignancy	324 (82·4)	173 (86·1)	151 (78·6)	(67·1–93·8)	
PDAC	161 (41·0)	83 (41·3)	78 (40·6)		
Common bile duct cancer	58 (14·8)	36 (17·9)	22 (11·5)		
Duodenal cancer	36 (9·2)	25 (12·4)	11 (5·7)		
Ampullary/papillary cancer	30 (7·6)	9 (4·5)	21 (10·9)		
Other	39 (9·9)	20 (10·0)	19 (9·9)		
Any benign disease	69 (17·6)	28 (13·9)	41 (21·4)	(6·3–32·9)	
IPMN without adenocarcinoma	25 (6·4)	5 (2·5)	20 (10·4)		
Pancreatitis	11 (2·8)	9 (4·5)	2 (1·0)		
Other	33 (8·4)	14 (7·0)	19 (9·9)		

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.). †Patient-reported weight loss in 6 months before surgery. ‡Defined by use of any antidiabetic medication, administered subcutaneously or orally. §Forced expiratory volume in 1 s less than 50 per cent or vital capacity less than 60 per cent. ¶New York Heart Association class 3–4 or arrhythmia requiring mechanical support. #Within medium–low volume category. **One patient died during surgery. ERCP, endoscopic retrograde cholangiopancreatography; PTC, percutaneous transhepatic cholangiography; ECOG, Eastern Co-operative Oncology Group; PDAC, pancreatic ductal adenocarcinoma; IPMN, intraductal papillary mucinous neoplasm. ††χ^2 test (high *versus* medium–low volume, dichotomized), except ‡‡Kruskal–Wallis test.

Failure-to-rescue

FTR was defined as any death within 90 days in patients with any major complication (Accordion grade 3 or above). Deaths with no recorded preceding major complication were included, in accordance with the original[20] and recommended[21] definition.

Hospital volume

Hospital units were dichotomized according to procedure volume, and defined as high volume for 40 or more procedures per year (1 unit) or as medium–low volume for fewer than 40 procedures per year (4 units). Others[3,5,6,22–24] have suggested this cut-off, and it allowed for meaningful comparison within the Norwegian setting. Length of stay was defined conventionally as the number of postoperative nights spent at the hospital after the procedure, omitting any transfer and/or readmission stays.

Primary outcomes

The primary outcomes of the study were incidence and type of major postoperative complications, overall 90-day

Table 2 Procedure characteristics

	Total (n = 394)	High volume (n = 201)	Medium–low volume (n = 193)	Unit range‡ (16–70)	P§
Estimated blood loss (ml) (n = 352)*	350 (700–1200)	200 (100–500)	490 (300–490)	300–1165	< 0·001¶
Duration of surgery (min) (n = 383)*	322 (262–386)	341 (283–418)	300 (240–300)	240–431	< 0·001¶
Without VR	308·5 (252–359)	323 (274–373)	300 (240–343)	240–354	< 0·001¶
With VR	420 (355–454)	420 (369–454)	393 (337–465)	240–431	0·415¶
Classical PD†	206 (52·3)	60 (29·9)	146 (75·6)	(12·5–100)	< 0·001
Peroperative blood transfusion	76 of 391 (19·4)	38 of 198 (19·2)	38 (19·7)	(10·0–35·5)	0·901
Any vascular resection	70 (17·8)	50 (24·9)	20 (10·4)	(5·7–17·7)	< 0·001

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.). †Classical pancreatoduodenectomy (PD) (Whipple procedure); all others were pylorus-preserving pancreatoduodenectomies. ‡Within medium–low volume group; the lowest case volume was 16 and the highest was 70. VR, vascular resection. §χ^2 test (high *versus* medium–low volume, dichotomized), except ¶Kruskal–Wallis test.

Table 3 Short-term outcomes

	Total (n = 394)	High volume (n = 201)	Medium–low volume (n = 193)	Unit range†	P‡
Any major complication	125 (31·7)	57 (28·4)	68 (35·2)	(31·2–42·2)	0·143
Accordion 3	46 (11·7)	21 (10·4)	25 (13·0)		0·436¶
Accordion 4	51 (12·9)	22 (10·9)	29 (15·0)		
Accordion 5	15 (3·8)	6 (3·0)	9 (4·7)		
Accordion 6 (30-day mortality)	10 (2·5)	8 (4·0)	5 (2·6)		
POPF	n = 393	n = 201	n = 192		
None or biochemical leak	327 (83·2)	180 (89·6)	147 (76·6)	(71·4–83·6)	
Grade B	41 (10·4)	13 (6·5)	28 (14·6)	(6·3–17·1)	< 0·001#
Grade C	25 (6·4)	8 (4·0)	17 (8·9)	(3·3–12·5)	
PPH	n = 393	n = 201	n = 192		
None or grade A	349 (88·8)	177 (88·1)	172 (89·6)	(85·7–100)	0·741#
Grade B	22 (5·6)	10 (5·0)	12 (6·3)	(0–8·2)	
Grade C	22 (5·6)	14 (7·0)	8 (4·2)	(0–7·1)	
Relaparotomy	71 (18·1)	32 (15·9)	39 (20·3)	(8·2–28·6)	0·258
Haemorrhage	23 (5·9)	13 (6·5)	10 (5·2)		0·026¶
Pancreatic leak	17 (4·3)	5 (2·5)	12 (6·3)		
Biliary leak	8 (2·0)	1 (0·5)	7 (3·6)		
Wound dehiscence	4 (1·0)	4 (2·0)	0 (0)		
Other	19 (4·8)	9 (4·5)	10 (5·2)		
90-day mortality	17 (4·3)	11 (5·5)	6 (3·1)	(0–6·3)	0·323
Length of stay at index hospital (days) (n = 391)*	9 (7–16)	7 (6–11)	14 (9–21)	7–18	< 0·001§
No major complication*	8 (6–13)	7 (6–8)	13 (8–15)	7–15	< 0·001§
Any major complication*	18 (11–29)	14 (10–30)	21 (13–28)	13–24	0·129§

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.) with median unit range. †Within medium–low volume group. POPF, postoperative pancreatic fistula; PPH, postpancreatectomy haemorrhage. ‡χ^2 test (high *versus* median–low volume, dichotomized), except §Kruskal–Wallis test; ¶univariable χ^2 comparison of Accordion grade or reason for relaparotomy distribution; #univariable χ^2 comparison of presence of clinically relevant POPF or PPH grade B–C.

mortality, and 90-day mortality among patients with major postoperative complications (FTR).

Statistical analysis

Crude demographics, procedure details, major complications and histopathology data are presented as median (i.q.r.) values, or as absolute numbers with percentages. Crude comparison across volume categories was done using the χ^2 test for categorical variables and the Kruskal–Wallis (non-parametric) test for continuous variables.

Multivariable logistic regression analyses of the postoperative outcomes any major complication, relaparotomy,

Table 4 Multivariable analysis of predictors of postoperative complications*

	Odds ratios				
	Any major complication	Relaparotomy	90-day mortality	CR POPF	PPH grade B or C
Age (years)					
< 65	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
65–74	1·19 (0·73, 1·91)	1·20 (0·68, 2·51)	4·63 (0·87, 24·22)	1·24 (0·69, 2·25)	0·95 (0·47, 1·92)
≥ 75	0·60 (0·31, 1·16)	0·57 (0·24, 1·34)	7·66 (1·14, 51·44)	0·62 (0·26, 1·49)	0·58 (0·20, 1·69)
P	0·112	0·212	0·098	0·271	0·594
Sex					
F	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
M	1·21 (0·78, 1·89)	1·23 (0·72, 2·09)	3·69 (1·05, 13·02)	0·97 (0·51, 1·85)	1·77 (0·91, 3·45)
P	0·393	0·452	0·042	0·934	0·092
Indication					
Any malignancy	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
Benign disease	1·75 (0·92, 2·98)	0·82 (0·39, 1·87)	0·41 (0·04, 3·84)	1·96 (0·94, 3·44)	0·86 (0·33, 2·27)
P	0·087	0·602	0·438	0·098	0·767
Vascular resection					
No	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
Yes	1·30 (0·72, 2·34)	1·62 (0·84, 2·81)	1·33 (0·30, 5·81)	0·72 (0·30, 1·71)	4·27 (2·20, 8·28)
P	0·381	0·149	0·709	0·456	< 0·001
Preoperative biliary drainage					
No	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
Yes	0·72 (0·45, 1·16)	0·79 (0·52, 1·64)	0·21 (0·05, 0·86)	0·50 (0·27, 0·92)	0·57 (0·28, 1·15)
P	0·178	0·781	0·030	0·025	0·117
Peroperative RBC transfusion					
No	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
Yes	1·68 (0·99, 2·85)	2·12 (1·17, 3·82)	1·78 (0·49, 6·33)	1·28 (0·64, 2·57)	1·68 (0·81, 3·49)
P	0·053	0·013	0·376	0·481	0·164
Relaparotomy					
No			1·00 (reference)		
Yes			20·72 (6·03, 71·18)		
P			< 0·001		
Unit volume					
High	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)	1·00 (reference)
Medium–low	1·28 (0·82, 1·98)	1·38 (0·82, 2·33)	0·24 (0·07, 0·82)	2·52 (1·43, 4·43)	1·10 (0·55, 2·19)
P	0·274	0·229	0·023	0·001	0·782

Values in parentheses are 95 per cent confidence intervals. *Other potential predictors evaluated in the multivariable logistic regression analysis, but not found to be significant predictors were BMI, weight loss greater than 10 per cent, albumin, diabetes mellitus, neoadjuvant chemotherapy, severe pulmonary disease, severe cardiac disease, Eastern Co-operative Oncology Group class above zero, ASA grade above II, duration of surgery and type of procedure. CR POPF, clinically relevant postoperative pancreatic fistula; PPH, postpancreatectomy haemorrhage; RBC, red blood cell.

clinically relevant (CR) POPF and PPH grade B/C were performed using a backwards stepwise approach, where centre volume was included as a predictor. A similar multivariable model was built to evaluate the predictors of death after major postoperative complications (FTR). The regression models were assessed for significant interactions and collinearity. Effect measures from multivariable analyses are reported as odds ratios (ORs) with 95 per cent confidence intervals. Level of significance for all final analyses was set to $P < 0{\cdot}050$.

IBM SPSS Statistics version 26.0 (IBM, Armonk New York, USA) was used for all statistical analyses.

Results

A total of 394 patients in Norway had a PD (all open resections) during the 2-year study period. Mean annual procedure volume ranged from 101 PDs in the high-volume centre to 35, 31, 23 and eight PDs respectively (median 27) in the four medium–low-volume

Table 5 Characteristics of 17 patients who died within 90 days of surgery

Sex	Age (years)	Unit	Co-morbidity	Procedure*	Pathology	Complications	Mortality (days)	Discharged from index unit alive
M	47	MV	None	CW, vein resection type 1	PDAC (R1)	Relaparotomy, POPF grade B, PPH grade C	30	No
M	67	HV	None	PPPD	Pancreatitis	Sudden cardiac arrest POD 5	30	No
F	85	HV	None	PPPD	PDAC (R1); extensive SMA dissection	Diarrhoea, renal failure	30	Yes
M	68	HV	None	PPPD	Duodenal adenocarcinoma	Relaparotomy, PPH grade C	30	No
M	76	HV	Cardiac disease	CW	Distal CC (R1)	Relaparotomy (wound dehiscence only)	30	No
M	76	MV	DM	PPPD	Other malignancy (R0)	Relaparotomy, POPF grade C, PPH grade C	30	No
F	71	MV	None	CW	Other malignancy (R0)	Relaparotomy (wound dehiscence only)	30	No
F	65	MV	DM	CW	No specimen retrieved	Peroperative death from haemorrhage	30	No
M	69	LV	None	PPPD	Distal CC (R0)	Relaparotomy, POPF grade C	30	No
F	70	HV	None	CW, vein resection type 3	Distal CC (R0)	Relaparotomy, POPF grade C, PPH grade C	30–90	No
F	71	HV	None	PPPD, vein resection type 3	PDAC (R1)	Relaparotomy, POPF grade C	30–90	Yes
M	63	HV	None	CW, vein resection type 3	PDAC (R1)	Infection after initiating adjuvant chemotherapy	30–90	Yes
M	78	HV	Cardiac disease	CW	Duodenal adenocarcinoma (R0)	Pneumonia, prolonged DGE	30–90	Yes
M	74	HV	DM	CW	Duodenal adenocarcinoma (R1)	Relaparotomy, POPF grade C, PPH grade C	30–90	No
M	74	HV	None	PPPD	Duodenal adenocarcinoma (R1)	Relaparotomy (wound dehiscence only)	30–90	Yes
M	74	MV	None	CW	PDAC (R0)	Relaparotomy, POPF grade C, PPH grade C	30–90	No
M	71	HV	None	PPPD	Distal CC (RO)	Relaparotomy, POPF grade C	30	No

*International Study Group of Pancreatic Surgery classification of vein resection. MV, medium volume; CW, classical Whipple procedure; PDAC, pancreatic ductal adenocarcinoma; POPF, postoperative pancreatic fistula; PPH, postpancreatectomy haemorrhage; HV, high volume; PPPD, pylorus-preserving pancreatoduodenectomy; POD, postoperative day; SMA, superior mesenteric artery; CC, cholangiocarcinoma; DM, diabetes mellitus; LV, low volume; DGE, delayed gastric emptying.

units. Follow-up at 30 days (complications) and 90 days (mortality) was complete (394, 100 per cent).

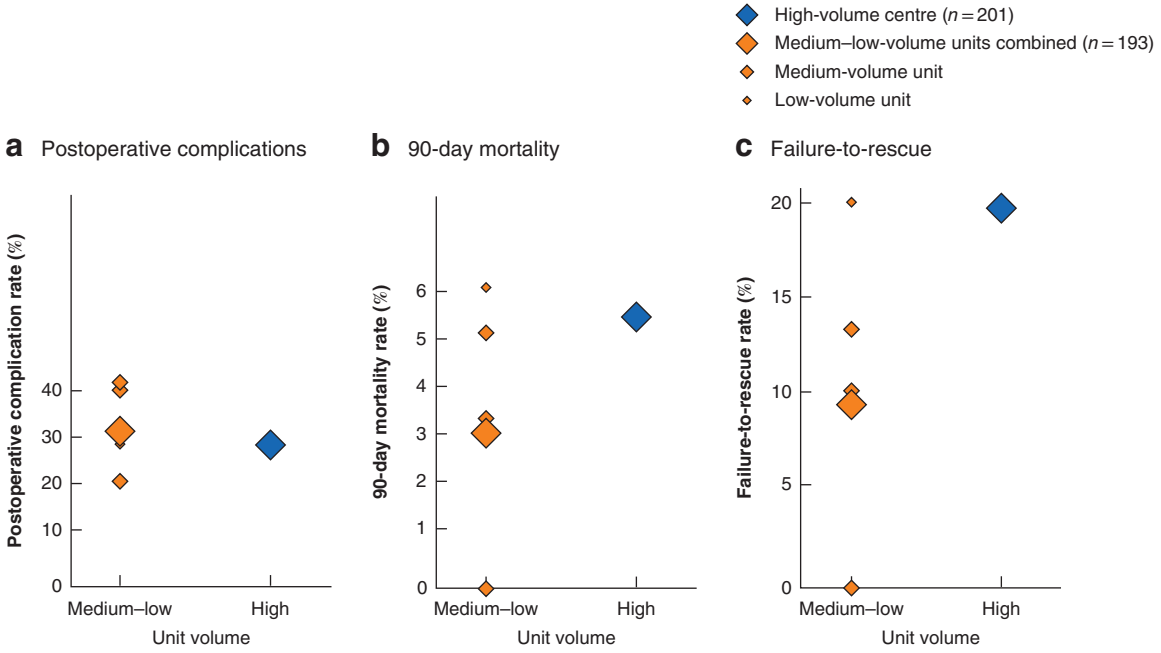
Patient demographics

Baseline patient data are presented in *Table 1*. The median age was 67·5 (i.q.r. 60–73) years, and 187 (47·5 per cent) of the patients were men. Of 393 extracted specimens (1 intraoperative death with no retrieved specimen), malignant disease was confirmed in 324 (82·4 per cent). Pancreatic ductal adenocarcinoma (PDAC) was found in 161 (49·7 per cent) of malignant specimens. Patients treated in the high-volume centre had a significantly higher rate of preoperative biliary drainage than those in the medium–low-volume units (88 of 201 (43·8 per cent) *versus* 62 of 193 (32·1 per cent) respectively; $P = 0{\cdot}017$), and a lower rate of severe pulmonary disease (3 of 201 (1·5 per cent) versus 12 of 193 (6·2 per cent); $P = 0{\cdot}014$). There were no other significant differences in patient characteristics between patients treated in the high- and medium–low-volume units, including no difference in proportions of specimens with malignant *versus* benign disease.

Procedure characteristics

Procedure characteristics are presented in *Table 2*. Concomitant vascular resection (vein or artery) was done in 70 (17·8 per cent) of the operations, and specifically in 54 of 161 (33·5 per cent) of resections for PDAC. Patients treated in the high-volume centre had significantly lower estimated blood loss and longer duration of surgery for all procedures

Fig. 1 Comparison of any major complication, 90-day mortality and failure-to rescue in medium–low-volume and high-volume units



a Postoperative complications (Accordion grade 3–6); **b** 90-day mortality; **c** failure-to-rescue. Multivariable analysis with high volume as reference (odds ratio (OR) 1·00): **a** OR 1·28 (95 per cent c.i. 0·82 to 1·98), $P = 0·274$; **b** OR 0·24 (0·07 to 0·82), $P = 0·023$; **c** OR 0·49 (0·26 to 1·63), $P = 0·243$.

and for PDs without concomitant vascular resection, a lower rate of classical PD (*versus* pylorus-preserving PD) and a higher rate of any vascular resection. Most arterial resections were performed in the high-volume centre (14 of 16); none of these 16 patients died within 90 days.

Postoperative complications

Crude rates of postoperative complications and univariable comparison between volume categories are presented in *Table 3*. Major complications occurred in 125 patients (31·7 per cent). Results from multivariable analyses are presented in *Table 4*. When analysing centre volume category as a predictor of postoperative outcomes, medium–low volume was a predictor of lower mortality within 90 days (OR 0·24, 95 per cent c.i. 0·07 to 0·82) but of a higher rate of CR POPF (OR 2·52, 1·43 to 4·43). Medium–low-volume unit did not independently predict occurrence of any major complication, relaparotomy or PPH grade B/C. Importantly, variation in the use of vascular resection between the volume categories was adjusted for.

Failure-to-rescue

Detailed patient data for all patients who died within 90 days are shown in *Table 5*. All but four of the patients who died within 90 days experienced at least one major surgical complication within 30 days: CR POPF (8 of 17), PPH grade B/C (6 of 17) and relaparotomy (12 of 17). The rate of FTR after any major complication was 13·6 per cent (17 of 125). The mortality rate after any relaparotomy and PPH grade B/C was 12 of 71 (17 per cent) and 7 of 44 (16 per cent). Overall mortality after CR POPF was eight of 66 (12 per cent), with separate mortality rates after POPF grade B and C of one of 41 (2 per cent) and seven of 25 (28 per cent) respectively.

The FTR rate in the high-volume centre was 11 of 57 (19 per cent), compared with six of 68 (9 per cent) in medium–low-volume units (*Fig. 1*). In multivariable analysis assessing the same predictors as for postoperative complications (*Table 4*), medium–low unit volume was not an independent predictor of higher FTR (OR 0·49, 95 per cent c.i. 0·26 to 1·63; $P = 0·243$).

Discussion

These data indicate that results similar to those in high-volume expert centres may be obtained within a single-payer PD service practising a moderate degree of centralization. The sole high-volume centre had outcomes on a par with those from internationally renowned

high-volume centres[24], but, importantly, so had the three medium-volume centres with 20–40 procedures per year. This suggests that a balance between beneficial short-term clinical outcomes and organizational concerns may have been obtained with this caseload.

The national outcomes in terms of rates of any major complication, POPF, PPH and FTR are comparable to the results and benchmarks cut-off values established from an international cohort of 23 high-volume expert centres[25]. Of note, whereas their benchmark values[25] were based on a subset of low-risk patients, excluding more than 50 per cent of their total patient cohort, the present study included 100 per cent of patients operated on across Norway during the study period (a true population-based cohort).

As shown previously[11], national 30- and 90-day mortality rates were low in comparison with contemporary cohorts from Germany, France and the USA, and in line with rates reported from Sweden and the Netherlands[1,2,26–28]. Rates of any major complication, CR POPF and PPH grade C were equal to coeval cohorts from the USA, Netherlands and Germany[22,29,30]. The relaparotomy rate in the present cohort (18·1 per cent) was similar to, or somewhat higher than, that reported from other studies[22,30,31]. Compared with similar population-based cohorts[29,30], the median operating time of 322 min was short and median estimated blood loss (350 ml) was low.

The national rate of FTR after PD of 13·6 per cent in the present cohort is in line with recent rates of 9 per cent reported from the US American College of Surgeons National Surgical Quality Improvement Program database[32] and 14·3 per cent in the Dutch Pancreatic Cancer Audit[6]. Importantly, the existing diversity in definitions of major postoperative morbidity used to calculate FTR rates hampers a direct comparison between studies. A Dutch study[33] of the management of POPF used a definition similar to that employed in the present study, and reported an in-hospital mortality rate after CR POPF of 17·8 per cent. In comparison, the present cohort demonstrated a 90-day mortality rate after CR POPF of 12 per cent.

The national mortality rate after PD achieved within the current organizational model in Norway is very low, and the improvement potential in terms of short-term mortality is not obvious. A root-cause analysis of mortality within 90 days after major pancreatectomy by Vollmer and colleagues[34] found pancreatic fistula or other surgery-related cause as the main reason for death in 13·8 and 26·6 per cent respectively, and the relaparotomy rate among the patients who died was 35·3 per cent. In contrast, the present cohort demonstrated that 14 of 17 patients who died within 90 days experienced surgical complications, and almost three in four had a relaparotomy within 30 days of the index operation. Despite the already reassuring national mortality rate, a potential for further decline may lie in a future focus on lowering the incidence, and timely and optimal handling, of surgical complications.

The medium–low-volume units had similar outcomes to those in the high-volume centre. This stands in contrast to a perceived more linear volume–outcome effect, as suggested in several earlier reports[1,5,31]. Moreover, and supporting the present observations, other reports[6,24,35] have also failed to show superior outcomes in high-volume units in comparison with medium-volume units. When assessing the literature of the volume–outcome relationship, one must be aware of the various definitions used for volume categories. Although the present analysis used 40 procedures a year as the cut-off for high volume, as have others[5,6,22], several other publications[4,36] have defined high volume as more than 20 procedures a year. According to this definition, the vast majority (95·9 per cent) of the procedures constituting the present cohort were performed in high-volume units, and hence the broadly accepted volume–outcome relationship would serve as an explanatory factor for the beneficial results. The single low-volume unit represents an outlier in the medium–low-volume category. It was included in the analyses in order to present a complete national cohort. The absolute numbers of resections performed in this unit (16 over 2 years) did not allow for statistical comparison in a separate low-volume category, but the degree of divergence in outcomes (*Fig. 1*) was deemed too low to skew the results in the medium–low-volume category combined.

The equity in key short-term outcome metrics observed across the large span in unit volume in the present cohort raises the question of whether other organizational factors can compensate for a moderate case load (20–40 procedures a year). A ceiling effect of the volume–outcome benefits may be reached within this interval, and several mechanisms may contribute to this. All five units performing pancreatic resections are academic centres, which have been shown previously to contribute more to lower mortality and FTR rates than unit caseload itself[7,37,38]. Further, all four medium–low-volume units annually perform other HPB and upper gastrointestinal resections in numbers at least fourfold of their caseload for PD. This frequent exposure to anatomically related surgery has been proposed to contribute to improved outcomes after PD, and even to compensate for a lower volume of pancreatic surgery[39]. The lower length of stay in the index unit (before transfer) in the high-volume centre, combined with higher 90-day mortality and (although statistically non-significant) almost twofold higher FTR rate, is also

of interest. It raises the question of whether follow-up in geographical and organizational vicinity to the index unit and operating surgeon, which is to a larger extent practised by the medium–low-volume units, is beneficial for optimal and timely recognition and handling of complications. Of note, the higher mortality rate in the high-volume centre found in the present cohort must be interpreted with caution, as the authors demonstrated previously[11], in a larger and partly overlapping cohort, that there was no difference in 90- and 180-day mortality between the regional health authorities in Norway.

From the patient's perspective, clinical outcomes after surgery are paramount, and outscore reasonable increases in longer travel distances to the treating hospital unit[40–42]. However, continuity in care during preoperative workup, surgery and long-term postoperative follow-up, as well as accessibility to specialized healthcare providers for contact and information, also weighs heavily[41], and is perhaps easier to obtain within an organizational model with a moderate level of centralization.

Several limitations deserve to be acknowledged. First, the present cohort is not large and, owing to a small absolute number of rare events, suffers from the risk of being underpowered. Second, as the analyses classified only one unit in the high-volume category, transferability to other high-volume units in general is weakened. Data on gland texture and duct diameter were not available, and a fistula risk score could not be included as a co-variable. However, as shown previously[11], both the identical population-based incidence of PD across the nation and the negligible regional patient drift, together with the similar proportions of malignant *versus* benign specimens found in the two unit-volume categories, make a large disparity in case mix and fistula risk score highly unlikely.

Disclosure

The authors declare no conflict of interest.

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